INTERNATIONAL COMMISSION

FOR THE

NORTHWEST ATLANTIC FISHERIES

Special Publication No. 4

NORTH ATLANTIC FISH MARKING SYMPOSIUM

Woods Hole, Mass., May 1961

Issued from the Headquarters of the Commission Dartmouth,
N. S., Canada

1963

Contents

Contributions:

N. B. A note by O. Rodriguez Martin on the tagging of tunas in the Gulf of Cadiz, Spain (original paper No. 55 at the Symposium) has not been printed here.

Introduction

It was more than half a century ago that the eminent Danish fisheries biologist, C. G. Joh. Petersen, first tagged plaice by attaching to them a numbered bone disc. From this beginning, tagging and marking techniques have become an indispensable tool in the study of fish populations; indeed, there are now very few species of fish of major commercial importance which have not been tagged or marked by one means or another, and the technique has been extended to molluscs, crustacea and sea mammals. The results of its application range from the dramatic discoveries of fish migrations, such as that of the Atlanto-Scandian herring between Norway and Iceland and of cod between Greenland and Iceland, to the less spectacular but vitally important estimation of the abundance, growth and mortality rates of exploited fish populations.

But it often happens that a technique which, in theory, has great possibilities also possesses certain inherent practical difficulties which make it a not unmixed blessing to the investigator, and tagging is no exception. However ingenious the tag and its attachment to the fish, and however carefully planned the experiment, there is always the disturbing thought at the back of the mind of the investigator that neither the individual tagged fish nor the population of tagged fish which he creates can be relied upon to behave as untagged fish would do in their natural state. The tag may cause the fish to die prematurely, or it may fall off; even catching the fish to tag it may cause it to be abnormal thereafter. The presence of a tag may render the fish more vulnerable to predators or make it more readily caught by the fishing gear. The way in which the tagged fish are distributed over the population and the efficiency of the recovery process may be critically important in determining the reliability of the recapture data for population estimation.

As the applications of the tagging technique have become more varied, and the questions asked of the resulting information more demanding, so have the shortcomings of the technique become more apparent and serious. The last decade or so has seen the challenge these present being taken up in various ways by fishery research workers in many parts of the world. One approach has been that of devising new kinds of tags and attachments which are less harmful to the fish but more easily detected, either by fishermen or by less direct means. Much has been accomplished in this way and species of fish can now be tagged successfully which not so long ago would have been regarded as quite unsuited for such a technique — although it is a sobering thought that no better tag for flatfish has yet been devised than the simple flat disc introduced by Petersen. Doubtless much remains to be done by way of tag improvement; but it is becoming accepted that the concept of a "perfect" tag is probably an illusion, and that refinement of other aspects of the technique is even more important. Therefore, attention has been paid to practical aspects of tagging such as recording the condition of tagged fish at release, observing the effect of tags by tank tests, and measuring directly the efficiency of the tag recovery process; other advances have been essentially theoretical, and have had the aim of eliminating the uncertainties in the technique by developing new methods of analysing the resulting data. The theme running through much of the recent research into the sources of bias and uncertainty of tagging can, in fact, be summed up as ... "eliminate them if you can; and if you can't, measure them".

Because research of this kind was proceeding largely independently in a great many laboratories and countries, the Research and Statistics Committee of ICNAF decided at their 1959 meeting that a useful purpose would be served by holding a symposium devoted essentially to recent advances in the techniques of tagging and marking, both practical and theoretical. The scope of the symposium was not restricted by area or species — which are somewhat artificial distinctions from the point of technique — and contributions were invited from a number of people and organisations outside those normally present at ICNAF meetings. The response was most encouraging; a total of 62 contributions was received, nearly all specially written for the symposium, and at the symposium itself, which was held at the Fisheries Laboratory, Woods Hole, in May 1961, we were fortunate to have a number of experts from various parts of the world in addition to many from the member countries of ICNAF.

The symposium contributions form the main part of this publication, and, apart from minor editing, they are reproduced here in their original form and numbered according to the order in which they were received. At the symposium itself a different plan was followed, and perhaps a brief digression is permissible at this point to explain the pages which follow this introduction. The subject matter was divided into two main topics, each subdivided into three minor ones, and two rapporteurs were assigned to each, as follows:—

1. *Methods and effectiveness of marking, tagging and tag recovery*
    1.1 Effectiveness of various types of marks, tags and attachments.
    (Rapporteurs: E. Bertelsen and V. M. Hodder)
    1.2 Influence of fish condition, method of capture and handling, and sea conditions on return rates; tagging mortality.
    (Rapporteurs: A. C. Jensen and R. L. Fritz)
    1.3 Estimating and improving the efficiency and return of recaptured tags.
    (Rapporteurs: F. D. McCracken and A. C. Kohler)

2. *Analysis of results of marking and tagging experiments*
    2.1 Estimation of growth
    (Rapporteurs: S. J. Holt and R. C. Hennemuth)
    2.2 Estimation of mixing, dispersal and migration; stock identification.
    (Rapporteurs: L. M. Dickie and W. Templeman)
    2.3 Estimation of population size and mortality rates.
    (Rapporteurs: J. A. Gulland and E. D. Le Cren)

By taking only those parts of each contribution relevant to the topic under discussion, it was possible — thanks largely to the co-operation of the speakers, some of whom spoke to their paper on several different occasions — for the rapporteurs to prepare reviews of the main features of the contributions and discussion on each topic, and these will be found in the pages following this introduction. There is also, on pages 13—14, a table showing where a major or minor reference to each agenda topic may be located in the various contributions as listed serially on pages 1—4.

It is realised that this publication is in no sense a comprehensive review of all that is going on in the field of tagging research; but it is hoped that the scope of the symposium was sufficiently broad for these proceedings to be useful both to the experienced researcher and to those who are beginning research on fish population dynamics and wish to know something of the possibilities and limitations of the tagging technique.

In conclusion, I would like to express my personal appreciation to Dr. H. W. Graham and his staff of the Woods Hole Fisheries Laboratory, to Dr. Erik M. Poulsen and the ICNAF Secretariat, and to the Rapporteurs, for the invaluable help they gave in preparing and organising the symposium. The subsequent editing of the contributions was shared between Dr. H. W. Graham, Dr. W. Templeman and Mr. J. A. Gulland, while my colleague Miss R. Bedford undertook much of the preparation of the manuscripts for printing. To all these I am most grateful for their help.

R. J. H. Beverton
(Chairman)
19th February, 1962.

Reviews by Rapporteurs

Section 1.1

Effectiveness of various types of marks, tags and attachments

Rapporteurs: E. Bertelsen and V. M. Hodder

Discussion under this heading could not be expected to lead to general conclusions about one type of tag being superior to any other. Such an ideal tag, suitable for all kinds of fish and for all purposes, does not exist. As might be expected, it appeared clearly that the type of tag and attachment to be used in an experiment depends on *what* you are tagging, *where* you are tagging, *why* you are tagging, as well as *how* the tags may be returned.

According to the method of recovery of marked fish, the experiments may be divided into three main groups each of which usually will require different tags or markings:

- I Recovery by the fishermen
  - a. external tags
  - b. large internal tags
- II Recovery by research workers
  - a. mutilation marks
  - b. staining and tattooing
  - c. small internal tags
  - d. isotopes
  - e. sonar tags
- III Recovery by physical means
  - a. magnetic tags
  - b. radioactive marks
  - c. fluorescent stains

The three groups are overlapping. For instance, intensive tagging, propaganda and high rewards may make recoveries of marks of types II a. and b. by fishermen high enough to be practicable (e.g., staining of shrimps (23)*, and internal tagging combined with tattooing in plaice (26), and combined with fin clipping in trout (Bertelsen)).

I. (a) As nearly all tagging experiments in the ICNAF area are based on the recapture of the tagged fish by fishermen, most of the presented papers concern tags designed for this purpose, and comparison of different external tags used for haddock (30), cod (2, 16, 17, 25, 45, 47), whiting (25), salmon (2, 24), plaice and sole (25, 26, 43), halibut (8), tuna (1, 46, 54), and herring (53, 57) were described and discussed.

The effectiveness of external tags depends mainly on tagging mortality, loss of tags, and risk of tags not being observed after recapture; but the effect may be influenced also by alteration in behaviour, growth rate and catchability (i.e. fishing mortality) of the fish, due to being tagged. For this reason, type of tag and tagging method must be chosen according to the robustness of the fish (species and size) and type of fishery. Accordingly, only a few general rules can be stated; for example, that comparisons between tag types tend to show that tags which are firmly fixed (Petersen discs, spaghetti tags, etc.) are superior to dangling tags (hydrostatic tags, labels, flags, streamers, etc.) (2, 16, 17, 25, 26). Metal straps (16), and discs attached by elastic material (22, 25, 57), however, show a higher rate of shedding or tagging mortality.

Furthermore, comparison between *attachment materials* shows that no material has been found superior to stainless steel (16, 25, 36), with the possible exception of titanium or tantalum (25, and Hile). *Position of the tag* on the fish influences the effectiveness in varying degrees.

Sometimes too many different factors are varied in the tag comparisons, which makes it difficult or impossible to establish which of those factors are responsible for the observed differences in rates of returns. *Double tagging* has proved a useful method for determining the rate of shedding of tags (8, 36).

(b) Large internal tags may in certain circumstances be used in experiments of the first group. Although the loss due to recaptured fish being overlooked is much greater than with the external tags, the reduced tagging mortality and especially the insignificant risk of shedding and effect on biology and catchability make this method to be recommended for special purposes (45, 47).

II. In experiments where the marked fish are caught and recovered by the research workers, markings can be used which are much less distinct or even completely concealed, and which therefore interfere much less with the mortality and biology of the fish. A number of such methods are described and discussed, e.g. fin clipping and punching (21); staining and tattooing (23, 26, 39); internal tags (22, 26); a special sonic tag for behaviour studies (14); and mutation (albino salmonids, Kasahara, verb. comm.).

III. In certain specialized fisheries where individual observation and handling of the fish is impossible, devices for the recovery of tags or tagged fish by

---

* The figures in parentheses are the serial numbers of the contributions.

physical means have been developed. A new method using radioactive tags was described and discussed (60).

IV. Tagging methods for crustaceans and molluscs were described and discussed. Staining of shrimps was shown to be effective (23), and for crabs and lobsters external tags which may remain through moulting were described (10, 29). External tags for scallops (44) and waterproof paint for whelks (28) have been used with success.

Section 1.2

Influence of fish condition, method of capture and handling, and sea conditions on return rates; tagging mortality

Rapporteurs: A C. Jensen and R. L. Fritz

This item of the agenda was concerned with some of the physical factors that affect the success of tagging experiments. The factors considered in the papers fall in four broad categories:

a. The physical condition of the marked fish at the time of their release, including the effects of capture and handling.
b. The temperature of the sea when the fish are tagged.
c. Physiological factors, particularly the build-up of toxic substances in the fish's blood.
d. Theoretical techniques for estimating tagging mortality.

Under category (a), a number of contributions showed that in a variety of species the appearance and activity of tagged fish at release had a significant effect on the return rate (18, 20, 24, 34, 53, 57). The criterea of "condition" differed somewhat according to the species, but degree of scale loss appeared to be the most generally significant. An important conclusion from these studies was that information on the return rate of fish of less than perfect condition when released could be of value in obtaining a proper interpretation of tagging experiments.

Several references (e.g. 18, 24, 34) were made to the difficulty of tagging young fish. Evidence that these are more susceptible to damage was offered (18); in discussion it was mentioned that trawl selectivity and the discarding of small fish at sea may also be responsible in certain circumstances for the lower return rate observed (McCracken).

It was noted that certain species, especially those with closed swim-bladders such as cod, haddock, whiting and redfish, present the special difficulty of distended or burst swim-bladders if caught at any appreciable depth. Tagged fish in such cases may have to be lowered in a cage to a suitable depth before release (18, 48), or their swim-bladders pricked before release (Grosslein). While there is evidence that a small puncture in a swim-bladder can heal, it is not known whether healing is possible if a swim-bladder is seriously ruptured, or whether this damage is a significant cause of mortality.

The technique of holding tagged fish in tanks before release, both to reduce and to measure initial tagging mortality, was discussed in several contributions (e.g. 8, 24, 59). Analysis of return rates according to time in tank was shown to be important in certain species (24, 59). In tuna (1, 49), the handling time was highly critical within a period of up to 20 sec. after capture.

On topic (b), high water temperature was shown to have an adverse effect on the success of tagging experiments, both for demersal fishes (17, 26 and 30) and pelagic fishes (49). In the case of cod and haddock, the problem may be associated with hauling the fish rapidly from cool bottom water to relatively warm surface water. In the case of tuna, hyperactivity of the fishes in the warm surface water probably contributes to a higher mortality rate. It may be advantageous to tag demersal fishes in a season when the water column is cool and isothermal, and pelagic fishes when the surface waters are cool.

In salmon a build-up of blood lactates to toxic levels, caused by hyperactivity when caught for tagging, contributes to their mortality (19). Air exposure and the use of narcotizing substances during tagging also contribute to formation of lactic acid (Larkin). Cool water may slow down the general activity of the fish and thus reduce the formation of lactic acid; cool water is frequently found during the spawning season of many fishes (Le Cren). Experimental evidence on the greater susceptibility of marked fish to predation was presented (19).

Theoretical techniques for estimating type (1) losses were presented (13, 37), based essentially on an analysis of the difference in return rate between batches of fish tagged at intervals during or before the fishing season.

In the general discussion, particular reference was made to the effects of fin-clipping as a marking technique. The questions arising in this method of marking include amount of fin to clip, choice of fin, and the possible effect of fin removal on the swimming ability of the fish. Fin clipping is used mostly for freshwater fishes and a few marine species that have a high market value and hence receive more or less individual handling. The use of fin-clipping in conjunction with an internal tag (Bertelsen), and the use of a railroad ticket punch to punch distinctive holes (Le Cren), were mentioned. If fins are clipped so close that a drop of blood is drawn, they should still be recognisable after a year or more (McCann). It was noted that a large-scale marking experiment using fin-clipping was planned for 1961 in a study of chinook salmon (Zimmer).

Section 1.3

Estimating and improving the efficiency and return of recaptured tags

Rapporteurs: F. D. McCracken and A. C. Kohler

During the 1959 ICNAF Annual Meeting, submissions from various countries about their tagging return publicity methods were received and discussed at length. These were reported upon in the 1959 "Red Book" (McCracken, page 22). In the present symposium a variety of techniques for both improving and estimating the efficiency of recovery and reporting of recaptured tags were considered. Wide differences between returns from fleets of different countries fishing the same stock were reported (3, 16), and methods were suggested for determining conversion factors to relate returns from different fleets and methods of fishing. Some of the dangers inherent in the use of conversion factors were pointed out during discussion. Principally, they were the effects of changes in publicity in attempts to improve returns, and possible changes in recovery and reporting efficiency with tag type.

Variations between returns from fisheries on a single species where catches are processed in different ways were described (33, 57). External tags which were useful for individually handled fish gave low returns for bulk-handled fish, compared with metal internal tags detectable by mechanical means. Scottish "combination" tags and Norwegian double tagging techniques have been used in attempts to meet both requirements (57).

Variation in return efficiency among different vessels of a single fleet might also be used to detect non-reporting (43). In the particular examples quoted, however, it was concluded that non-random distribution of tagged fish was probably responsible for the differences between the actual and expected distributions of tagged fish among the vessels.

Direct measurement of the efficiency of reporting and recovery, by "seeding" the catch on board and when laid out on the market with known numbers of tagged fish, was described (40). It was shown how this information, together with a knowledge of the various sources from which tagged fish were returned, enables an estimate to be made of the overall recovery efficiency, with the exception of tags picked out on board but not subsequently reported.

Another way of measuring the efficiency of reporting by a fleet is that based on the idea of achieving "perfect" reporting by a small section of the fleet or from a small part of the total catch (38). Tables were presented from which could be determined how many tags need to be released in order to estimate the efficiency of reporting with any desired accuracy.

Attention was drawn to the relevance of the theory of advertising in planning a publicity campaign for returning tagged fish (5). Thus, research on advertising sometimes indicates steadier response from intermittent publicity campaigns than from a single continuous one. Tests for application of this theory to tagging experiments were suggested.

In discussion it was noted that although there were no contributions about the success of lottery schemes, the one recently introduced in Norway had had a marked effect on the recovery efficiency. It was pointed out (Costello) that a lottery connected with shrimp tag returns improved returns by about 48 per cent. However, the dangers of these schemes for inland waters where fish could be exploited for lottery purposes were also noted (Le Cren, Zimmer).

Instances of the effect of increased rewards were also mentioned in discussion. A particularly striking case was that in the oceanic tagging of Pacific salmon, where requests on posters, without a reward, for the return of both tag and fish, led to two per cent being returned, a reward of $ 5 yielded five per cent returns, and a reward of $ 25 resulted in a return of 80 per cent of tags accompanied by the fish.

A general conclusion was that while every attempt should be made to obtain as high a recovery efficiency as possible by means of publicity and rewards, direct measurement of the efficiency should also be made by one or more techniques as appropriate.

Section 2.1. Estimation of growth

Rapporteurs: S. J. Holt and R. C. Hennemuth

Determination of rate of growth from marking experiments depends normally on the possibility of measuring with sufficient accuracy the sizes of the animals at the time of release and of the same individuals at the time of recapture. When individuals cannot be recognized at recapture, as in mass marking experiments, some appreciation of growth rate may nevertheless be made from comparisons of average sizes at release and at subsequent recapture, as estimated from means of individual measurements or from a grading process (23).

Measurements of size of individuals at release may be difficult or impracticable in the case of very delicate, sensitive or large animals (whales, sharks, etc., 27). Even when there are no such difficulties, the measurements of size at release and at subsequent recapture may necessarily be made with differing accuracy or precision. Thus, recaptured marine fish are usually measured when dead rather than when alive, and often some while after death and preservation in ice. Shrinkage of soles after death seems possible (20), and is known to occur in other fishes. Le Cren observed that at least in some freshwater fish shrinkage at death is followed by relaxation and consequent expansion. Again, the size at recapture may be measured by fishermen or by other untrained observers. This difficulty was pointed out in (30) in relation to the haddock fishery, and several speakers confirmed its existence in other cases. Measurement, even by trained observers, can never be entirely precise; there are always observational errors which can on occasion be serious. Beverton pointed out that errors of measurement would be especially important for fish near to the asymptotic length where growth is relatively slow.

For all the above reasons, apparent growth increments between marking and recapture can be biased; they may, in particular, be considerably less than the real growth and even, on occasions, negative. Examples of such bias were given for sharks (27), redfish (32), soles (20), and *Tilapia* (41). A warning was given that ignoring returns with negative increments may as well increase the bias as reduce it, and Holt wondered if this had affected the *Tilapia* study in (41). Corrections for errors of this kind could usually be made on the basis of special experiments to measure change in length at death and any constant bias by untrained observers, etc. Holt pointed out that if the bias is independent of the size of the animal only the intercept, but not the slope, of the regression of increment per unit time or average size is affected (see later). In general, however, the bias is more likely to be proportional to size, in which case both parameters are affected in a predictable direction.

It appears that there can be a real decrease in growth rate, or even in size, of live fish following marking. Thus, many tagged redfish repeatedly recaptured alive and measured under comparable conditions showed reductions in size (32), although it was pointed out that some at least of the negative increment might be accounted for by the difficulties of measuring such fish alive within a millimetre or so. Tagged soles in tanks shrank even when given sufficient food (20). It was noted that in tank experiments it is necessary to observe the growth of untagged controls; this would presumably distinguish the effects of capture in the first place from the effects of the tagging operation and of the tag itself.

The effects of tagging on cod growth have been studied in such a way (12). In this case tagged fish and controls fed at both maximum and intermediate rates grew at about the same rate over a two-year period; growth differences observed were not consistent from year to year and were not due to tagging. Gulland confirmed that growth of marked North Sea cod agrees with data for size at age in catches. A similar agreement was reported in (12) and also for scallops in (44). Smith warned that average size at age is affected by selectivity of fishing, and may therefore not measure the growth rate. Back-calculated sizes at previous ages might be used; Hile pointed out that selective fishing may also change the real average growth rate, but this is what the tagging experiment would also be intended to measure. Caution is thus necessary in interpretation and comparison. It is desirable also to examine, when possible, the growth of the recaptured tagged fish as shown by their otoliths, scales, etc.

Different tags may affect growth to different degrees and in different ways, and the gear used to capture fish for marking purposes and the condition of the fish are also presumably significant. Contribution (30) gave comparative growth data for haddock captured for marking by lines inshore and by otter trawls offshore, marked in rotation with Petersen discs on the operculum, dorsal spaghetti tags, and a combination of internal anchors with hydrostatic capsules. The differential effect on growth may make one of two otherwise equally useful types of tag preferable to the other. Beverton reported that *Tilapia* in Lake Victoria marked with opercular tags showed little or no growth, but gave good growth with dorsal tags. Tagging does not seem to affect the growth of scallops (44), but a check mark on the shell is made at the time of tagging and this is used for the measurement of subsequent growth.

The effects of tagging may be observed in the structure of the hard parts used for age determination. For this purpose otoliths of tagged redfish have been examined (32) and the effects of repeated recapture are recognisable. In this study males and females were treated separately because the sexes have different growth rates. The fish recaptured three times appeared to have a faster growth rate than those recaptured only once or twice. Growth of fish which were at liberty for three or more years appeared to approach that of untagged fish. It was thought that flashing of the bright opercular tag might scare the prey, and hence reduce feeding and growth rate, but that this effect would diminish as the tag became fouled during prolonged immersion. Kohler suggested that examination of stomach contents of tagged and untagged fish could elucidate this point. Jónsson thought that use of tags the same colour as the fish or otherwise less conspicuous might eliminate the effect; this would be practicable where recapture is by experimental rather than by commercial fishing. Larkin wondered why a conspicuous tag should startle the prey at night, but apparently there is sufficient light even then, including natural luminescence. Reliable data for growth of *Sebastodes* and other scorpaenids are apparently too few to confirm redfish growth rate by comparative methods.

The simplest treatment of data for growth studies is to plot increment against time at liberty as was done for redfish (32) and soles (20), or to calculate growth per unit time as done for haddock (30). The increment is usually, however, itself a function of the size of the animal, being less for bigger animals than for smaller ones, as shown for soles (20). Kelly replied, in response to a question, that he had not observed a relation between increment and size in redfish (32) but the size range of marked fish was not large.

In certain cases it is possible to select data for returned fish which had been at liberty equal times, preferably one, two or more years, and to plot either the sizes at recapture, or the increments, against the sizes at the time of release. This commonly gives a straight line, the constants of which are the parameters K and L_∞ of an asymptotic growth curve. The method was illustrated for cod (12) and scallops (44). The data for whelks (28) were also treated in this way for a series of time periods, including portions of a year, and with consistent results.

A more efficient method is to plot the increments per unit time at liberty against the mid-sizes between the sizes at time of marking and at subsequent recapture. This was illustrated for *Tilapia* (41). In this case the method proved useful in separating males from females on the basis of differing growth parameters when sex could not be determined directly. Holt thought that the K values thus obtained were not inconsistent with other growth data for this species. Gerking wondered whether monthly variations in growth could have affected this analysis; Gulland thought not, as the data referred to many months pooled.

The practical difficulty in estimating the asymptotic size from a graph of initial length against recapture length ("Walford plot") was discussed. It was pointed out that plotting increments instead of initial lengths permits easier estimation. Le Cren remarked that for larger fish the plot of l_t against l_{t+1} frequently tended to become parallel with the bisector, rather than intersect it; this phenomenon has several possible causes including change in K and/or L_∞ with size, and biases in age determination at higher ages.

Knowledge of growth increments, or the parameters K and L_∞, estimated from tagging data can sometimes be used to discriminate between alternative hypotheses concerning the interpretation of age readings. Thus, tagging studies seem to support the "slow-growth" hypothesis for redfish (32), although this support is perhaps weakened by the fact that growth of tagged fish is even slower than would be expected from the "slow-growth" age interpretations.

Holt suggested that even if marking affected one growth parameter (the asymptotic size, L_∞) by, for example, interfering with feeding, the slope of the regression of increment per unit time on mid-size might still be used to check age determinations, or to provide estimates of K for use in population studies in cases where age determination was not possible. He observed that discrimination between age-reading hypotheses may also be possible when information about size at liberation is not available, though this is not strictly a question of growth. Thus, the numbers of laminations in earplugs of tagged baleen whales recaptured many years after marking provide evidence that the number of laminations laid down per year is on the average less than two, which was presumed to be the number from other evidence.

The Crustacea are a special case, since normally tagging can here be used only to estimate the increment per moult; alternatively the moulting frequency may sometimes be estimated from rate of disappearance of tags attached in such a way that they are lost at moulting (29). Determinations of growth per moult and of moulting frequency, both as functions of size or age, provide data for growth rate estimates, and one or both of these factors may be estimated by tagging. For example, the growth per moult was obtained by tagging king crab (10) and related to moult frequency estimated by other means. Such data give growth rates and age estimates on a true time scale, the origin of which is, however, not usually known. Knowledge from tagging of growth during early stages is useful to estimate age at recruitment in crustacea (42). Costello enquired whether attempts to determine the age of king crabs from eyestalk structure had been continued; apparently they have not.

Finally, it was pointed out that in relation to growth studies, tagging or marking experiments may be used to estimate growth, to study the effect of tagging on growth, or to check age determinations. The effect of tagging on growth may be observed in order to improve tagging methods or to correct the results of experiments to estimate growth, or as part of an evaluation of the general suitability of different types of tags for other purposes including mortality estimation. It should be noted that in general these different objectives of tagging experiments concerning growth and age cannot all be achieved simultaneously. It might be possible, however, to establish that a particular type of tag had, for example, no effect on growth in a stock or species for which age determinations were available (by tank experiments and age analysis of catches), and to conclude that the same type of tag would therefore probably be useful to estimate growth rate, and hence age composition, in another stock or a related species for which age determinations were for some reason not available.

Section 2.2

Estimation of mixing, dispersal and migration; stock identification

Rapporteurs: L. M. Dickie and W. Templeman

Two papers (15, 49) dealt specifically with the definition and measurement of directional and random components in fish movements, as reflected both in tag returns and in changes in population parameters. Estimates of coefficients for the random "mixing" components derived from tag returns may be high and can be checked against estimates of the amount of mixing necessary to produce observed changes in variance of length at age (15). Estimates of the random component from tagging are used to correct observed "loss" rates of tags for deriving mortality rates (49) (see Section 2.3). Discussion of the tagging results revealed that different investigators have favoured different methods of weighting, including equal weights to all returns, weighting by time at liberty, and stratification of runs in schools by time or space. Results of the studies show seasonal changes in hoth the directional and random components of movement. While these changes may be related to environmental variables, e.g. temperature, the magnitude of change in both components is often too great to suggest direct cause-effect relations.

A number of papers dealt with the general subject of "homing" in species other than salmon (7, walleye; 20, sole; 21, char and perch). In these species tagging experiments on spawning concentrations showed that there may be extensive mixing in the periods between spawning periods, but in subsequent spawnings there is a strong tendency for fish to return to the precise local area of tagging, and apparently at the same time during the seasonal cycle as when originally tagged. Hile related similar experience with lake trout of Lake Michigan.

Scallops (44) and whelks (28) show almost no straying from point of release, even after several years, although observations of individuals show that they are by no means inactive. Adjacent stocks of king crabs appear to mix little with each other despite marked inshore-offshore movements associated with spawning (10). There is no mixing between stocks in the Bering Sea and those south of the Alaska peninsula.

Upstream migrations of fall-run chinook salmon were traced in detail for periods of up to 15 hours, using a sonic tag (14). In the examples discussed the fish appeared to move upstream along paths near shore. There was no indication of aberrent behaviour with the relatively high sound frequencies used.

Recent developments in the use of natural distinguishing features such as parasites (6, 52) and hlood groups (50) in identifying stocks were reported. Five criteria were proposed for the use of parasites as stock indicators (6), namely, (a) high rate of infestation, (b) simplicity of life history, (c) adequate length of life cycle, (d) stability, (e) wide environmental tolerance. Several species of myxosporidian gall-bladder parasites of whiting in the North Sea and of haddock at the Faroe Islands were shown to meet these criteria sufficiently well to serve as biological stock indicators (6). Results of the analyses indicate that the southern and northern North Sea whiting stocks are virtually distinct except in the region of the Dogger Bank; and that those in the northern North Sea are in turn separate from the Faroese whiting. Similarly, haddock occupying the Faroe Islands shelf appear to separate from those occupying the outlying banks. The incidence of occurrence of adults of *Lernaeocera* on cod may be used to distinguish between stocks that regularly move into the inshore water of Newfoundland, and those which remain all year round on the offshore banks (52). Kasahara reviewed studies of the distribution of sockeye salmon from Bristol Bay, Alaska, using the parasite *Trianophorus* which occurs only on salmon from this area. It was reported that Dr. Sindermann has published some results on the successful use of frequency of parasite occurrence and blood groupings to distinguish stock units in the Gulf of Maine herring populations. Larkin and Costello reported that attempts are now being made to develop deliberate inoculation by parasites as a marking technique. Bertelsen mentioned the promising results obtained by Dr. K. Sick (University of Copenhagen) from the application of zone electrophoresis techniques to the analysis of fish haemoglobin for racial studies*.

In recent use of blood type groupings for identifying stocks (50), antigens are found for all alleles of the gene complex studied. The technique provides a powerful tool for identifying stocks and measuring the degree of mixing. In discussion it was pointed out that antigen production from animals had been a major obstacle until the recent introduction of phytoaglutinants, primarily from bean juices.

Section 2.3

Estimation of population size and mortality rates

Rapporteurs: J. A. Gulland and E. D. Le Cren

Papers in this section described a wide range of situations in which, by various methods, estimates of population size or mortality rates could be obtained. In the simplest situation, when both tagging and recapture is done by the experimenter, the population size may be estimated by the Petersen (or Lincoln index) method and its modifications; the theory was

---

* A preliminary account of this work has since been published; K. Sick, Haemoglobin Polymorphism in Fishes; Nature, **192**, (4805), 2. Dec. 1961.

reviewed (58), and the method applied to both freshwater (21) and marine fish (31) and, with extensions to cover returns by commercial fishermen, to molluscs (28) and crustacea (29). A theoretical value of the variance of the estimate may be obtained (56), but Robson considered that as the model was deterministic, the true variance would be greater than this theoretical value. The model gave biased estimates (4) if there is a correlation between the probability of being tagged and of appearing in subsequent samples; this bias may be severe when there is direct gear selection for tagged fish (e.g. Petersen discs caught by gill net (26)). With simple extensions, mortality or recruitment rates can be estimated (58) though in many situations it may be unrealistic to assume that recruitment is proportional to the population present. If the population is constant, then the decline in the proportion of tagged individuals (essentially due to recruitment) may be used as an estimate of mortality (31).

More generally, the decline in numbers of tagged individuals, or, better, number per unit effort, will give a total loss rate (10, 13, 22, 35). This will include the fishing and natural mortality rates typical of the population, but also shedding or other loss of tags, or extra mortality among tagged individuals, and, particularly if returns within only a small area are considered, a factor due to emigration (35). By extrapolation to time zero, or otherwise, an estimate of fishing mortality, or mortality per unit fishing intensity, can be obtained, and from independent estimates of total mortality the natural mortality can be estimated (8, 10, 22, 35). Such estimates have been in reasonable agreement with those by other methods for North Sea plaice (35), Bering Sea king crab (10), maskinonge (62), whelks (28) and scallops (44).

Another check is to relate the estimated fishing mortality from tag returns to the fishing intensity (effort per unit area) in the region of tagging; this has given a better fit than relating mortality from age data to fishing intensity (8).

In special situations, tags may be recovered after the tagged individual dies; this may help to give estimates of mortality due to tagging or natural mortality, or to eliminate all losses except those due to fishing (28, 44).

Fishing mortality may also be estimated by assuming various values of the loss rate, and from this, plus the known returns, computing the surviving population of tagged fish; the proportion of this returned in any time interval may be correlated with the fishing effort in the interval (13).

Tagging has also been used to give estimates of catches not otherwise reported (7), though this depends on having equal probability of tag reporting by all sections of the fishery.

A further specialised use of tagging involves fishing where a known number of tags have been seeded in a small area, to give the efficiency of the fishing gear on a population of known density. Dickie reported that by this technique it has been shown that on rough ground scallop dredges have efficiencies as low as 10 per cent.

Classification of Contributions by Agenda Topics

		Agenda topic					
		1.1	1.2	1.3	2.1	2.2	2.3
	Contribution	Tags & attachments	Fish-condition, capture method, etc; tagging mortality	Recovery of tags	Growth	Mixing, dispersal, migration	Population size & mortality rates
No. 1	(Marr, J. C.)	(x)	x				
No. 2	(Nielsen, J.)	x					
No. 3	(Horsted, S. A.)			x			
No. 4	(Junge, C. O.)						x
No. 5	(Holt, S. J.)			x			
No. 6	(Kabata, Z.)					x	
No. 7	(Crowe, W. R., E. G. Karvelis, and L. S. Joeris)					(x)	x
No. 8	(Myhre, R. J.)	(x)	(x)	x			x
No. 9	(Thompson, J. M.)	x					
No. 10	(Cleaver, F. C.)	(x)			x	(x)	(x)
No. 11	(Trefethen, P. S. and A. J. Novotny)	x					
No. 12	(Kohler, A. C.)				x		
No. 13	(Dickie, L. M.)		x	(x)			x

	Contribution	Agenda topic 1.1 Tags & attachments	1.2 Fish-condition, capture method, etc; tagging mortality	1.3 Recovery of tags	2.1 Growth	2.2 Mixing, dispersal, migration	2.3 Population size & mortality rates
No. 14	(Trefethen, P. S.)	(x)				x	
No. 15	(Jones, R.)					x	
No. 16	(McCracken, F. D.)	x		(x)			
No. 17	(Wise, J. P.)	x	x				
No. 18	(Beverton, R. J. H. and B. C. Bedford (a))		x				
No. 19	(Parker, R. R., E. C. Black and P. A. Larkin)		x				
No. 20	(Kotthaus, A.)		(x)		x	(x)	
No. 21	(Le Cren, E. D. and C. Kipling)	(x)				x	x
No. 22	(Allen, K. Radway (a))	x					(x)
No. 23	(Costello, T. J.)	x			(x)		
No. 24	(Hartt, A. C.)	(x)	(x)				
No. 25	(Williams, T.)	x					
No. 26	(Andersen, K. P. and O. Bagge)	(x)	(x)		(x)		x
No. 27	(Hansen, P. M.)	x			(x)		
No. 28	(Hancock, D. A.)	(x)			x	(x)	x
No. 29	(Simpson, A. C.)	x			(x)		(x)
No. 30	(Jensen, A. C.)	x	(x)		(x)		
No. 31	(Kelly, G. F. and A. M. Barker (a))						x
No. 32	(Kelly, G. F. and A. M. Barker (b))				x		
No. 33	(Fritz, R. L.)			x			
No. 34	(McDermott, J. P. and R. Livingstone, Jr.)		x				
No. 35	(Gulland, J. A. (a))						x
No. 36	(Gulland, J. A. (b))	x					
No. 37	(Paulik, G. J. (a))		x				
No. 38	(Paulik, G. J. (b))			x			
No. 39	(Gerking, S. D.)	x					
No. 40	(Margetts, A. R.)			x			
No. 41	(Garrod, D. J.)				x		
No. 42	(Hayes, M. L.)				(x)		
No. 43	(de Veen, J. F.)	(x)		x			
No. 44	(Posgay, J. A.)	(x)		x	x	(x)	(x)
No. 45	(Templeman, W.)	x		(x)			
No. 46	(Mather, Frank J., III)	x					
No. 47	(Templeman, W. and T. K. Pitt)	x		(x)			
No. 48	(Sandeman, E. J. and E. I. S. Rees)		x				
No. 49	(Schaefer, Milner B., B. M. Chatwin and G. C. Broadhead)		(x)			(x)	(x)
No. 50	(Marr, John C. and Lucian Sprague)					x	
No. 51	(Aslanova, N. E.)	x					
No. 52	(Templeman, W. and A. M. Fleming)					x	
No. 53	(Ancellin, J.)	x	(x)				
No. 54	(Letaconnoux, R.)	(x)					
No. 55	(Allen, K. Radway (b))						x
No. 56	(Eipper, A. E., J. L. Forney and D. S. Robson)					(x)	x
No. 57	(Parrish, B. B. and G. McPherson)	x	(x)	(x)			
No. 58	(Pope, J. A.)					(x)	x
No. 59	(Beverton, R. J. H. and B. C. Bedford (b))		x				
No. 60	(Wilimovsky, N. J.)	x					
No. 61	(Reintjes, John W.)	x					
No. 62	(Muir, B. S.)						x

x — mainly relevant
(x) — incidental reference
General descriptive papers: 7, 42, 51

1.

Note on the Return Rate of Tagged Skipjack, *Katsuwonus pelamis*, and the Effects of Handling

By

JOHN C. MARR*

Large-scale tuna tagging experiments commenced with the development of the plastic loop or "spaghetti" tag by Wilson (1953), following the earlier work of Alverson and Chenoweth (1951), Powell et al. (1952) and Schaefers (1952). This tag, a section of vinyl tubing, is applied through the muscle of the dorsal surface posterior to the second dorsal fin. The free ends are tied together after the tag is in place.

Subsequent improvements, as judged by increased return rates, have arisen from modifications in (1) materials and methods of application, resulting in longer tag life; (2) tagging technique, resulting in a reduction of the time during which the fish is out of water and in the amount of handling to which it is subjected; (3) materials and techniques, resulting in a greater discovery rate of recaptured fish.

Modifications of the first type include the use of a clamp instead of a knot to secure the free ends of the tag, a tag core of monofilament nylon, and the use of a different vinyl tubing capable of withstanding longer exposure to sea water (Schaefer, 1958).

Modifications of the second type include not measuring the length of the tagged fish, the use of an automatic clamping device for securing the free ends of the tag (Schaefer, 1958), and the use of a dart tag (Yamashita and Waldron, 1958). With the dart tag, oceanic skipjack (*Katsuwonus pelamis*) can be hooked, tagged and released in as little as four to seven seconds (Waldron, personal communication), as contrasted to 20 seconds for loop tags (Yamashita and Waldron, 1959). Modifications of the third type include more conspicuous tag color (Blunt and Messersmith, 1960; Schaefer, 1958) and an attractive reward system (Schaefer, 1958).

Skipjack are perhaps the most delicate of the tunas and have shown the greatest improvement in the return rate of tagged individuals as a result of reduction in tagging time and concomitant handling. For example, Blunt and Messersmith (1960) report a return rate of 2.56% from 742 skipjack tagged with dart tags and 0.29% from 695 tagged with loop tags, in an experiment in which the two types of tags were applied to alternate fish in the eastern tropical Pacific. Yamashita and Waldron (1958) report a return rate of 0.61% from 1961 skipjack tagged with loop tags in the vicinity of the Hawaiian Islands between 1954 and 1956. They also report a return rate of 9.15% from 8161 skipjack tagged with dart tags in the same area in 1957. Tagging mortality is apparently directly proportional to the time and handling required by tagging. The experience of the Honolulu Laboratory staff members in establishing skipjack in captivity clearly supports this conclusion.

Nakamura (MS) has recently reported on the establishment and behavior of skipjack in captivity. Initial attempts involved catching skipjack with barbless hooks, carrying them from the fishing racks to a bait well into which they were released, returning to port, removing the fish from the bait well and carrying them about 60 yards to an experimental tank. Ten attempts, involving 44 skipjack as well as two *Euthynnus yaito* and two *Coryphaena hippurus*, were made in this manner. All fish died within 48 hours. Various refinements, including carrying the fish in water-filled plastic bags and the use of thorazine, made no apparent difference in survival rate.

These difficulties led to the use of a portable tank. Skipjack caught with barbless hooks were lowered into the portable tank and allowed to shed the hook. When the ship returned to port, the portable tank was lifted (by crane) from the ship, carried to the experimental tank and lowered into it. Once in place, a hatch on the side of the portable tank was opened, the skipjack swam out into the experimental tank and the portable tank was removed. Thus, the fish were not directly handled and, in fact, did not come in contact with any foreign object except the barbless hook.

Two lots of skipjack have been introduced into the experimental tank in this manner. They exhibited little bruising and did not swim at high speeds nor bump into the tank walls, as did fish introduced in the original manner. Fish of the first lot survived for as long as 73 days and of the second lot for as long as 173 days. Food was taken on the ninth day by fish of the first lot and on the second day by fish of the second lot. After they began to feed, the fish were easily conditioned to an artificial stimulus for feeding. Death probably resulted from dietary insufficiencies, rather than other environmental conditions, and almost certainly not from handling.

---

* Director, Hawaii Area, U. S. Bureau of Commercial Fisheries, P. O. Box 3830, Honolulu 12, Hawaii.

Summary

Return rates of tagged skipjack were increased approximately tenfold with dart tags in comparison with loop or "spaghetti" tags. Increased return rates were presumably a reflection of increased survival rates resulting from decreased handling and time out of water. This conclusion is supported by evidence from attempts to establish skipjack in captivity. Such attempts were successful only when the skipjack were not directly handled and came in contact with no foreign objects except a barbless hook.

References

ALVERSON, DAYTON L., and HARRY H. CHENOWETH (1951). Experimental testing of fish tags on albacore in a water tunnel. *Comm. Fish. Rev.*, **13** (8): 1—7

BLUNT, C. E., Jr., and JAMES D. MESSERSMITH (1960) Tuna tagging in the eastern tropical Pacific, 1952—1959. *Calif. Fish Game*, **46** (3): 301—369.

NAKAMURA, EUGENE L. (MS). The establishment and behavior of skipjack tuna (*Katsuwonus pelamis*) in captivity.

POWELL, DONALD E., DAYTON L. ALVERSON and ROBERT LIVINGSTONE, Jr. (1952). North Pacific albacore exploration — 1950. *Fish. Leafl., Wash.*, 402: 56 p.

SCHAEFER, MILNER B. (1958). Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1957. *Inter-Amer. Trop. Tuna Comm. Ann. Rept. for* **1957**, 31—79.

SCHAEFERS, EDWARD A. (1952). North Pacific albacore tuna exploratioo — 1951. *Comm. Fish. Rev.*, **14** (5): 1—12.

WILSON, ROBERT C. (1953). Tuna marking, a progress report. *Calif. Fish Game*, **39** (4): 429—442.

YAMASHITA, DANIEL T., and KENNETH D. WALDRON (1958). An all-plastic dart-type fish tag. *Calif. Fish Game*, **44** (4): 311—317.

YAMASHITA, DANIEL T., and KENNETH D. WALDRON (1959). Tagging of skipjack in Hawaiian waters. *Pacif. Sci.*, **13** (4): 342—348.

2.

Comparison between Different Types of Tags used on Cod, Char and Salmon in Subarea 1

By

JØRGEN NIELSEN*

Introduction

During half a century great numbers of fish have been tagged in different countries, but very little has been published about the results of comparative tagging experiments with different types of tags. In order to find the most suitable types, Greenland Fisheries Investigations have carried out some comparative tagging experiments with cod, char and salmon, in which a number of fish have been tagged at the same time and in the same locality with different types of tags. The preliminary results of these experiments are given in the present paper.

Cod: Technique

The following types of tags have been used:

Plastic tag. Small boat-shaped tags of plastic. Length 30 mm, extreme breadth 9 mm, thickness 1 mm, weight 0.20 grams. The tags used were red, yellow and blue. They were attached at the base of the anterior edge of the first dorsal fin either by means of *stainless steel wire* or by means of *terylene*, a synthetic polyester fibre (in the experiments mentioned in the present paper, a black spinner line of 11 lb breaking strength was used). Until 1952 common stainless steel, diameter 0.40 mm, was used. Later a special, more flexible, surgical wire, diameter 0.35 mm, was employed.

Lea's hydrostatic tag. Lea tags were used in two sizes, length 48 and 31 mm, diameter 4 mm. The tags were yellow, with blue at the top and bottom. They were attached at the base of the anterior edge of the first dorsal fin by means of a wire clamp and a pin.

Petersen tag. In most of the experiments black discs, diameter 16 mm, thickness 2 mm, were used; in a few experiments in recent years white discs, diameter 25 mm, thickness 2 mm, were used. The discs were attached to the gill-cover by means of either silver wire, diameter 1.00 mm, or surgical stainless steel wire, diameter 0.80 mm.

The comparative experiments were carried out by using different types of tags at the same time and in the same locality, and in most cases on fish of approximately the same length. In most cases the fish were tagged alternately with different types of tag, or each tag was used in a certain time interval. However, in some experiments small fish have been tagged with one type of tag and large fish with another. In such cases the percentages of recapture are, of course, not directly comparable, since one may expect a greater mortality of small fish than of large ones as a result of the tagging process. As the recapture of small tagged fish is delayed, the total period of recaptures will be longer for small than for large fish. Returns of cod up to the end of 1959 have been included in the analysis.

Results

A summary of the various comparisons of types of tags and materials for attaching tags, made from the results of all the comparative experiments, is given in Table 1.

Comparison between *different colours of plastic tags.* Both Experiment A and Experiment B show that red colour gives a higher percentage of recapture than yellow.

Comparison between *terylene and steel wire* to attach *plastic tags* (C, D, E, F, G and H). With the exception of E and H, the experiments prove that tags attached with steel wire give a much higher percentage of recapture than tags attached with terylene. In experiment H the percentages of recapture are not comparable, as the fish tagged with plastic/steel were considerably smaller than those tagged with plastic/terylene. The experiments with cod have shown that in the first year after tagging there is no significant difference in the percentages recovered of either type of tag, but that in subsequent years the percentage of plastic/steel tags recaptured is much higher than that of the plastic/terylene type. This is also borne out by the tagging experiments with the char (see below).

Comparison between *plastic/steel, plastic/terylene, and Lea tags* (I and K). The percentages of recapture seem to be a little higher for Lea tags than for plastic/terylene, but considerably higher for plastic/steel than for Lea tags. The comparison is made with yellow plastic tags attached with steel; judging from the above-mentioned, a comparison based on red plastic tags would have given a still higher percentage of recapture for plastic/steel.

Comparison between *Petersen tags and Lea tags* (L, M, and N). The first two experiments show more re-

---

* Greenland Fisheries Investigations, Charlottenlund, Denmark.

Table 1. Cod

Comparison between	Experiment	Tag	Colour	Attached with	Year of Tagging	Mean Fish Length cm	Number Tagged	Number Recaptured	Percentage Recaptured
Yellow and red Plastic	A	Plastic	Yellow	Terylene	1951	31.4	116	1	0.9
	A	Plastic	Red	Terylene	1951	30.3	100	8	8.0
	B	Plastic	Yellow	Terylene	1952	65.5	209	13	6.2
	B	Plastic	Red	Terylene	1952	64.4	94	8	8.5
Terylene and Steel	C	Plastic	Yellow	Terylene	1951	31.4	116	1	0.9
	C	Plastic	Yellow	Steel	1951	32.6	67	9	13.4
	D	Plastic	Red	Terylene	1955	36.7	144	19	13.2
	D	Plastic	Red	Steel	1955	37.8	100	20	20.0
	E	Plastic	Red	Terylene	1956	26.4	50	5	10.0
	E	Plastic	Red	Steel	1956	26.2	149	6	4.0
	F	Plastic	Blue	Terylene	1957	27.6	50	1	2.0
	F	Plastic	Blue	Steel	1957	28.5	60	5	8.3
	G	Plastic	Blue	Terylene	1957	41.8	50	5	10.0
	G	Plastic	Blue	Steel	1957	41.1	15	2	13.3
	H	Plastic	Blue	Terylene	1957	31.5	25	4	16.0
	H	Plastic	Blue	Steel	1957	23.9	79	2	2.5
Plastic/Steel and Lea	I	Plastic	Yellow	Steel	1951	32.6	67	9	13.4
	I	Lea	—	Steel	1951	34.7	193	19	9.8
Plastic/Terylene and Lea	K	Plastic	Yellow	Terylene	1951	31.4	116	1	0.9
	K	Plastic	Red	Terylene	1951	30.3	100	8	8.0
	K	Lea	—	Steel	1951	34.7	193	19	9.8
Petersen and Lea	L	Petersen	Black	Silver	1949	66.4	287	31	10.8
	L	Lea		Steel	1949	64.8	197	29	14.7
	M	Petersen	Black	Silver	1951	46.9	105	6	5.7
	M	Lea		Steel	1951	34.7	193	19	9.8
	N	Petersen	White	Steel	1958	59.0	28	5	17.9
	N	Lea		Steel	1958	58.9	100	17	17.0
Petersen and Plastic/ Steel	O	Petersen	Black	Silver	1951	46.9	105	6	5.7
	O	Plastic	Yellow	Steel	1951	32.6	67	9	13.4
	P	Petersen	Black	Silver	1955	50.7	138	38	27.5
	P	Plastic	Red	Steel	1955	37.8	100	20	20.0
	Q	Petersen	White	?	1957	56.8	200	49	24.5
	Q	Plastic	Blue	Steel	1957	41.1	15	2	13.3
Petersen and Plastic/ Terylene	R	Petersen	Black	Silver	1951	46.9	105	6	5.7
	R	Plastic	Yellow	Terylene	1951	31.4	116	1	0.9
	R	Plastic	Red	Terylene	1951	30.3	100	8	8.0
	S	Petersen	Black	Silver	1952	68.1	412	24	5.8
	S	Plastic	Yellow	Terylene	1952	65.5	209	13	6.2
	S	Plastic	Red	Terylene	1952	64.4	94	8	8.5
	T	Petersen	Black	Silver	1953	56.7	26	8	30.8
	T	Plastic	Yellow	Terylene	1953	36.8	65	7	10.8
	U	Petersen	Black	Silver	1955	50.7	138	38	27.5
	U	Plastic	Red	Terylene	1955	36.7	144	19	13.2
	V	Petersen	Black	Silver	1957	45.3	73	19	26.0
	V	Plastic	Red	Terylene	1957	31.7	394	30	7.6
	W	Petersen	White	?	1957	56.8	200	49	24.5
	W	Plastic	Blue	Terylene	1957	41.8	50	5	10.0

captures with Lea tags than with Petersen tags, although in experiment M the Lea tags were used on smaller fish than the Petersen tags. In experiment N the percentages of recapture are almost the same, but the number of fish tagged with Petersen tags is small (28).

Comparison between *Petersen tags and plastic tags* attached with *steel* (O, P and Q). In the first experiment the recapture percentage is higher for plastic/steel than for Petersen tags, whereas the last two experiments show the opposite. It should be noted that none of the percentages in the experiments are comparable, because the mean lengths of fish with the different tags vary; also the number of fish tagged with plastic tags in experiment Q is very small. Judging from the experiments showing a higher percentage of recapture for plastic/steel than for Lea, and for Lea a higher percentage than for Petersen tags, it is likely that plastic/steel gives a higher recapture than Petersen tags, other conditions being equal.

Comparison between *Petersen tags and plastic tags* attached with *terylene* (R, S, T, U, V and W). In experiment S only, the mean lengths of the fish with different tags are similar. This experiment shows a slightly higher percentage of recapture of yellow, and a considerably higher percentage of red plastic tags than of Petersen tags. Experiment R also shows a higher percentage for red plastic tags than for Petersen tags. However, all the other experiments show considerably higher percentages of recapture of Petersen tags than of plastic tags, but, because of the difference in mean fish length, it is not possible to draw any reliable conclusion from these experiments. On the basis of the only comparable experiment, S, plastic tags with terylene may be considered better than Petersen tags, but the difference is insignificant.

From the experiments mentioned above, it is possible to give the following grading to the tags as to their value, when considering the objective to be the highest possible percentage of recapture:

1. Red plastic tags, attached with steel wire.
2. Yellow plastic tags, attached with steel wire.
3. Lea's hydrostatic tags.
4. Red plastic tags attached with terylene.
5. Yellow plastic tags attached with terylene.
6. Petersen tags.

The Petersen tag (No. 6) should possibly be placed before the plastic tags attached with terylene (Nos. 4 and 5).

Char and Salmon: Technique

For tagging of char (*Salvelinus alpinus*) and salmon (*Salmo salar*) in comparative experiments, the following tags mentioned above have been used: plastic tags (red, yellow and blue) attached with steel wire or terylene, and Lea tags. An additional type was also used in one experiment — the Swedish Carlin tag, consisting of a small paper label prepared with celluloid, length 16 mm, width 5 mm, which is connected by a link to a U-shaped piece of steel wire (total weight 0.165 g). This steel wire is passed through the body of the fish, at the base of the dorsal fin, by a double needle, and its two free ends are then twisted together.

The experiments are otherwise carried out in the same manner as described for cod. The mean lengths of the fish tagged with different tags were the same in all experiments. The recaptures are brought up to date, up to and including 1960.

Results

Table 2 gives a survey of the experiments.

Comparison between *plastic tags of different colours* (a, b and c). As in the case of cod, all experiments show a higher percentage of recapture of red tags than of yellow. In the experiments with blue tags, there is too little material for comparison.

Comparison between *terylene and steel wire* to attach *plastic tags* (d, e, f, g, h, i, and o). All experiments except no. f, where the number of tagged fish is small, show a considerably higher percentage of recapture of tags attached with steel wire; this is in accordance with the results in the case of cod.

Comparison between *plastic/steel*, *plastic/terylene* and *Lea tags* (k, l, m, n, and p). In all cases the Lea tag gave a considerably higher recapture than plastic tags attached with terylene. The same is the case, though less marked, in experiments with cod. In the case of cod (one experiment), plastic/steel showed a higher percentage of recapture than Lea tags; the opposite was the case with char (one experiment). In both cases yellow plastic tags were used. The difference between the two species may be due to the difference in size, the cod tagged being larger than the char. The experiments with char have shown that, for small char, Lea tags give a considerably higher percentage of recapture than plastic/steel; for larger char, the difference is much less.

Comparison between *plastic/steel and Carlin tags* (q). The experiment shows a slightly higher percentage of recapture with Carlin tags. All tagging experiments with salmon (but not char) have been carried out with fish in the parr or smolt stage, and all recaptures have been of smolt or parr except in two cases where the salmon recaptured were adult. In both these cases the salmon were tagged with Carlin tags.

The comparative experiments with salmon and char show that the different types of tag can be graded in the same manner as in the case of cod (the Petersen tag was not used for salmon or char), but possibly showing the Lea tag as No. 1 or 2 for small fish. If the Carlin tag is to be shown, it would probably be placed as No. 1.

Discussion

The percentage of recaptures depends upon the different properties of the tag used. Some tags may cause a higher tagging mortality than others, especially when small fish are used. The resistance of the tags may be different. It is worth mentioning that the silver wire used for attaching Petersen discs has been corroded in some cases, which never happens with steel wire. This corrosion of silver wire is particularly pronounced in certain localities (fjords) in Greenland. Some types of tags may cause one fish to be more easily caught than another with a different type of tag or untagged. It is, e.g., likely that a fish tagged with a Lea tag attached with a steel clamp is more liable to capture in a gill-net than a fish with a tag attached with terylene. This *could* explain the higher

Table 2. Char

Comparison between	Experiment	Tag	Colour	Attached with	Year of Tagging	Number Tagged	Number Recaptured	Percentage Recaptured
Yellow and red Plastic	a	Plastic	Yellow	Terylene	1953	78	23	29.5
	a	Plastic	Red	Terylene	1953	18	6	33.3
	b	Plastic	Yellow	Terylene	1954	5	0	0
	b	Plastic	Red	Terylene	1954	58	13	22.4
	c	Plastic	Yellow	Terylene	1954	151	9	6.0
	c	Plastic	Red	Terylene	1954	12	1	8.3
Terylene and Steel	d	Plastic	Yellow	Terylene	1953	19	7	36.8
	d	Plastic	Yellow	Steel	1953	19	9	47.4
	e	Plastic	Yellow	Terylene	1953	78	23	29.5
	e	Plastic	Yellow	Steel	1953	22	18	81.8
	f	Plastic	Red	Terylene	1954	9	3	33.3
	f	Plastic	Red	Steel	1954	20	3	15.0
	g	Plastic	Red	Terylene	1954	58	13	22.4
	g	Plastic	Red	Steel	1954	38	15	39.5
	h	Plastic	Red	Terylene	1954	12	1	8.3
	h	Plastic	Red	Steel	1954	19	8	42.1
	i	Plastic	Yellow	Terylene	1955	23	2	8.7
	i	Plastic	Yellow	Steel	1955	19	8	42.1
Plastic/Steel and Lea	k	Plastic	Yellow	Steel	1958	73	3	4.1
	k	Lea		Steel	1958	40	5	12.5
Plastic/Terylene and Lea	l	Plastic	Yellow	Terylene	1952	12	3	25.0
	l	Lea		Steel	1952	19	11	57.9
	m	Plastic	Yellow	Terylene	1954	110	9	8.2
	m	Lea		Steel	1954	74	29	39.2
	n	Plastic	Blue	Terylene	1958	35	6	17.1
	n	Plastic	Yellow	Terylene	1958	22	11	50.0
	n	Lea		Steel	1958	43	24	55.8

Table 2 (cont'd). Salmon

Comparison between	Experiment	Tag	Colour	Attached with	Year of Tagging	Number Tagged	Number Recaptured	Percentage Recaptured
Terylene and Steel	o	Plastic	Red	Terylene	1954	17	4	23.5
	o	Plastic	Red	Steel	1954	72	23	31.9
Plastic/Terylene and Lea	p	Plastic	Yellow	Terylene	1952	56	1	1.8
	p	Lea		Steel	1952	68	8	11.8
Plastic/Steel and Carlin	q	Plastic	Blue	Steel	1956	49	2	4.1
	q	Carlin	Blue	Steel	1956	79	4	5.1

percentage of recapture of tags attached with steel than of tags attached with terylene in the case of char, but does not apply to cod, which are never caught in gill-nets in Greenland.

The appearance of the tag is also important in the detection of a tagged fish when captured. This may explain the fact that more red plastic tags are recovered than yellow. Regarding the Petersen tag, we have observed a case in which the disc was completely overgrown so that the tag was not noticed until we were going to tag the same fish again. In trawl catches particularly, the tags are often not noticed on the fresh fish, as indicated by later discovery of tags on salt or dried fish. This only applies to tags attached to the body of the fish; a Petersen tag attached to the gill-cover will be thrown away with the head, when not observed on the fresh fish. The comparative tagging experiments with cod have yielded 48 recaptures of Lea tags, of which 6, or 12.5%, were from salt or dried cod. Of 147 recaptures of plastic tags, 18, or 12.2% were first observed on salt or dried fish. Of plastic tags recovered from salt fish, the percentage is twice as high for tags attached with steel as for tags attached with terylene, which may be due to the fact that terylene is more easily loosened during the salting process than steel.

Finally, it is important when deciding on the type of tag to use to choose one which is practical and quick to handle during the tagging process; also the price of the tag may be worth considering.

It is very important in most tagging experiments that the tag be of a type which the fish does not lose too quickly. For the Petersen tag, the longest time recorded between tagging and recapture in Greenland waters is 15 years for a cod and 16 years for a Greenland shark (*Somniosus microcephalus* Schneider). Both tags were attached with silver wire. Lea tags and plastic tags have not been used for as long or as widely

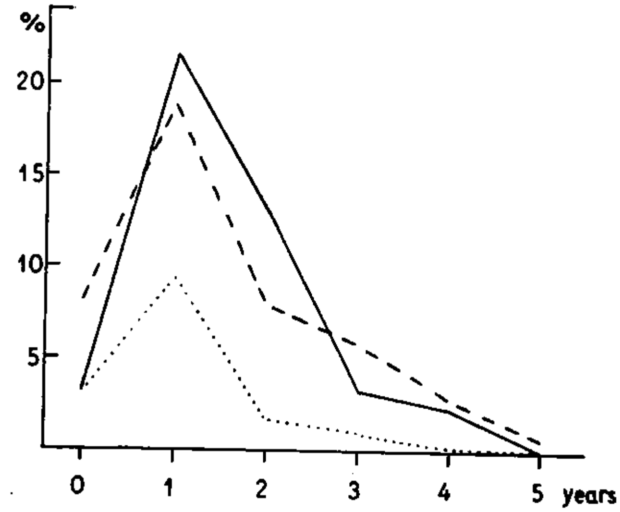


Figure 1. Comparative tagging experiments with char, giving the percentage of recapture for Lea tags (full line), plastic tags attached with steel wire (broken line) and plastic tags attached with terylene (dotted line).

as Petersen tags, but in the case of Lea tags we have had recaptures 8 years after tagging, and in the case of plastic tags attached with steel and with terylene 7 years after tagging. Comparative experiments with char give some information on this question, as shown in Figure 1. The figure shows for experiments from 1952—1955 the recapture percentage in the various years up to and including 1960 of the different types of tags used. The full line indicates Lea tags, the broken line plastic tags attached with steel, and the dotted line plastic tags attached with terylene. As to recaptures in the same year (0), there is little difference between the various types of tag; the agreement is even greater than shown by the curves, as the experiments were carried out partly in summer and partly in autumn. In the autumn experiments, no recaptures could be expected the same year, and there were none. As the different types of tags were not used in the same proportion in the summer and autumn experiments, a comparison of the two series of experiments will give misleading percentages for recaptures in the same year. Actually, for the summer experiments alone, the recapture percentages in the same year were 16.0 19.3 and 15.8 respectively. It is only for recaptures in the subsequent years after tagging that there is a decisive difference between the three different types of tags. In the following year (1), the plastic/terylene tags showed far fewer recaptures than the two other types, and no recapture of fish tagged with plastic/terylene was made more than four years after tagging. For the other two types, there appears to be no great difference, although the plastic/steel type appears to give more recaptures than the Lea tags after three years or more, just as Lea tags have given no recaptures later than four years after tagging. However, in taking into consideration the size of the fish tagged, Lea tags provide more recaptures of small fish than do plastic/steel tags.

In the recaptured char which I have had an opportunity to examine, the wound around terylene wire seemed to heal as readily as around steel wire, but possible the terylene knots will loosen while the fish is in the water. An experiment has shown that an ordinary reef-knot, even when tightened very hard, will, as a rule, loosen after the fish has been only twenty-four hours in the water. In the tagging experiments a special knot has been used which does not seem to be so likely to loosen, as shown by several recaptures after three and even four years.

It is considered important to continue such comparative experiments on a larger scale in order to obtain better information on the applicability of the different types of tags.

Summary

In the tagging experiments dealt with in this paper numbers of fish have been tagged at the same time and in the same locality with different types of tags. The following tags were used:

Plastic tag (red, yellow or blue), attached at the base of the anterior edge of the first dorsal fin either by means of stainless steel wire or by means of terylene (cod, char and salmon).

Lea tag, attached at the base of the anterior edge of the first dorsal fin by means of a wire clamp and a pin (cod, char and salmon).

Petersen tag, attached to the gill-cover by means of either silver wire or surgical stainless steel wire (only cod).

Carlin tag, description on page 19, attached dorsally by means of steel wire (only salmon).

From the point of view of total return rate, the experiments with cod show the following order for the tags (No. 1 giving the highest percentage of returns): 1. Red plastic tags attached with steel wire; 2. Yellow plastic tags/steel wire; 3. Lea tags; 4. Red plastic tags/terylene; 5. Yellow plastic tags/terylene and 6. Petersen tags. It is here pointed out, that the Petersen tags are attached at the gill-cover, while all the other types of tags mentioned are attached at the first dorsal fin. An attachment of the Petersen tags at the first dorsal fin would most possibly change the order of the tags mentioned above.

The experiments with char and salmon give the same order (Petersen tags not used) but to some degree dependent upon the size of the fish. The Carlin tag employed for salmon parr and smolt should possibly be placed as No. 1.

3.

On Non-Reported Recaptures from Danish Tagging Experiments on Cod, Subarea 1

By

SVEND AAGE HORSTED*

Tagging is one of the best known methods of estimating fishing mortality. If the sample of tagged fish is the same in every respect as the total stock in question, the fishing mortality in a certain period, e.g. the first complete year after liberation, is readily determined from the number of tagged fish returned in the same period, by the equation

$$n = \frac{F \cdot N}{F + M} \left(1 - e^{-(F + M)}\right)$$

where N = total number of tagged fish liberated or present at the beginning of the period in question, and n = number of recaptures.

This theory is, however, based upon several assumptions. Unfortunately the assumptions are rarely correct and errors therefore appear in the assessments. Some of the most serious errors are due to:—

a. death of fish due to tagging (at or soon after tagging)
b. shedding of tags (e.g. by corrosion of silver wire)
c. tagged fish not being equally mixed with the stock and therefore perhaps being subject to a larger (or smaller) local fishing mortality than the whole stock
d. non-reporting of tagged fish when recaptured.

This paper deals with this last-mentioned error, the non-reporting of recaptures. The material is from the Danish tagging experiments on cod in West Greenland (Subarea 1). The problem has been considered previously by Erik M. Poulsen (1957).

To illustrate the influence of non-reported recaptures on the estimated fishing mortality an example is given. If the natural mortality coefficient $M = 0.30$, the number of liberated, tagged fish $(N) = 100$ and the total recaptures (n) (reported + non-reported) in the first whole year after liberation = 50, then F will be calculated as shown in Table 1.

It is immediately seen that non-reporting of recaptures may cause serious error, if the non-reporting is extensive. *In fact, one cannot use tagging experiments to estimate F and other assessments without considering the non-reporting of recaptures.*

Table 1.

$M = 0.30$ $N = 100$ $n = 50$

Non-reported percentage of n	calculated F
0	0.84
25.00	0.56
33.33	0.48
50.00	0.34
75.00	0.16

In the following an attempt will be made to measure the non-reporting of tags for cod in Subarea 1.

Many of the recaptures (roughly about one-third) from the Danish experiments in Subarea 1 are taken by Greenland fishermen. As the fishery of the Greenlanders is carried out by hand- or long-line, every cod caught will pass through the hands of a person several times. Everyone in Greenland is familiar with the tags and knows that a reward will be paid if the tag is delivered to one of the administrators located in every place. In addition, the Greenlanders are very interested in the fishery and fishery problems — and in the reward too. We therefore assume (1) that every tag found will be delivered, and (2) that almost 100% of the recaptured tags are found because of the detailed handling of every fish. Some tags, however, are found in salted fish (*vide* paper by Jørgen Nielsen) and a few may never be found, but we normally consider the reporting by Greenland fishermen to be very close to 100% of the recaptures.

It would have been a great help had the Greenlanders fished on the same grounds as the other countries; however, this is not the case. Greenlanders still fish only in inshore waters and, thus, on a different stock from the other countries, so that we cannot use the reporting by the Greenlanders for comparison with that of other countries.

Fortunately, since 1953 Portugal has developed an excellent organization for collecting recaptures, and it may well be correct to assume that Portuguese fishermen also report almost 100% of *recovered* tags. The question then is whether all *recaptured* tags really are *recovered*. As to the dory-caught cod, we know that each of them is handled individually several times more than the trawl-caught cod. As Poulsen (l.c.)

---

* Greenland Fisheries Investigations, Charlottenlund, Denmark

says, there is little doubt that the opportunity to observe tagged cod is greater and better in the dory fishery than in the trawl fishery. It is reasonable to suppose that the Portuguese dory-vessels deliver almost 100% of their recaptures. From this assumption, it is possible to calculate the number of recaptures made by all other fleets fishing in the same small area (division), provided that

1. the tagged fish are evenly mixed with the whole stock in the area concerned;
2. gear selectivity is not influenced by the tag.

ad. 1. Cod used for tagging are caught by hand-line. This fishery often takes place on special grounds, whereas trawling takes place on other grounds within the same division. Thus, in the year of tagging it is possible that the different fleets do not fish on shoals with the same density of tagged fish. Tagging is, however, carried out in many localities within the same division and, due to migration (seasonal and long-term), the tagged fish are likely to become evenly dispersed in the stock in this division within one year after tagging. Thus, it can be assumed that after the elapse of the year of tagging, we have an even density of tagged fish in the statistical areas (divisions).

ad. 2. Most of the tags used in this material are Petersen disks fastened externally on the gill-cover. There is no reason to assume that a cod tagged in this way is more easily caught by hook than an untagged cod. The same can be said about the trawl, although it may happen that a tagged cod which would have escaped through a mesh is caught when the mesh catches the tag. Normally, however, the fish tagged in this way are of a size which would not escape through the trawl meshes. Gill-nets are not used in the cod fishery in this area. So we assume that a tagged cod has exactly the same chance of being caught as an untagged cod.

Thus — excluding first-year recaptures, *the number of recaptures from ship to ship, fleet to fleet, or country to country, is proportional to the catch within the same division.*

In his paper, Poulsen (l.c.) found conversion factors to use when recaptures by various fishing fleets (different countries) are compiled. In practice, however, this is not the best way to handle individual tagging experiments. In considering recaptures from a single tagging experiment, we frequently find that some countries have made no recaptures, and consequently the use of a conversion factor gives no idea of the actual number of recaptures by such a country.

A better method is to compare recaptures by Greenland fishermen (100% reporting), Portuguese dories (100% reporting), Portuguese trawlers (conversion factor about 2.5 — see below) and all other fleets combined. Comparison between Portuguese liners (dory vessels) and Portuguese trawlers is made in Table 2. Gear is not reported in the recaptures before 1954. For some of the recaptures gear is still unreported, but in most of these cases it is possible to deduce the gear used from other information (date, position, etc.). Such recaptures are given in brackets and are included in total recaptures.

The average of the conversion factors in Table 2 is 3.37. In the 1955 recaptures Poulsen (l.c.) found a conversion factor of 2.79 for Portuguese trawlers, which is very much the same as 2.71 in Table 2. The difference may be due to the fact that Poulsen included the 1955 tagging experiments.

Margetts (1963) has reported results of placing a known number of tagged fish (cod) in the catch of English trawlers at sea, unknown to the fishermen. Only about one-third of these were subsequently reported. Thus, it seems proper to use a conversion factor of at least 2.5 for trawlers where all recovered recaptures are reported (Portuguese trawlers). Only

Table 2

Comparison between reports from Portuguese trawlers (tr) and dory-vessels (d). Fish recaptured in the year of tagging not included. rp = number of reports; rp/c = number of reports per 1000 tons cod caught.

(Average only calculated from divisions where both types of vessel fish).

		Year of recapture								
Division	Gear	1955		1956		1957		1958		1959
		rp	rp/c	rp	rp/c	rp	rp/c	rp	rp/c	rp
1B	tr	3	1.23	6	1.20	0	0.00	9	1.99	8
	d	87	2.57	102	3.20	160 (11)	4.11	70	2.22	90
1C	tr	18	1.71	24	2.21	11 (2)	2.00	16	1.45	0
	d	64	6.84	27	3.68	129 (7)	12.32	89	10.33	25
1D	tr	41	1.37	68	1.81	12	1.22	23	2.43	8
	d	45	2.54	145 (1)	4.91	158 (4)	6.37	172	5.94	43
Total incl.	tr	62	1.45	112	1.96	48	1.26	77	1.76	29
1E, 1F and NK	d	196	3.22	276	4.01	462	6.18	332	4.81	162
Average	tr		1.46		1.87		1.44		1.81	
	d		3.96		4.15		7.26		6.33	
Conversion factor	d/tr	2.71		2.22		5.05		3.50		

one method seems possible to reduce this error, namely to make the tags more noticeable, perhaps by using double tagging.

For countries other than Portugal, the conversion factors found by Poulsen are much higher than 2.5. France and Spain have the highest factor — about 20. Using Poulsen's method, I found conversion factors of the same size, in some years as high as 50. As Portuguese, French and Spanish trawlers fish in almost the same localities and at the same time of year, the only explanation appears to be that few of the recaptures are reported even when they are recovered. I do not know what happens to the unreported recaptures; they may be thrown away or kept as souvenirs.

We are fortunate in having almost 100% reporting from Portuguese dory vessels and a conversion factor of about 2.5 for Portuguese trawlers. From this it is possible to estimate roughly the actual number of recaptures in divisions where Portugal fishes to some extent. However, this is only the case in Divisions 1B, 1C and 1D (in the case of Subarea 1 only). Since 1957 Portuguese trawlers have also fished in Division 1E and 1F, but not always to an extent which enables corrections to be made in the material of reports. In Divisions 1E and 1F it is very difficult. In Divisions 1B, 1C and 1D it can be done in this way:

	catch	reports	total recaptures
Portuguese liners (dories) ...	Y_1	n_1	n_1
Portuguese trawlers	Y_2	n_2	$2^1/_2 \cdot n_2$
Portugal (total)	$Y_1 + Y_2$	$n_1 + n_2$	$n_1 + 2^1/_2 n_2$
other nations (inc. Greenland)	Y_3	n_3	$\frac{(n_1 + 2^1/_2 n_2)\, Y_3}{Y_1 + Y_2}$
			Total (inc. Greenland)

Some examples are given to illustrate the size of the error of the non-reporting.

Example 1. Tagging: 28 July—1 August 1953, Div. 1B 887 cod.
Recaptures Div. 1B, 1954:

	tons cod	reports		recaptures
Portuguese liners	44,534	63		63
Portuguese trawlers......	10,274	8	$8 \times 2^1/_2 =$	20
Portugal	54,808	71		83
Other countries (inc. Greenland)	56,200	(6)		85
Total (inc. Greenland) ..	111,008	77		168

Example 2. Tagging: 5—11 August 1953, Div. 1D 439 cod.
Recaptures Div. 1D, 1954:

	tons cod	reports		recaptures
Portuguese liners	24,373	11		11
Portuguese trawlers......	30,218	3	$3 \times 2^1/_2 =$	8
Portuguese, egearn ot known		10	at least	10
Portugal	54,591	24	minimum	28
Other countries (incl. Greenland)	66,996	2	minimum	34
Total (inc. Greenland) ..	121,587	26	minimum	62

Poulsen (l.c.), using the conversion factor 2.0 for trawlers, found that in 1955 300 recaptures from Danish tagging in Subarea 1 were reported by all nations excluding Greenland, and estimated that it should have been 864 by a 100% reporting. This is very similar to the foregoing examples. However, the less Portugal fishes in a division, the larger of course is the error in the reporting. The tagging experiments must be handled division by division, year by year.

In Divisions 1E and 1F, it is more difficult to estimate the non-reported recaptures. One method may be to get a conversion factor for the United Kingdom and Germany in subareas where both Portugal and these countries fish. However, this is not a satisfactory method when handling a single tagging experiment, as in most of them only a few recaptures are reported from Divisions 1E and 1F. Reporting of 0, 1 or 2 recaptures is not enough to estimate the non-reported recaptures by means of a conversion factor. From the foregoing it is obvious, however, that many recaptures in 1E and 1F (and many other grounds) are not reported. So long as the reporting of recaptures and distribution of the fishery of the various countries is as varied as at present, it is necessary to allow for the non-reporting when making any assessments based on tagging experiments, but I am not able to suggest how a satisfactory estimate can be made. *The purpose of this paper is first and foremost to stress the fact that it is impossible to obtain a correct estimate of migrations, or of rate of mortality, from tagging experiments when only the actual reported recaptures are considered.*

Everyone knows that the best means of avoiding these difficulties is by every country building up an effective organization for the reporting of recaptures, using intensive propaganda among the fishermen. A very expensive tagging operation is almost fruitless if the last part, the reporting of recaptures, is not effective.

Summary

In estimating the fishing mortality the theory of tagging is one of the best known methods. The theory, however, is based upon certain assumptions, which are rarely satisfied. This paper deals with the most serious error, namely the non-reporting of recaptures. The material is the Danish tagging experiments on cod in Subarea 1.

The paper outlines the difference between the reported, recovered and actually recaptured number of tagged fish, and shows a way to make correction for the non-reported part of the recaptures. This correction is possible in statistical areas (divisions) where Portugal is fishing to some extent, since we can consider the Portuguese reporting to be 100% of the recoveries. Furthermore we consider the re-

covering in the Portuguese dory fleet to be nearly 100% of the number actually recaptured. In the Portuguese trawlers we find the recovering to be about 40% of the recaptures (conversion factor 2.5) compared with the dory fleet. From this it is shown how to calculate the number of recaptures from all other fleets together, in divisions where Portugal is fishing. In other areas it is very difficult to make correction for the non-reporting, but the paper shows that it is impossible to use only the actual reported recaptures when giving percentage of migration or when calculating mortalities.

References

MARGETTS, A. R. (1963). The measurement of the efficiency of recovery and reporting of tags from recaptured fish. *This symposium*, No. 40.

NIELSEN, JØRGEN (1963). Comparison between different types of tags used on cod, char, and salmon in Subarea 1. *This symposium*, No. 2.

POULSEN, ERIK M. (1957). Defects in the recovering of tagged fish. *ICNAF Ann. Meeting* 1957, Document No. 4.

4.

A Quantitative Evaluation of The Bias in Population Estimates Based on Selective Samples*

By

C. O. JUNGE, Jr.**

In the study of fish populations an expanding field of methodology has been developing. Techniques involving tagging or marking have been extended (Chapman and Junge, 1956; DeLury, 1954; Jackson, 1939; Leslie and Chitty, 1951; Schnabel, 1938), and measures of precision have been developed (Chapman, 1948, 1952). The importance of obtaining representative samples has been stressed (DeLury, 1954; Gulland, 1955) but the application of statistical tests has generally led to a dichotomy of acceptance or nonacceptance of samples. It is not difficult to illustrate that samples have been rejected when the bias introduced was negligible, and samples have been utilized when estimates were seriously affected.

At the present time there is a pressing need for the development of a quantitative measure of the degree by which a sample deviates from being representative or random. If properly defined, such a measure should permit an evaluation of the magnitude and direction of bias in estimates based on such selective samples.

In estimating population sizes by tagging and recovering procedures, the problem may be approached in the following manner. When fishing is selective (i.e., not random), associated with each fish is a rate of exploitation at time of tagging, x, and a distribution function G (x), which describes the distribution of fish according to the fishing rate, x. Similarly, in the sampling or recovery operation, a rate of exploitation, y, may be associated with a distribution function, H (y). More generally, F (x,y) may be considered as the joint distribution function defining the distribution of the tagging and recovery rates, with G (x) and H (y) the marginal distributions. In the deterministic model it can be shown that the standard estimate of the population size is given by

$$\hat{N} = \frac{nt}{s} = \frac{E(x) \cdot E(y)}{E(xy)} \cdot N \qquad (1)$$

where $\hat{N}$ is the estimate using t as the number tagged, n as the number sampled and s as the number tagged in the sample. Equation (1) follows from the fact that,

$$\begin{aligned} t &= \int_0^1 Nx \, dG(x) = N\,E(x) \\ n &= N\,E(y) \qquad\qquad (2) \\ s &= \int_0^1\!\!\int_0^1 Nxy \, dF(x, y) = N\,E(xy) \end{aligned}$$

Since N is the population size being estimated, the coefficient of N in equation (1),

$$B = \frac{E(x)\,E(y)}{E(xy)} \qquad (3)$$

which is a function of the mathematical expectations of x, y and xy can be considered as the bias factor. Even in the non-deterministic model, B as defined above measures the bias due to selective sampling. Noting that the correlation coefficient between x and y is given by

$$\frac{E(xy) - E(x)\,E(y)}{\sigma x \, \sigma y} \qquad (4)$$

it is clear that the necessary and sufficient condition that B equals one (no bias) is that the correlation coefficient between x and y is zero. Further, B will be less than one, giving an underestimate, if the catchability at tagging and recovery are positively correlated. Conversely, a negative correlation will lead to an overestimate.

It is clear that the usual requirement that either tagging or recovery be nonselective (x or y constant) is not a necessary condition for an unbiased estimate. Selectivity may exist in both the tagging and recovery operation without introducing bias if the sources of selectivity in the two processes are independent. For example, in tagging migrating salmon in a river it may be possible to tag nonselectively with respect to size but not with respect to time (early portion tagged at a different rate from the late portion). On the spawning grounds, however, the recovery process may be selective with respect to size of fish and area of recovery. If time of passage past the tagging site is uncorrelated with size of fish and area of spawning, no bias is introduced. Such a situation is not uncommon (Smith, in press). In other cases it may be possible to develop fishing techniques which will reduce the correlation between the tagging and recovery operations.

---

* Contribution No. 129, College of Fisheries, University of Washington.

** Fisheries Research Institute, College of Fisheries, University of Washington, Seattle 5, Washington.

In many cases, however, it may not be possible to eliminate bias. Of course, if the joint distribution function F (x, y), is known, the bias factor, B, could be computed and the bias removed from the standard estimate, $\hat{N}$, by dividing it by B. If selectivity is mainly due to size, then by procedures similar to those suggested by Holt (1957) for gill net selectivity a selection curve and the length distribution of the population may be estimated, and from these F (x, y) may be determined.

In most other cases where selectivity is spatial or temporal this would not be possible. It can be shown, however, that bias is somewhat insensitive to variations in tagging and recovery rates, and may be unimportant in some cases. It should be noted that if x and y are zero for substantial portions of the population, the bias will obviously be severe. Such situations must be avoided in population studies.

A study of extreme distributions may give some indication of the insensitivity of the bias factor to selectivity. For this purpose we will limit ourselves in all of the following discussion to the very extreme condition,

$$y = kx,$$

where the correlation between x and y is one, and the recovery rate for any fish is directly proportional to the tagging rate. Here the bias factor becomes

$$B = \frac{[E\ (x)]^2}{E\ (x^2)} \qquad (5)$$

which may be easily determined for many distributions. This assumption limits us to values of B less than one (underestimates), though a similar development may be used when x and y are negatively correlated.

Distributions in which x is bounded from zero will be considered first. The most extreme condition here results from a dichotomous distribution. In this case a variation of 100 percent in both the tagging and recovery rates will result in little more than 10 percent error in the estimated population size ($B = 0.89$). Such distributions, however, would be uncommon in practice. It seems more reasonable to suppose that most situations would be adequately approximated by continuous distributions. For purposes of illustration, a uniform distribution will be considered, which for a fixed range of x would generally be a more extreme condition than would result for a unimodal distribution with the same range. Since B is independent of a change in scale, for a uniform distribution it will depend only on

$$z = \frac{\text{upper limit of x}}{\text{lower limit of x}} .$$

For values of $z = 1, 2, 5$ and infinity, the respective values of B are 1, 27/28, 27/31, 3/4.

Since the upper limit of x cannot exceed one, z can only approach infinity if the lower limit of x approaches zero. This brings us to the case where x is not bounded from zero. To study this situation let us consider a family of distributions with the probability density function

$$f\,(x) = (n + 1)\ (1 - x)^n,\ 0 < x < 1. \qquad (6)$$

When n equals zero, f (x) is the limiting uniform distribution considered above. When n equals one, f (x) is a triangular distribution. As n increases, E (x) approaches zero and the bias becomes more severe, as indicated in the following table

n	0	1	2	3	∞
B	3/4	2/3	5/8	6/10	1/2

Since B is independent of a change of scale the upper limit of one for x is arbitrary, and a change of scale

$$x' = px\ 0 < x' < p$$

will give similar distribution functions and the same values of B for each n as in the above table.

In conclusion, by considering the distribution function of the rates of exploitation in the tagging and recovery operations, the bias due to selectivity may be derived. The necessary and sufficient condition that no bias is introduced is that the tagging and recovery rates be uncorrelated. Positive or negative correlations generate underestimates or overestimates respectively. If fishing rates are bounded from zero, bias is not likely to be severe unless the range as measured by z is great. For distributions not bounded from zero bias may become significant, and, if tagging and recovery rates are zero for a substantial portion of the population, the bias will be severe.

The techniques developed here may be extended to other estimating procedures based on tagged recoveries or on catch per unit of effort. For example, in estimating survival rates from the ratio of tagged recoveries in successive fishing periods (Jackson's method), it can be shown that even though tagging is nonselective, selectivity in the recovery process will overestimate mortalities. This results from the fact that recovery groups are weighted by the rate of exploitation at the time of recovery (y), so that the groups most heavily fished and which consequently have the highest total mortality rates are most heavily weighted.

Summary

A quantitative measure of the degree by which a sample deviates from being random or representative is developed. In some cases, such a measure permits an evalution of the magnitude and direction of bias in estimates based on selective samples.

In estimating population sizes by tagging and recovery procedures, the problem may be approached in the following manner. When fishing is selective, associated with each fish is a rate of exploitation at time of tagging, x, and a distribution function G (x) which describes the distribution of fish according to the fishing rate, x. Similarly, in the sampling or recovery operation, a rate of exploitation, y, may be associated with a distrihution function H (y). More generally, F (x, y) may be considered as the joint distribution function defining the distribution of the tagging and recovery rates, with G (x) and H (y) the marginal distributions. In the deterministic model it can be shown that the standard estimate of the population is given by:

$$\hat{N} = \frac{nt}{s} = \frac{E(x) \cdot E(y)}{E(xy)} \cdot N$$

where $\hat{N}$ is the estimate, using t as the number tagged, n as the number sampled, and s as the number tagged in the sample. Since N is the population size being estimated, the value

$$B = \frac{E(x) \cdot E(y)}{E(xy)}$$

which is a function of the mathematical expectations of x, y, and xy, can be considered as the bias factor. If B equals one there is no bias, and this will occur if and only if the correlation coefficient between x and y is zero. Further, B will be less than one, giving an underestimate, if the tagging and recovery rates are positively correlated. Conversely, a negative correlation will lead to an overestimate.

The usual requirement that either tagging or recovery be nonselective (x or y, constant) is not a necessary condition for an unbiased estimate. Further, it can be shown that bias is somewhat insensitive to variations in tagging and recovery rates even if x and y are perfectly correlated. Severe distribution functions are considered to illustrate this effect. In making use of this principle, however, situations which can introduce extreme bias must be recognized. These situations are discussed.

References

CHAPMAN, D. G. (1948). A mathematical study of confidence limits of salmon populations calculated from sample tag ratios. *Bull. Int. Pacif. Salm. Fish.* No. 2: 69—85.

CHAPMAN, D. G. (1952). Inverse, multiple and sequential sample censuses. *Biometrics*, 8 (4): 286—306.

CHAPMAN, D. G. and C. O. JUNGE, Jr. (1956). The estimation of the size of a stratified animal population. *Ann. Math. Statist.*, 27 (2): 375—389.

DeLURY, D. B. (1954). On the assumptions underlying estimates of mobile populations. *Statist. and Math. in Biol.*, Iowa, 287—293.

GULLAND, J. A. (1955). Estimation of growth and mortality in commercial fish populations. *Fish. Invest., London*, Ser. II, 18 (9).

HOLT, S. J. (1957). A method for determining gear selectivity and its application. F.A.O., S. 15, 2743.

JACKSON, C. R. N. (1939). The analysis of an animal population. *J. Anim. Ecol.*, 8 (2): 238—246.

LESLIE, P. H. and D. CHITTY. (1951). The estimation of population parameters from data obtained by capture — recapture method. *Biometrika*, 38: 269—292.

SCHNABEL, Z. E. (1938). Estimation of the total fish population of a lake. *Amer. Math. Monthly*, 45: 348—352.

SMITH, H. D. The segregation of red salmon in the escapements to the Kvichak River system, Alaska. *Submitted for publication as Fisher. Bull.*, U.S.

5.

Tagging Experiments and the Theory of Advertising

By

S. J. HOLT*

The purpose of this note is to draw the attention of fisheries biologists to some recent applications of operational research methods to marketing problems which might contribute to improvement in the conduct of tagging experiments.

The failure by fishermen, other workers in the industry and consumers to recover and return or report recaptured tagged fish leads to bias in estimates of mortality and of population size. Estimates may be improved by "planting" a known number of marked fish in the catch and determining the proportion recovered and returned or reported. The proportion recovered may be increased by making marks more conspicuous by colour etc., introducing electronic or other recovery devices, placing marks in positions where they are more likely to be seen by the fishermen during handling, or perhaps by making small alterations in the handling procedures. The proportion recovered in the normal way may also be estimated by conducting special examinations of catches on a sample basis. Relative conspicuousness of different tags can also be studied by simultaneously releasing batches of fish bearing one or other tag, provided the tag types have the same loss rates and are equally vulnerable to fishing. If this latter assumption cannot be made because the tags differ substantially or because the difference in conspicuousness makes them liable to differential predation for example, the results of comparative tagging experiments might be checked against those from double marking experiments using the same types of tag.

The rate of return, and perhaps in some circumstances, the rate of recovery, may be improved by advertising, offering rewards and by similar means. These inducements are an integral part of the tag retrieval program, and should presumably be kept constant during any study to estimate recovery and reporting efficiency. Even if the absolute efficiency of recovery and return, and therefore the effects on these of changing inducements, are not known, it would be useful to measure the *relative* improvement gained by various patterns of advertising and levels of reward. Further, it is clearly desirable to maximise the information obtained from a marking experiment by increasing the rate of return as far as possible with a reasonable expenditure. In this connection it should be borne in mind that although either a high or an accurately estimated level of return is desirable for fishing mortality determination, it is perhaps more important to have a *constant* efficiency of return for the determination of total loss rates (including fishing and natural mortality and emigration). Constant high levels will not necessarily best be obtained by continuous propaganda, but alternatively by an optimal frequency of "reminders".

A difficulty in studying the effects of propaganda and inducement programs on return rates is that only in very special situations will it be possible to have two programs in operation simultaneously; instead, different programs have to be introduced experimentally at different times. For this reason it should be informative to follow the transient effects after an experimental change in the program. This is a procedure followed in many studies of human behaviour, including response to advertisement, of which the tag return problem is a special case.

In the analysis of experiments involving different types and degrees of publicity and reward, the following relations, which are reported by Benjamin, Jolly and Maitland (1960) to have been verified empirically, may be useful. The models used were initially derived as analogies with physiological stimulus and response, and an electronic analogue simulator was designed for the prediction of response to a proposed campaign.

The first relation describes the cumulative total response to a single advertisement as a function of time elapsed since the placement of the advertisement. In terms of a tagging experiment for which one announcement and offer of reward is made at time $t = 0$ we have

$$n_t = n_o \left[1 - \exp\left(- k_1 t\right)\right]$$

where n_t is the total number (or proportion) of tags returned or reported up to time t,

n_o is the total (or proportion) which will eventually be returned or reported as a result of that advertisement,

and the parameter k_1 measures the instantaneous rate of response. Clearly both k_1 and n_0 measure different aspects of the effectiveness of the publicity.

---

* Fisheries Biology Branch, F.A.O., Rome.

The second relation describes the cumulative effect of repeating the same publicity at regular intervals. For repeated advertisements the response from each will follow the first law stated above, but the value of n_0 for each successive advertisement will decrease in such a way that the total response to an advertisement made at time T is given by

$$n_0 = N_0 + N_1 \exp(-k_2 T)$$

where N_0 is the proportion of recaptured tags eventually reported or returned in response to an announcement made late in the campaign ($T \rightarrow \infty$), and $(N_0 + N_1)$ is the proportion of recaptures reported or recaptured in response to the first announcement ($T = 0$).

The value of the parameter k_2, like that of k_1, depends on the effectiveness of the publicity, including the attractiveness of the reward offered, and, presumably, also on the frequency of advertisement.

By combining these two equations expressions may be devised for the overall rate of response to successive advertisements inserted at known intervals, which may be constant or irregular.

A note by Rothman (1961) gives a solution to the optimum allocation of a given advertising budget for repeated advertising.

A third relation, found empirically, is that if, late in a campaign, one advertisement is omitted, the resulting drop in the rate of response is wholly made good after the appearance of the next advertisement, and the cumulative total response continues on the original curve.

It is suggested that some developments of this theory needed for its application to tagging experiments include:

1. Elaboration of models to cover varying rate of capture of tagged fish during the period of observation.
2. Extension of the repeated advertisement model to cover continuous publicity.
3. Evaluation of the inter-dependence of values of the parameters n_0 and k.

A slightly different approach to advertising theory, which nevertheless seems pertinent, is given by Stigler, 1961.

Summary

Recent applications of operational research methods to marketing problems are reviewed. It is suggested that a model which has been derived from a physiological analogy may, if extended, be useful in making decisions concerning levels of reward for tag returns, methods of publicising experiments, and adjusting their results for non-return of marks by fishermen.

References

BENJAMIN, B., W. P. JOLLY & J. MAITLAND 1960. Operational Research and Advertising, Theories of Response. *Operat. Res. Quart.*, 11: 205—18.

ROTHMAN, L. J. 1961. Letter to the Editor, *Operat. Res. Quart.*, 12: 79—80.

STIGLER, G. J. 1961. The economics of information. *J, polit. Econ.*, 69: 213—25.

6.

Parasites as Biological Tags

By

Z. KABATA*

The essential difference between biological and conventional tags is the fact that their appearance and continuing presence in fish are due to natural processes, all of which are usually beyond human control and many of which are not even fully understood. In order to assess the value of such tags, therefore, these processes must be studied and correctly interpreted. This means that their use often calls for extensive preliminary work, a considerable part of which might not produce results readily applicable to the problems in hand. They are also unsuitable for the study of the movements of individual fishes. In spite of these drawbacks, however, they have many advantages. For one thing their use does not involve any arbitrary and artificial introduction of external influences into the natural situation, with the consequent risk of upsetting the balance of nature and producing results not indicative of the true state of affairs.

Ideally, in order to make the best use of parasites as biological tags in marine fishes, one would need to know the entire parasite fauna of all the fish species inhabiting the area in question and, in addition, to have the knowledge of parasites of the local marine invertebrates, so many of which serve as intermediate hosts to numerous fish parasites.

Behind the practice of using parasites as biological tags lies the vexatious problem, which occupies so much attention of most parasitologists: the problem of specificity. The parasite must be adapted to the life and the development in the host, which in turn must be adapted to a particular environment. Thus, the specificity and the host-parasite relationship can be considered only against the background of environmental influences, as a kind of parasitological "eternal triangle". The change in any one of its three components can result in displacing the balance, either ultimately precluding the parasite from entering and remaining in the host, or offering the parasite such favourable conditions that it becomes able to swamp the defences of its host and to kill it. With changes in the environmental conditions, the balance of these three factors differs from area to area, producing differences in the general state of parasitic infections and infestations between the populations of the same fish species.

The value of a particular parasite species as a biological tag depends on several conditions.

(1) The parasite should be common in one population and rare or absent in another population of the studied host species. Russian authors (Dogiel, 1958; etc.) consider that, in order to be suitable as a tag, a parasite must infest at least 25% of the population. In their view, lower incidence can be due to accidental infestation. This is true, however, only when the study is based on a small number of examinations. When samples numbering several thousands of fish are examined, incidence even as low as 2% cannot be dismissed as fortuitous, and can be used as a label, particularly in a confirmatory and supporting capacity.

(2) Preferably, the parasite should include in its life cycle only the host species which is the object of the study. The necessity for other hosts, whether intermediate or final, greatly complicates the picture, since the occurrence of the parasite, and even more so the level of its incidence, must depend on the distribution and abundance of the populations of all its hosts. This does not mean that the parasites with complex life cycles are not suitable as biological tags; it does mean, however, that their use involves more work and requires a wider study than in the case of the parasites with simple life cycles.

(3) The infestations or infections produced by the parasite must be of a reasonably long duration. Moving from the territory of an infected and allegedly separate stock into one of a stock unaffected by the infection, a fish might lose a short-lived parasite en route. Its movements, under those circumstances, cannot be detected by the use of parasitological tags.

(4) The incidence of the parasite must remain relatively stable, without extensive fluctuations either within an annual cycle, if such a cycle exists in the life history of the parasite, or from year to year.

(5) The environmental conditions throughout the area studied should be, preferably, within the physiological range of the parasite intended as a tag. Should the parasite be excluded from a part of the area by its inability to survive in the external environment and should it, in addition, be capable of producing only short-lived infection or infestation, its suitability as a tag would be correspondingly reduced. If, therefore, the territory of an uninfected fish population borders on one inhabited by an infected population, it is a reasonable precaution to search the uninfected area for the presence of the parasite in fishes other than those belonging to the species examined.

---

* Marine Laboratory, Aberdeen, Scotland.

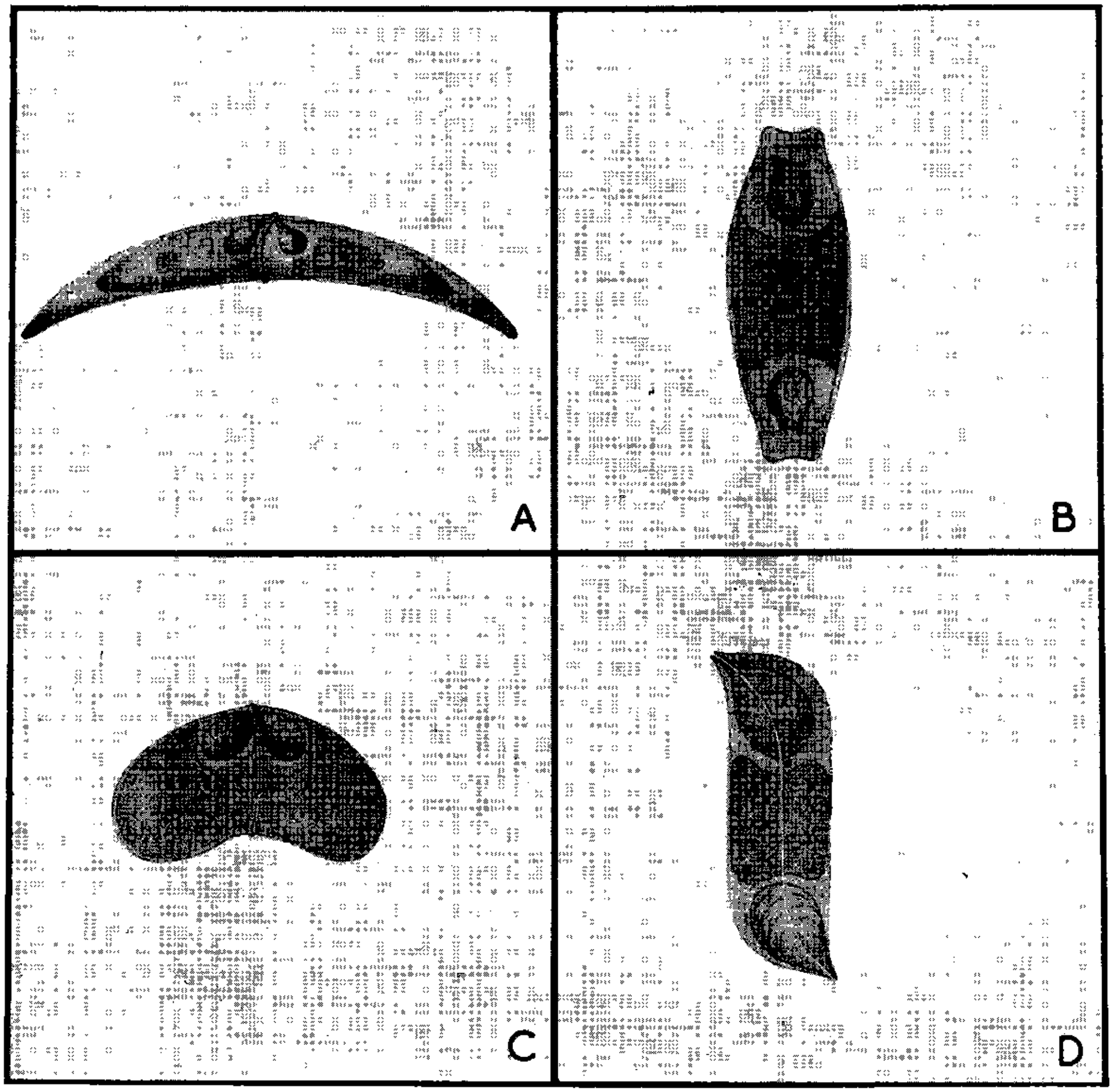


Figure 1. The spores of some gall-bladder Myxosporidia: A: *Ceratomyxa;* B: *Sphaeromyxa;* C: *Leptotheca;* D: *Myxidium.*

Although the usefulness of parasitological evidence in the study of the structure of fish populations has been generally recognised for some time now, very little use has been made of it so far. Dogiel and Bykhovski (1939) distinguished between two separate stocks of acipenserid fishes in the Caspian Sea on the basis of differences between their parasite faunas. Shulman and Shulman-Albova (1953) found similar differences between various stocks of herring, gadoids and other fishes in the White Sea, while Shulman (1950) found them also in stocks of cod and other fishes in the Baltic. Sindermann (1957, 1959) used parasites as indicators of herring movements along the coast of Maine and for discrimination of redfish stocks. Templeman and Squires (1960) studied infestation with *Sphyrion lumpi* as a means of distinguishing between redfish populations, while Sherman and Wise (1961) applied the study of infestation with *Lernaeocera* as a discriminant between cod populations. Kabata (1959) published a preliminary report on the infection of the gall-bladder of whiting with Protozoa as an indicator of stock subdivisions. In the North Pacific, Margolis (1956) applied parasitological data to the solution of the problem of marine migrations of salmon, and Bishop and Margolis (1955) used larval nematodes as biological indicators in herring. These useful pioneering efforts provided indications that the parasitological evidence can be used as a very useful

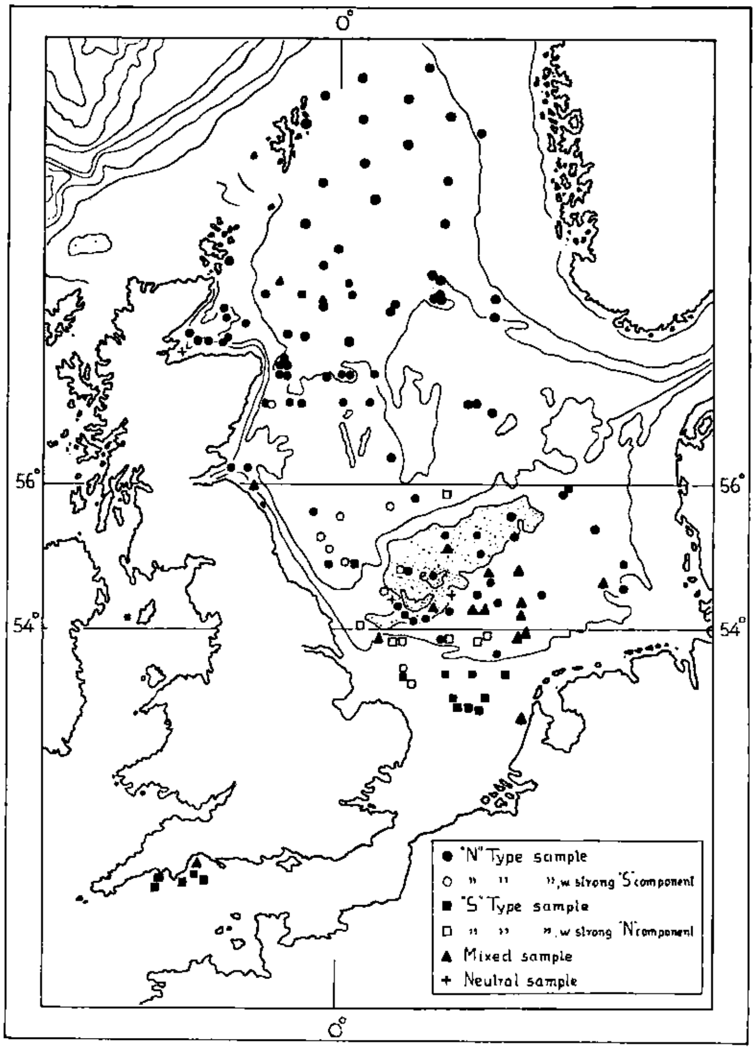


Figure 2. Localities in which the gall-bladders of whiting were collected.

corroboration of other methods of research, and even that it can be used as the main tool of investigation of the fish population and fish migration problems.

Myxosporidia as Tags of Whiting Populations around the British Isles

A preliminary survey of the parasite fauna of the gadoid fishes in the northern North Sea was undertaken by the Marine Laboratory at Aberdeen in 1957. In the course of that survey it was found that the gall-bladder of whiting, *Gadus merlangus* L., is extensively infected with a myxosporidian parasite *Ceratomyxa arcuata* Thelohan, 1892 (Fig. 1a). Also present were *Leptotheca informis* Auerbach, 1910 (Fig. 1c) and, though very rarely, *Zschokkella hildae* Auerbach, 1910 and *Myxidium sphaericum* Thelohan, 1892 (Fig. 1d). This paper will be concerned mainly with *Ceratomyxa* and *Myxidium*.

The findings of the survey contrasted strongly with the results obtained by Noble (1957), who studied the protozoan fauna of whiting in the Plymouth area and found that the incidence of *Ceratomyxa* there was only about 2%, while *Myxidium* occurred in 58% of the whiting examined. Since this was quite opposite to the position in the northern North Sea, the possibility arose of using these parasites as tags for studying subdivisions, if any, of the whiting populations around the British coasts. For this purpose some 5,000 whiting gall-bladders were examined from the North Sea, the English Channel, the west coast of Scotland and the Faroe Islands. The main effort was concentrated on the North Sea, where 3,507 whiting were examined.

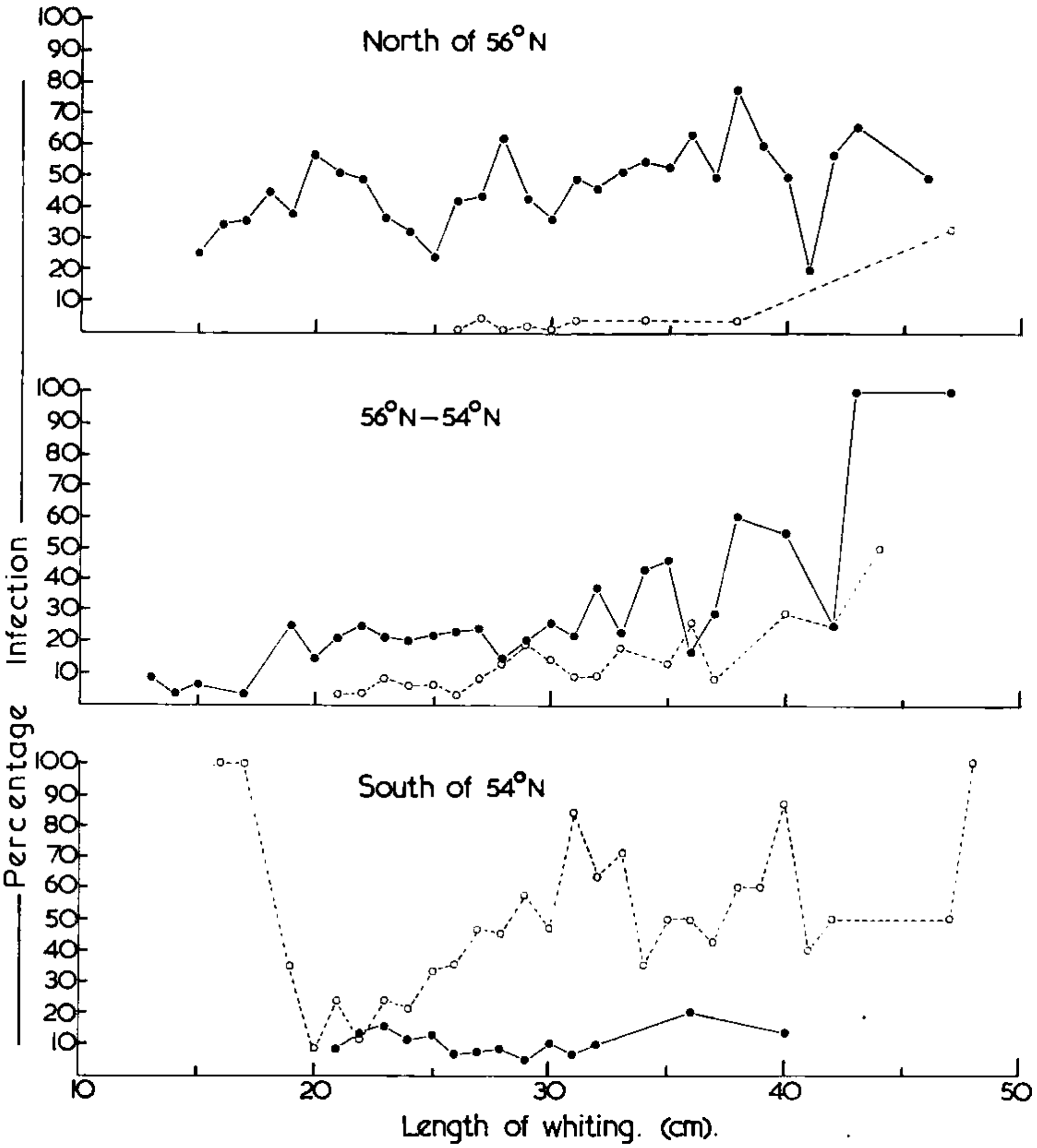


Figure 3. Infestation (in %) of the gall-bladder of whiting with Myxosporidia at different latitudes. Solid line = *Ceratomyxa;* interrupted line = *Myxidium.*

The results of the examination are shown in Table 1 and in Fig. 2.

Table 1

Infection with *Ceratomyxa arcuata* and *Myxidium sphaericum* in various areas of the North Sea

Latitude	No. of fish examined	*Ceratomyxa* No. infected	%	*Myxidium* No. infected	%
North of 56°N	1,290	592	46	17	1.3
56—54°N	1,319	273	21	108	8
South of 54°N	898	79	9	360	40

It will be seen that the North Sea can be divided roughly into three areas: (i) north of 56°N; (ii) between that latitude and 54°N and (iii) south of 54°N. The area between 56 and 54°N can be referred to as the intermediate or mixing zone. North of the mixing zone the average infection with *Ceratomyxa* is 46%, while that with *Myxidium* is only 1.3%. South of the mixing zone *Myxidium* is found in 40% of whiting, and *Ceratomyxa* in only 9%. In the mixing zone itself the levels of incidence are intermediate, *Ceratomyxa* infecting about 20% and *Myxidium* about 10% of whiting gall-bladders. These results suggested that in the North Sea there are two stocks of whiting, one infected predominantly with *Ceratomyxa* and the other with *Myxidium.* Similar results were obtained by the workers who used meristic characters as their discriminants (Gamble, 1959; Messtorff, 1959).

To eliminate the possibility of environmental factors excluding *Myxidium* from the northern parts of the North Sea, a search was made for it in gadoids other than whiting. It was found to be present in young saithe, *Gadus virens,* 174 of which were examined and 65% infected. The reason for the absence of *Myxidium* from northern North Sea whiting must therefore be sought in differences between that stock and its southern North Sea relative.

Infections of whiting with *Ceratomyxa* and *Myxidium* do not fluctuate greatly with the age of the host. Fig. 3 shows that the fish becomes infected quite early, certainly in the first year of its life, and that the infection shows some tendency to increase with the growth of the host, but it can be regarded as reasonably stable throughout the population. It does not fluctuate widely with the seasons either, although the relative abundance of various developmental stages varies with the seasons, the spores being less abundant at the peak of the summer than at other times of the year.

The duration of myxosporidian infections has not been established experimentally. Erdmann (1917) fed spores of *Chloromyxum leydigi* to fish and found sporulating individuals 39 days later. There is no reason to suppose that the infection terminates until the gall-bladder becomes completely destroyed and is no longer able to support a parasite population. From this point of view, therefore, Myxosporidia appear to be suitable as parasitological tags.

The indication that two adjacent areas contain two separate populations of fish of the same species suggests the existence of some environmental differences between them. Only the existence of such differences can prevent free mixing of the fish stock throughout the entire area. Polyanski (1955), who studied the parasite fauna of fishes of the Barents Sea, found that it is quite uniform over all the localities examined. He attributed this to the lack of separate stocks of fishes which, in turn, was due to the absence of environmental differences strong enough to prevent free migration of the fish throughout the region.

In the case of the North Sea, the area of the Dogger Bank appears to form the key point of such environmental differences. Our knowledge of the hydrography and plankton of the North Sea, particularly of plankton indicator species, confirms the existence of a certain discontinuity line between the northern and the southern North Sea. This line passes through the Dogger Bank area (Russell, 1935, 1939). This difference, of course, does not form an absolute obstacle. Some intermixing of the two stocks of whiting does take place, as can be seen from Fig. 2. It appears that the northern stock is more or less predominant over the bank itself, while the southern stock sometimes penetrates in the northerly direction, mainly through the deeper water channels.

In contrast to the whiting of the northern North Sea, the small whiting population in the Faroes is 29% infected with *Myxidium.* This supports the evidence, obtained by other means of tagging, that no exchanges occur between the populations of whiting off the Faroes and in the waters over the continental shelf.

Myxosporidia as Tags of Haddock Populations in the Faroes and the North Sea

The gall-bladder Myxosporidia of haddock, *Gadus aeglefinus* L., can also be used to confirm the absence of exchanges between the Faroes and the continental shelf. The most common parasite species in the gall-bladder of haddock in the northern North Sea and off the west coast of Scotland is *Leptotheca* sp. (probably *informis*), some 10% of them being also infected with *Myxidium* and 2% with *Sphaeromyxa hellandi* Auerbach, 1909 (Fig. 1b), a parasite not previously recorded in haddock. *S. hellandi* is absent from haddock in the Faroes. Since the numbers examined were 703 in the Faroes and 679 in the North Sea, this difference in infection cannot be regarded as accidental.

In the Faroes, where the plateau round the islands is separated from several outlying banks (Fig. 4), the haddock population on the main plateau is infected both with *Leptotheca* and with *Myxidium,* but on three of the four banks *Myxidium* is absent. This supports the data on the differences in the rates of growth, which suggested that the outlying bank fishes form separate stocks (Jones, in press).

It must be remembered that it is not only for the investigation of population structure that the parasitological evidence can be used. In addition to the zoogeographical problems of marine fishes, it can assist the study of the biology of some fishes, particularly of their food and feeding habits, as well as the study of phylogenetic problems.

References

BISHOP, Y. and MARGOLIS, L. (1955). A statistical examination of *Anisakis* larvae (Nematoda) in herring (*Clupea pallasi*) of the British Columbia coast. *J. Fish. Res. Bd Can.,* **12**: 571—92.

DOGIEL, V. A. (1958). *Parasite fauna and its environment. Some problems of the ecology of the parasites of freshwater fishes.* In Dogiel, V. A., Petrushevski, G. K. and Polyanski, Yu. I., *Parasitology of Fishes,* Leningrad Univ., 363 pp.

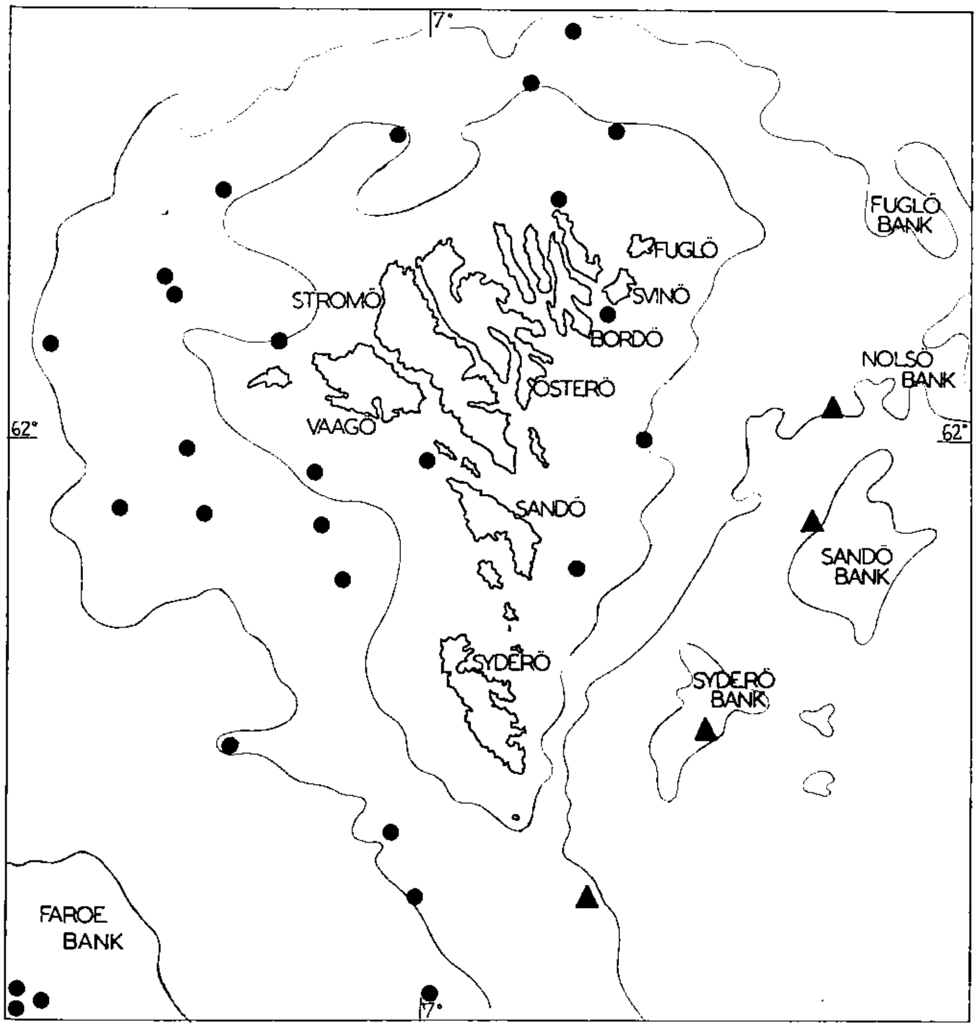


Figure 4. Faroe Islands. Localities where gall-bladders of haddock were collected. Circles = samples infected with *Leptotheca* and *Myxidium;* Triangles = samples infected with *Leptotheca* only.

DOGIEL, V. A. and BYKHOVSKI, B. E. (1939). Parasites of fishes of the Caspian Sea (In Russian). *Trud. kompl. izuch. Kasp. morya*, 7.

ERDMANN, R. (1917). *Chloromyxum leydigi* und seine Beziehungen zu anderen Myxosporidien, II. *Arch. Protistenk.*, **37**: 276.

GAMBLE, R. (1959). Investigations of the subdivisions of North Sea whiting population. I. Further observations on the vertebral counts of whiting in the North Sea area. *Paper No. 36 Near Northern Seas Committee*, I.C.E.S. 1959.

JONES, R. (in press). Haddock bionomics, II. The growth of haddock in the North Sea and at Faroes.

KABATA, Z. (1959). Investigations of the subdivisions of North Sea whiting population. II. Some observations on gall-bladder Protozoa in North Sea whiting. *Paper No. 36, Near Northern Seas Committee*, I.C.E.S. 1959.

MARGOLIS, L. (1956). Report on parasite studies of sockeye and pink salmon collected in 1955, with special reference to the utilisation of parasites as a means of distinguishing between Asiatic and American stocks of salmon on the high seas — a progress report on work being carried out as part of F.R.B.'s commitments to INPFC. *Fish. Res. Bd Can., Manuscr. Rep. Biol. Sta.* No. 642.

MESSTORFF, J. (1959). Untersuchungen über die Biologie des Wittlings, *Merlangus merlangus* (L), in der Nordsee. *Ber. Deutsch. Komm. Meeresforsch.*, N.F., **15**: 272—334.

NOBLE, E. R. (1957). Seasonal variations in host-parasite relations between fish and their Protozoa. *J. mar. biol. Ass. U.K.*, **36**: 143—155.

POLYANSKI, Yu. I. (1955). Contributions to the parasitology of fishes of the northern seas of the U.S.S.R. (In Russian). *Trav. Inst. zool. Acad. Sci.* **19**: 5—170.

RUSSELL, F. S. (1935). A review of some aspects of zooplankton research. *Rapp. Cons. int. Explor. Mer*, **95**: 5—30.

RUSSELL, F. S. (1939.) Hydrographical and biological conditions in the North Sea, as indicated by plankton organisms. *J. Cons. int. Explor. Mer*, **14**: 171—92.

SHERMAN, K. and WISE, J. P. (1961). Incidence of the cod parasite *Lernaeocera branchialis* in the New England area and its possible use as an indicator of cod populations. *Limn. & Oceanogr.*, **6**: 61—67.

SHULMAN, S. S. (1950). Parasites of fishes in the waters of Latvian Republic (In Russian). *Trud. gel'mint. Lab.*, 4.

SHULMAN, S. S. and SHULMAN-ALBOVA, E. R. (1953). *Parasites of fishes of the White Sea* (In Russian), Acad. Sci. Moscow & Leningrad, 198 pp.

SINDERMANN, C. J. (1957). Diseases of fishes of the western North Atlantic. V. Parasites as indicators of herring movements. *Res. Bull. Maine Dep. Sea Shore Fish.*, No. 27, 30 pp.

SINDERMANN, C. J. (1961). Parasitological tags for redfish of the western North Atlantic. ICNAF *Spec. Publ.* 3

TEMPLEMAN, W. and SQUIRES, H. J. (1960). Incidence and distribution of infestation by *Sphyrion lumpi* (Kröyer) on the redfish, *Sebastes marinus* (L) of the western North Atlantic. *J. Fish. Res. Bd Can.*, **17**: 9—31.

7.

The Movement, Heterogeneity, and Rate of Exploitation of Walleyes in Northern Green Bay, Lake Michigan, as Determined by Tagging

By

WALTER R. CROWE*, ERNEST KARVELIS**, and LEONARD S. JOERIS**

Introduction

The Michigan waters of northern Green Bay are an important center for commercial and sport fishing. This 400-square-mile area has supported a commercial fishery for many years but the development of the intensive sport fishery is more recent,mostly since World War II. The commercial fishery is based on several species, whereas anglers are particularly interested in the walleye, *Stizostedion v. vitreum.*

Broad objectives of tagging studies initiated in September 1957 were to obtain information on the heterogeneity, movement, and exploitation of the walleye population of northern Green Bay. The statistical data on the commercial fishery are very sound but other information on the Green Bay walleye has been sketchy.

Shortages of personnel and money have limited the numbers of walleyes that could be tagged and have placed undesirable restrictions on the time and locality of tagging. Our early findings have, nevertheless, brought out some useful information and have indicated rather clearly the lines along which further tagging experiments should be organized. The present article is concerned with some of the special uses of tag-recovery data that should prove profitable in Green Bay.

Methods

Tags were applied to a total of 4,690 walleyes — 770 in 1957, 917 in 1958, 1,981 in 1959, and 1,022 in 1960. Total lengths, which were recorded at tagging, ranged from about 10 inches upward to 30 inches but 68.6 percent of the fish were at or above $15^1/_2$ inches, the minimum size for commercial fishermen. (The minimum for anglers is 13 inches.) Most of the tagging was done in the early spring. Walleyes were tagged at 14 different localities (Fig. 1) but most were released at three sites: 1,480 (32 percent) at a sea lamprey barrier on the Whitefish River; 1,777 (38 percent) in the extreme northern end of Little Bay de Noc, and 314 (7 percent) in Big Bay de Noc, near Nahma. The geographical distribution of the tagging sites in the initial stages of this study was governed largely by the availability of fish.

Most of the fish were marked with monel-metal tags (Shetter, 1936) placed around the maxillary and premaxillary, or "spaghetti-dart" tags (Yamashita and Waldron, 1958) inserted immediately below the soft dorsal fin. Other types were placed on too few fish to have any bearing on results given in this report. The reports of recapture for the two principal kinds of tags have been closely similar.

Recaptures of tagged walleyes were reported voluntarily by anglers and commercial fishermen; no rewards were offered. Fishermen were alerted to the presence of tagged walleyes by the local press, by posters at boat liveries, fish houses, and public-access points, and by word of mouth. To stimulate continued coöperation, all reports of recapture were acknowledged with a form letter giving locality, date, and length of fish at tagging. In addition to the recaptures reported by fishermen, we took numerous tagged walleyes in our own nets.

Homogeneity and Heterogeneity of the Walleye Population

The walleyes remained in Green Bay and most of the recaptures were in the northern part. Of 417 fish reported by anglers and commercial fishermen only 5 had left northern Green Bay; all of these were recaptured in central or southern Green Bay. None have been reported from Lake Michigan proper. Results of this and earlier experiments (Eschmeyer and Crowe, 1955) indicate that the walleye stocks of Lake Michigan are local.

Evidence of homogeneity of the walleye stock of northern Green Bay comes from extensive post-spawning intermingling of fish tagged during the spawning run. Anglers and commercial fishermen have reported the recapture of tagged walleyes in all areas at most times of the year.

Despite the general mixing through much of the year, our own recaptures during the spawning season of fish tagged from previous spawning runs give strong evidence that the northern Green Bay walleye population is subdivided into discrete spawning units. Nearly all (72 of 76) recaptures during the spawning

---

* Institute for Fisheries Research, Michigan Department of Conservation, Ann Arbor, Michigan.

** Bureau of Commercial Fisheries, U. S. Department of the Interior.

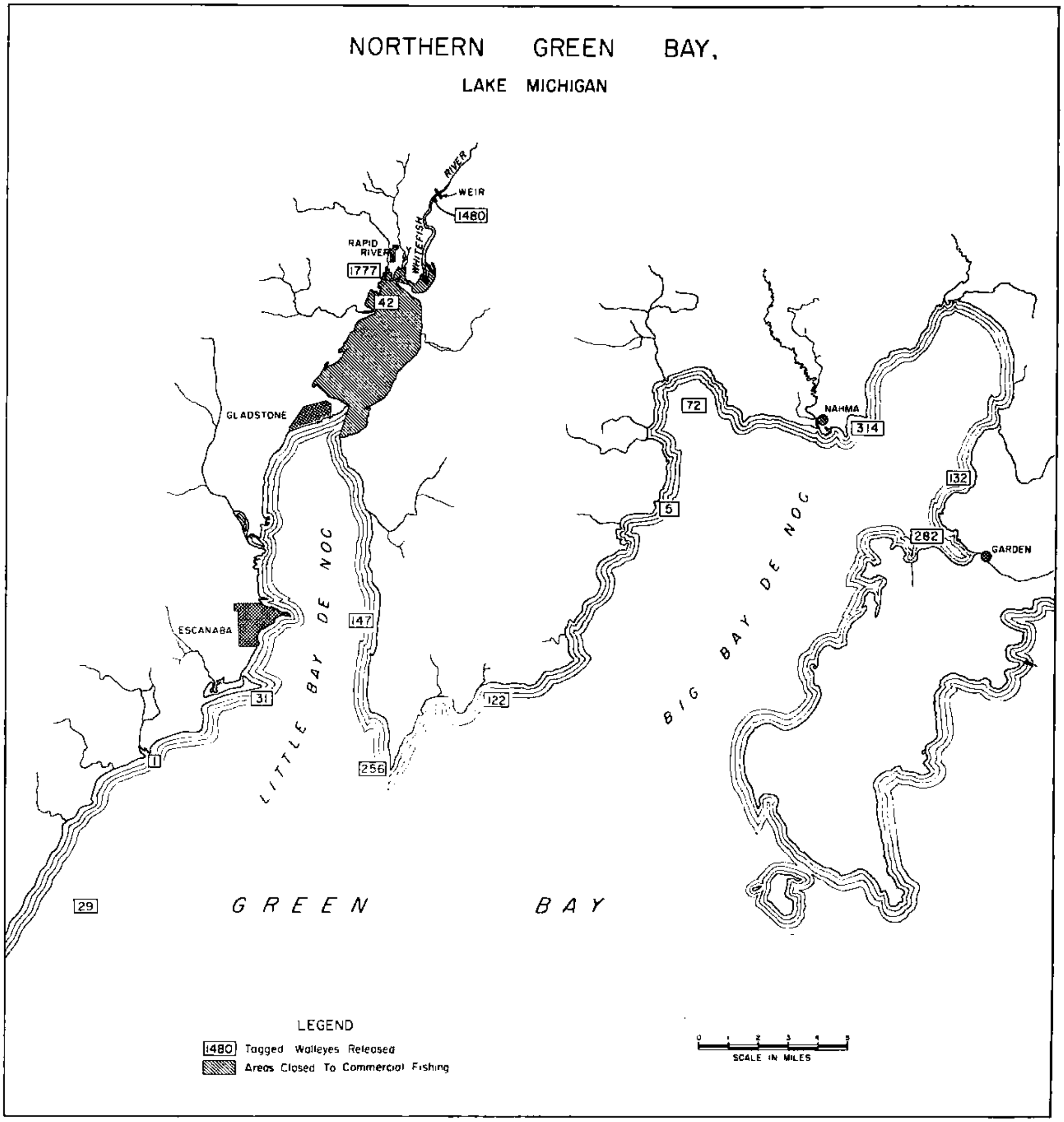


Figure 1. Location of tagging localities and number of walleyes tagged at each site. The shaded area is closed to commercial fishing.

period were made at or very near the point of release. Of 65 recaptures in northern Little Bay de Noc, 64 had been released there; of 11 recaptures near the lamprey weir on the Whitefish River 8 had been released there. Our first spawning-season fishing near Nahma in Big Bay de Noc in 1960 did not, on the other hand, yield a single fish tagged at other spawning localities in previous years. Results to date, then, give rather strong evidence that the walleye population of northern Green Bay breaks down into distinct subpopulations during the spawning season. These subpopulations are identified with particular spawning sites; at the approach of spawning, walleyes return to their chosen grounds and do not merely move randomly to any suitable grounds. Tagging at a greater number of sites is needed to give more information on this point.

The existence of discrete spawning units within populations has long been known among certain species, particularly the salmonids, but little is known about fish that spawn in the open water or, as the walleye, facultatively in the lake or in a tributary. The only previous indication in the Great Lakes that a characteristically open-lake spawner may return annually to the same spawning grounds was obtained by the returns of tagged spawning lake trout in Lake Superior (Eschmeyer, 1955). Stream-spawning lake trout, known only in certain tributaries of northeastern Lake Superior, have been shown conclusively to return annually to the same streams (Loftus, 1958).

Exploitation by Sport and Commercial Fishermen

Sport fishermen long have angled for walleyes in northern Green Bay, particularly in the more northerly part of Little Bay de Noc where the confined waters are usually safe for small boats. This fishery expanded rapidly following World War II, especially in the late 1940's and in the early and middle 1950's. A prime factor in the growth of the sport fishery for walleyes was the phenomenal strength of the 1943 year-class which continued important into the 1950's; the general growth of the tourist travel also furthered the great expansion of tourist facilities.

Although the growth of the sport fishery has been obvious, opportunities to measure its true extent have been lacking. Money and personnel were far too limited for the establishment of an effective creel census. The reported recaptures of tagged walleyes, however, now suggest a procedure which conceivably may supply a reasonably sound estimate of the take of anglers. This estimate is based on the application of data on relative numbers of tags reported by sport and commercial fishermen to the statistics on commercial production and data on the average weight of walleyes in commercial landings.

This procedure can be illustrated from the records for 1958. The commercial take in that year amounted to 206,000 pounds and the mean weight of commercially landed walleyes examined by staff members of the Bureau of Commercial Fisheries was 1.73 pounds; the number of fish caught by commercial operators is estimated as 119,000.

In 1958 anglers reported 52.8 percent and commercial fishermen 47.2 percent of the walleyes that were $15^{1}/_{2}$ inches long or larger at the time of tagging (Table 1); the anglers' take of these larger fish is then estimated to have been 133,000 fish. The estimate of the full take of anglers must include the additional fish down to 13.0 inches. Since 68.3 percent of all fish caught by anglers in 1958 (Table 2) were in the size range 13.0—15.4 inches, their catch is increased by an estimated 287,000 and the total becomes 420,000. The total removed by sport and commercial fisheries in 1958 amounts then to 539,000 fish.

Table 1

Reported recapture of tagged walleyes, $15^{1}/_{2}$ inches and over at time of tagging, through 31 December 1960

	Group of fishermen reporting			
	Sport fishermen		Commercial fishermen	
Year of recapture	Number of recaptures reported	Percentage of total reports	Number of recaptures reported	Percentage of total reports
1958	19	52.8	17	47.2
1959	89	74.8	30	25.2
1960	68	68.0	32	32.0
Total	176	69.0	79	31.0

Table 2

Size at time of tagging for walleyes recaptured and reported by anglers to 31 December 1960

	Size range (inches)			
	13.0—15.4		> 15.4	
Year of recapture	Number of recaptures reported	Percentage of fish within length interval	Number of recaptures reported	Percentage of fish within length interval
1957*	6	100.0	...	...
1958	41	68.3	19	31.7
1959	46	34.1	89	65.9
1960	9	11.7	68	88.3
Total	102	36.7	176	63.3

* 97.9 percent of the fish tagged in 1957 were under 15.5 inches.

Actually, the estimates of the sport-fishery catch and hence of total removal cannot be accepted as closely accurate. The present data indicate that anglers capture many more walleyes than do commercial fishermen, but sources of bias that prohibit a more definite statement of relative numbers taken are clearly apparent and others may be uncovered as the tagging proceeds.

More small walleyes should have been tagged to improve the estimate of take by anglers; 68.6 percent of all the walleyes tagged were at or above the commercial minimum legal length of $15^{1}/_{2}$ inches, but sport fishermen take great numbers of fish between 13 and $15^{1}/_{2}$ inches (Table 2).

The distribution of tagging localities has tended to produce an overestimate of the take of anglers. Of the total of 4,690 walleyes tagged, 3,257 or 69.6 percent were marked in late April or early May in the extreme northern part of Little Bay de Noc (or a tributary) in waters closed to commercial fishing. This area includes the major angling waters (Fig. 1). These spawning-run fish moved gradually southward after tagging, but when fishing started on May 20 at the end of the spring closed season (April 1—May 20) some were still in the closed area, where they were fished heavily by anglers but were not available to commercial fishermen. More fish should be tagged in Big Bay de Noc, in the lower part of Little Bay de Noc, and in the open water to the south.

We need also more precise knowledge of the growth of walleyes so that we can judge better the time interval that must be allowed before undersized fish of various lengths are to be considered vulnerable to the sport or commercial fishery.

Summary

The walleye, *Stizostedion v. vitreum*, long a valuable commercial fish in the Michigan waters of northern Green Bay has become, since World War II, a very important sport fish. A tagging study was initiated in September 1957 to obtain information on the heterogeneity, movement, and exploitation of the walleye population. The fish were tagged with monel-metal jaw tags or spaghetti-dart tags. Returns from tags indicated that walleyes remained in the northern end of Green Bay, but fish from different spawning sites mixed after spawning. Recaptures during the spawning season of fish tagged from previous spawning runs gave strong evidence that the walleye population is subdivided into discrete spawning stocks.

In 1958, commercial fishermen are estimated to have caught 119,000 fish, and anglers took an estimated 420,000 fish — a grand total of 539,000. The estimate of the numbers caught by commercial fishermen was based on statistical records of production and the weighing of samples from commercial landings. The estimate of the number caught by sport fishermen was based on the ratio of the numbers of tags returned by commercial fishermen and anglers. Inadequacies in the marking program as conducted to date, and explained briefly in the text, prohibit acceptance of the estimate of take in the sport fishery as closely accurate. Improvements of procedure and analysis should make possible a satisfactory appraisal of the total catch in a sport fishery where a creel census is impractical.

References

ESCHMEYER, PAUL H., and WALTER R. CROWE (1955). The movement and recovery of tagged walleyes in Michigan, 1929—1953. *Mich. Dept. Cons., Inst. Fish. Res., Misc. Pub.* 8. 32 p.

ESCHMEYER, PAUL H. (1955). The reproduction of lake trout in southern Lake Superior. *Trans. Amer. Fish. Soc.*, 84 (1954): 47—74.

LOFTUS, K. H. (1958). Studies on river-spawning populations of lake trout in eastern Lake Superior. *Trans. Amer. Fish. Soc.*, 87 (1957): 259—277.

SHETTER, DAVID S. (1936). The jaw-tag method of marking fish. *Pap. Mich. Acad. Sci*,. 21 (1935): 651—653.

YAMASHITA, DANIEL T., and KENNETH D. WALDRON (1958). An all-plastic dart-type fish tag. *Calif. Fish Game*, 44 (4): 311—317.

8.

A Study of Errors Inherent in Tagging Data on Pacific Halibut (*Hippoglossus stenolepis*)

By

RICHARD J. MYHRE*

Introduction

The International Pacific Halibut Commission (hereinafter referred to as the Commission) has used catch statistics, which include catch, effort, and catch per unit of effort, as its basic measure of stock condition. Tagging and age composition data provide information on the relative level of utilization and total mortality and help to explain or corroborate population changes indicated by catch statistics.

Agreement between these three stock measures has been good except in the western part of the Gulf of Alaska. In this region the tagging data have consistently indicated a low rate of utilization, in contradiction to conclusions obtained from studies of catch statistics and age composition data. The use of tagging data for estimating fishing mortality requires several assumptions that are difficult to satisfy and in 1955 a study of the validity of tagging data for this purpose was initiated.

Estimates of fishing mortality based on tagging data may be subject to two basic types of error in addition to sampling error. They may be subject to constant errors, which will not alter their proportionality with the true fishing mortality rates, or they may be subject to variable errors which occur at different levels with respect to some characteristic associated with the experiment, such as the time or place of tagging. A variable error may manifest itself by either reducing the correlation or altering the proportionality between the estimates and the true fishing mortality rates.

Experiments were designed to test directly for tag loss and tagging mortality because the presence of both is probable and both are likely to result in constant errors. To test for variable errors, estimates of fishing mortality based on tagging data have been compared with estimates of gear density. Only preliminary results of these tests can be reported at this time.

Tag Loss

Ricker (1948, 1958) described two types of error which result from tag loss and designated them Type A and Type B errors. Beverton and Holt (1957) acknowledged the same two types of error, but labeled the various losses causing them as Type (1) and Type (2) losses respectively. In the text that follows, Type-A and Type-B will be used as adjectives to modify either error or loss. It will be understood that Type-A losses will result in Type-A error and Type-B losses will result in Type-B error.

Type-A losses include all events that result in the removal of tags such that the proportion of tags lost is independent of the time interval between tagging and recapture. These losses may occur soon after tagging or after recapture, or both, and will affect fishing mortality estimates but not total mortality. Type-B losses include those events that result in the continuous removal of tags in the time interval between tagging and recapture. These losses will affect the estimate of total mortality only.

Double-tag experiments have been used to estimate the gross loss of tags on a simple binomial basis (British Columbia Fisheries Department, 1935; Schefer, 1950). Beverton and Holt (1957) attempted to isolate the loss factors included in the "other loss"** term from the difference in the rate of decrease of one-tag and two-tag fish. Unfortunately, their data must have included Type-A loss since their estimates of loss were inversely related to the duration of the period over which their data were summarized.

Myhre (1960) proposed a method of separating Type-A and -B losses from data obtained from double-tag experiments. This method is based on the concept that the proportion of the returns taken at a particular time, with one of the two tags still intact, will be composed of two groups: one that has lost the other tag and one that has not. Assuming that the loss of each tag is independent of the other tag, the proportion of this group with the tag missing will provide a measure of the combined result of both Type-A and Type-B losses. Since Type-B losses are operating continuously the two may be estimated separately by an appropriate method of slope analysis. The resulting slope is the rate of Type-B loss, and the intercept on the Y axis is the proportion that lost tags as a result of Type-A loss.

The method was applied to several experiments in which halibut had been double-tagged. It was found that Type-A loss of large strap tags, which are used

---

* International Pacific Halibut Commission, Seattle, Washington.

** The sum total of all factors other than fishing that result in a reduction of marks with time.

on halibut 80 cm and longer at tagging, was 0.02, while the Type-B loss of large strap tags was 0.03 annually. Small strap tags are used on fish less than 80 cm at tagging and Type-B loss of these tags was 0.07 annually (estimates of Type-A loss were not obtainable). The difference between Type-B loss of large and small strap tags was statistically significant when the results of all experiments were combined. Although the number of returns available for the analyses were quite small the results were consistent. Similar experiments involving larger numbers of tagged individuals are now under way and preliminary results corroborate those described above.

Unreported losses include both tags that are overlooked and those that are unreported because the finder simply fails to report the recovery of the fish. The former loss is included in the estimate obtained from a double-tag experiment, since a two-tag fish should be less likely to be overlooked than a one-tag fish. The latter type of loss will not be measured by a double-tag experiment if a two-tag fish has the same likelihood of being unreported as a one-tag fish. Furthermore, this type of loss could result in a considerable error if the finder has no incentive to turn in recovered tags.

Rewards or other inducements have been used with some apparent success to encourage the return of recovered tags. The effectiveness of this method may depend on the size of the reward (International North Pacific Fisheries Commission, 1961). One large reward paid to a "lucky" finder may be more effective than a small paid to each one (Collyer and Young, 1953; Inter-American Tropical Tuna Commission, 1958). Unfortunately, fishery agencies are loath to use this technique because it has some characteristics in common with a lottery. If the agencies now using this technique can show that it is effective and that it does not engender public criticism, it may become an acceptable means for encouraging the return of tags. ▮

Tagging Mortality

In 1958 and 1960 the Commission conducted experiments in which tagged halibut were held in live-boxes to measure the incidence of death that could be attributed to the tagging operation. Detailed analyses are still under way and will be reported when this work is completed (Peltonen, MS). A brief description of this work is included here because the results have a bearing on the material that follows.

The experimental methods that were used in the two years were essentially the same except for the construction and operation of the live-boxes. In each case, fish were captured and tagged in the manner conventionally used for Pacific halibut as described by Thompson and Herrington (1930). After being tagged, the experimental fish were placed in a holding-box on deck where they were retained until they could be released into the live-boxes. The holding-boxes had bottom areas of approximately 33 square feet and were filled to a depth of approximately 30 inches with a continuous supply of water.

Fish were held in the holding-boxes for periods ranging from 2 to 14 hours. During periods of stormy weather the fish were subjected to a considerable amount of motion. The conditions sustained by the experimental fish during these periods were rigorous and unnatural and may have resulted in some adverse effects.

The 1958 experiment took place from May through July at Kitoi Bay, Afognak Island, Alaska. Tagged fish were held in floating live-boxes for two-week periods during which time they were examined at two-day intervals by divers using scuba equipment. There were no deaths during the first six days, but the frequency of deaths increased during the remainder of the holding period. During the entire experiment, a total of 60 fish were held for two-week periods during which time 21 (35 percent) of the fish escaped and 23 (38 percent) died. If escapes are treated as an additional loss from which there were no deaths, the estimated mortality rate was 0.50 per two-week period. On the basis of observations made on the fish during the holding period and the lag in mortality, it was concluded that the chief cause of death was the unnatural conditions under which the fish were held. The most serious condition appeared to be the constant motion of the boxes due to surface waves. This motion resulted in considerable abrasion of the skin on the white side of the fish as they rested on the bottom of the live-boxes.

These results provided no useful measure of tagging mortality because tagging-induced deaths could not be separated from live-box-induced deaths. However, it was concluded that tagged halibut did not suffer mortality from hyperactivity, which would have resulted in deaths within a matter of hours after tagging (Black, 1958; Parker and Black, 1959).

The 1960 experiment took place from May through August at Butler Cove, Stephens Island, British Columbia. In this experiment sunken live-boxes were used which permitted the fish to rest on the natural bottom and eliminated all live-box motion. Daily observations were made by divers using scuba equipment. Out of 261 fish held for two-week periods, 36 (14 percent) died and 26 (10 percent) escaped. This is equivalent to a mortality rate of 0.15 for the first two-week period after the fish were tagged. No deaths occurred during the first five days and the fish appeared to adapt well to conditions in the live-boxes.

There was a progressive increase in temperature during the experimental period and by late June the

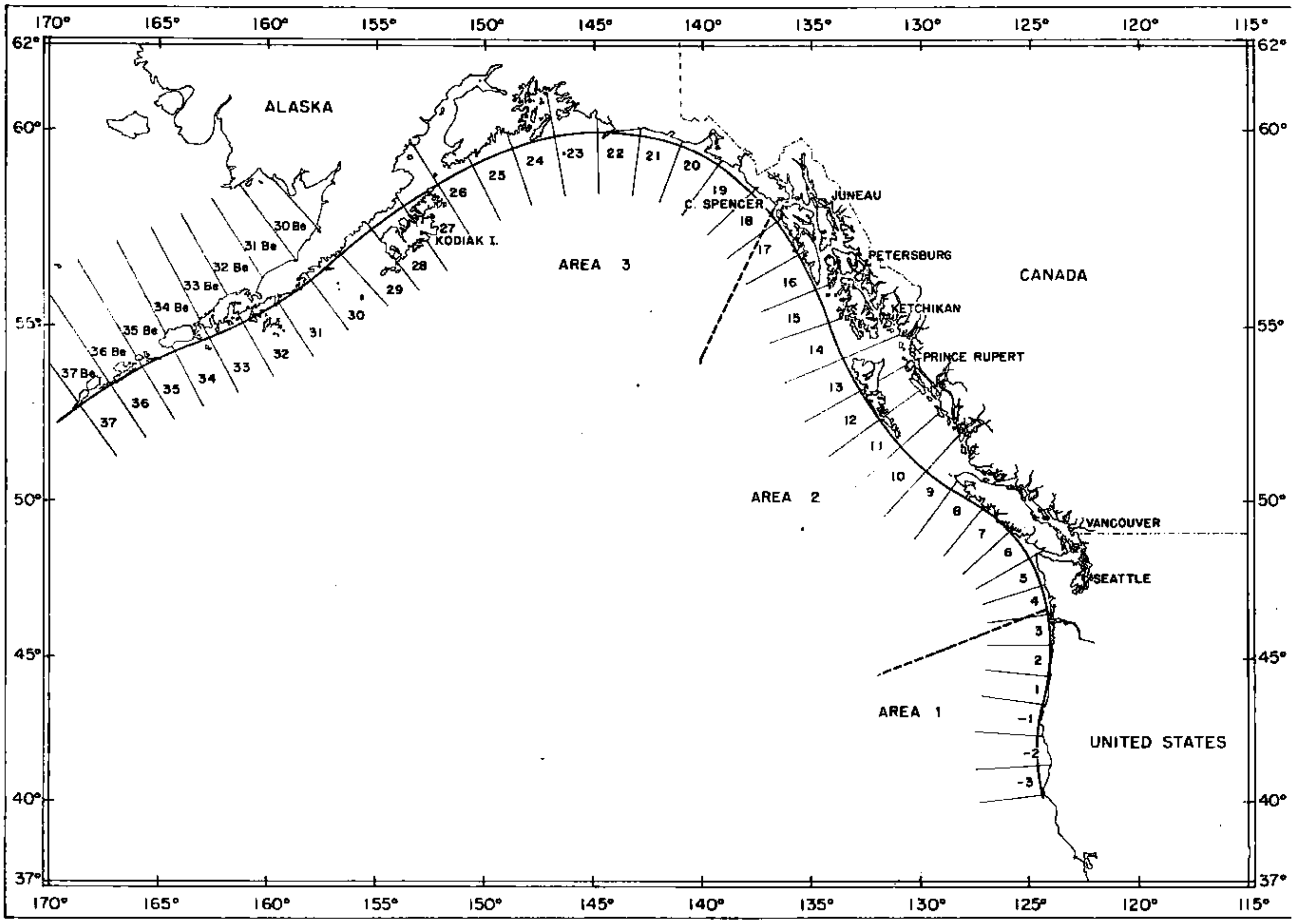


Figure 1. Pacific Coast of North America showing statistical areas and regulatory areas.

water temperature exceeded 9° C. Halibut are usually found in water between 3° and 9° C (Thompson and Van Cleve, 1936), and the latter is generally accepted as the upper limit for this species (Thompson and Van Cleve, ibid). Thus, it was concluded that mortalities observed during the first half of the experimental period more nearly represented the conditions that might have resulted if these fish had been returned to their natural habitat. Prior to July 1, which was approximately the midpoint of the experimental period, 120 fish were held for two-week periods, of which 4 (3 percent) died, and 25 (21 percent) escaped. This amounts to a mortality rate of 0.037 during the first two-week period after the fish were tagged.

The observed value of 0.037 may include deaths from other causes, three of which are particularly obvious. First, the experimental fish probably suffered some traumatic effect from being tossed about in the holding-box on the deck of the tagging vessel. Second, although the submerged live-boxes were a great improvement over the floating ones, some harm may have resulted from confinement itself. Third, some of the ill effects associated with high water temperatures actually occurred prior to July 1.

It is doubtful that this type of experiment can be used to provide unconditional estimates of tagging mortality, because it does not provide a control group. Certainly a significant tagging mortality was not indicated by these experiments, and if one does exist it must either occur after the first two weeks of freedom or as a result of conditions from which the experimental fish were protected.

Comparability of Tagging Data by Area of Tagging

A more critical argument against the use of tagging data to estimate fishing mortality is that the inherent errors may occur at different levels in different areas. It has been suggested that this condition might exist in the western part of the Gulf of Alaska and it has been suggested that some special tag loss or tag mortality, or both, may occur in this region (International Pacific Halibut Commission, 1957, 1960).

This condition lends itself to a test of the hypothesis: that tagging data provide a valid measure of the relative level at which halibut are utilized. This means that, even though errors may result in biased estimates of mortality, this bias does not change with the area of tagging or with fishing mortality. This hypothesis can be tested by correlating estimates of fishing mortality obtained from tagging data with those from a third source which is independent of tagging and age data.

Beverton and Holt (1957) suggested that if "the relative distribution of fish and fishing remains fairly consistent" the amount of gear fished per unit area per unit time should be proportional to the rate of fishing. These authors suggested that the fishing area could be divided into sub-areas to minimize errors from a variable distribution of fish and fishing. This method was selected as the third source of fishing mortality estimates since it appeared to have the desired attributes and since the required data were available.

Pacific halibut catch and effort statistics are tabulated by statistical and regulatory areas as shown in Fig. 1. These areas were established by projecting perpendiculars at 60-mile intervals from a line which was drawn along the coast to simulate the smoothed coastline. The amount of gear fished in each statistical area was available from Commission records. It was convenient to use one year as the unit of time.

The problem of estimating the amount of bottom area that is fished in each statistical area is more complex. Because of marked differences in the distribution of fish and fishing within individual statistical areas it would be necessary to divide each statistical area into sub-areas and compute a gear density for each sub-area. The gear density for the statistical area would then be the weighted mean of all sub-area gear densities. This method requires detailed data on the distribution of fishing, plus a considerable amount of computation.

An alternative would be to consider only the bottom area within the sub-areas known to be fished. This approach is not entirely satisfactory since seasonal and random movements of fish within the statistical areas probably extend the influence of fishing beyond the limits of the sub-areas that are actually fished. The simplest approach, and the one which was used as a first approximation, was to assume that halibut were probably absent in all depths that are not fished. This division probably eliminates much area that is devoid of halibut but may eliminate some that is sparsely inhabited. In addition, it leads to two additional assumptions: first, that all sub-areas within the range of fished depths are inhabited by halibut and, second, that these fish are subject to some degree of fishing. The conclusions that follow depend intimately on the validity of these assumptions.

A failure of these assumptions need not result in serious error. Within the range of depths fished in a statistical area, there may be sub-areas that are also devoid of halibut. If these sub-areas are included in the estimate of fishable area, the estimate of gear density will be too low. This problem will not result in error if it occurs uniformly in all statistical areas. It will add to the variance of gear density estimates if it occurs at different levels in different statistical areas. It will result in bias only if it occurs most extensively in groups of statistical areas which yield high or low estimates of fishing mortality. The extent at which this condition may exist in the various statistical areas is not known at present.

The range of depths fished in each statistical area was determined by examining actual fishing records for the years 1959 and 1960. The number of units of gear fished at various depths were tabulated by 10-fathom intervals for each statistical area, and for each a range was determined which included 95 percent of the sampled fishing effort. The five percent not included represented exploratory sets or sets made to "wash" the gear at the end of a trip. The range for each statistical area was reasonably consistent between the two years examined. The maximum and minimum depths for each statistical area were traced on charts issued by the U.S. Coast and Geodetic Survey or by the U.S. Hydrographic Office. The amount of bottom area included within this range was then determined for each statistical area by planimeter and converted to area in square miles. Table 1 shows the range of depth, the average depth, and the amount of bottom area included within the depth range for Statistical Areas 9—32, inclusive. In the text that follows, the term "bottom area" will refer to the latter values and the reader should bear in mind the assumptions required in using them as an estimate of the fished area.

Information on depths fished was available for 18 percent of the fishing effort expended in Statistical Areas 9—32 in 1959 and 1960. However, depth information for Statistical Areas 15, 16 and 17 was available on only about five percent of the total fishing effort and, consequently, the ranges shown for these areas are probably less accurate. Another source of inaccuracy in these statistical areas resulted from the presence of many long narrow channels having steep slopes from the shore to the channel bottom. This made it difficult to trace contours with a planimeter and probably resulted in an underestimation of the amount of fishable bottom. These inaccuracies will not affect the conclusions reached in this report, because the analyses that follow do not require the use of data from these areas.

Table 1

Range of depths over which fishing is done in Statistical Areas 9—32 inclusive, and the approximate bottom area included within this range

Statistical Area	Depths Fished (fm.)			Bottom Area in Square Miles
	Upper	Lower	Average	
9	15	75	46	2410
10	25	75	49	2770
11	15	125	56	3740
12	5	75	33	2580
13	15	155	59	3500
14	55	125	83	2020
15	35	165	94	2210
16	25	155	103	1660
17	25	125	92	830
18	35	145	110	1930
19	35	135	94	2530
20	15	145	97	3120
21	75	145	113	1210
22	45	165	108	1220
23	25	155	84	3750
24	25	125	88	3570
25	35	165	98	3520
26	25	175	100	7520
27	35	105	58	4500
28	25	145	82	4480
29	15	155	77	6090
30	35	155	94	5470
31	45	85	60	3870
32	15	165	70	4370

Bell and Pruter (1958) computed the amount of bottom area inside the 100 fathom contour for Statistical Areas 5—17. Their results compare reasonably well with those shown above, if allowance is made for differences in the depth ranges used.

Correlation of Gear Density with Fishing Mortality from Tagging Data

The estimates of fishing mortality from tagging data used in this comparison were taken from published data (International Pacific Halibut Commission, 1960) to reduce the number of required computations. These estimates were obtained from 13 experiments, eight from Regulatory Area 2 and five from Regulatory Area 3, all of which involved large numbers of tagged fish. Fish less than 80 cm at tagging were omitted because these fish are incompletely recruited to the commercial population. Fish recaptured outside the statistical area of tagging were included in all experiments. Although the exclusion of migrants would have resulted in better estimates of fishing mortality, it would have seriously reduced the number of returns available for analysis in Area 3 experiments. Their inclusion is somewhat justified by the knowledge that, on the average, migrants will be subject to fishing intensities not too dissimilar from those in the area where they were tagged. Total mortality was estimated from a modification of Jackson's (1939) equation using returns taken during the first five full recovery years. Recaptures in the year of tagging and in a few cases in the first full year were not used because they were not comparable to those of subsequent years (Type C error of Ricker, 1948). The method used in estimating fishing mortality was a modification of one described by Ricker. This method provides an estimate of the average rate of fishing mortality that must have prevailed during the recovery periods used.

Table 2

Fishing mortality estimates from halibut tagging experiments and corresponding estimates of gear density

Tagging Areas	Recovery Years	Average Gear Fished Annually	Bottom Area in □ Miles	Gear Density	Fishing Mortality
10	1948—52	35000	2770	12.6	0.33
10	1953—57	34300	2770	12.4	0.32
11	1954—58	16800	3740	4.5	0.21
11	1954—58	16800	3740	4.5	0.26
13	1951—55	58900	3500	16.8	0.25
13	1952—56	52100	3500	14.9	0.34
13	1953—57	51900	3500	14.8	0.30
13	1954—58	52600	3500	15.0	0.38
20—21	1952—56	27700	4330	6.4	0.14
26	1950—54	34000	7520	4.5	0.03
25—27	1953—57	87400	15500	5.6	0.06
28—29	1951—55	33100	10600	3.1	0.04
27—29	1952—56	50800	15100	3.4	0.07

For each estimate of fishing mortality a comparable estimate of gear density was computed. This was done by dividing the average number of units of standard setline gear fished in the tagging area during the recapture period by the appropriate estimate of bottom area. A tabulation of the resulting estimates of fishing mortality and gear density for the 13 experiments is given in Table 2 and plotted in Fig. 2.

A coefficient of correlation was computed between these two sets of data. The resulting value of 0.808 with 11 degrees of freedom was significantly different from zero correlation ($p \leq 0.01$). Ninety-five percent confidence intervals of $0.402 \leq 0.808 \leq 0.948$ were obtained by the $\mathcal{Z}$ test (Snedecor, 1956). On the basis of this test, there is no reason to reject the hypothesis that the tagging data provide a valid measure of the relative level at which Pacific halibut are utilized.

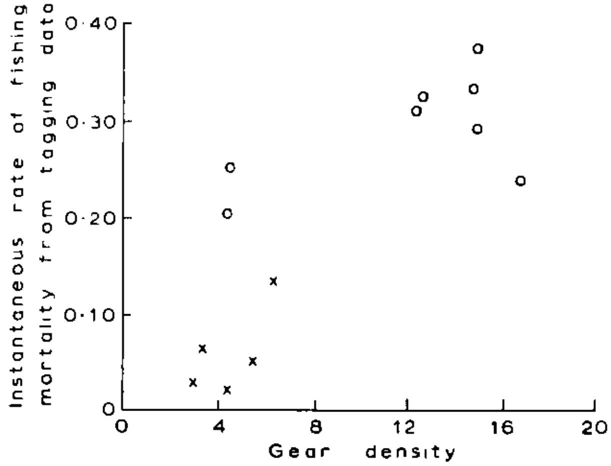


Figure 2. Correlation between gear density and fishing mortality estimates from tagging data. X Area 3 experiments, O Area 2 experiments.

Unfortunately, the results of this test are not clear-cut. First, the observations tend to be clustered into two groups, one representing low gear densities and containing mostly Area 3 observations and the other representing high gear densities and containing only observations from Area 2. Two clusters of points will almost always give a good correlation if the clusters are fairly compact. The good correlation computed above may have occurred because of a fortuitous clustering and not because of a measurable relationship between gear density and fishing mortality as estimated from tagging data.

Secondly, if the two variants are true measures of the same parameter they should also be proportional to each other, a characteristic not measured by the correlation coefficient. The test for proportionality measures the difference between the variance around the regression line and the variance around a line forced to pass through the origin and the data. The resulting value of F was 0.52 (df = 1, 11), which is not significant at the 95 percent confidence level ($p \sim 0.55$). Although there is no reason to deny the proportional relationship between these two variables on the basis of the data presented, the power of this test is probably insufficient to eliminate all alternative possibilities.

Correlation of Gear Density with Fishing Mortality from Age Data

Estimates of fishing mortality from age data were taken from the same source as the tagging estimates (International Pacific Halibut Commission, 1960). Total mortality was estimated from the average year-to-year decline in the number of fish caught from all fully recruited year-classes per 10,000 skates fished. Natural mortality was estimated from a large number of age samples taken from regions that are widely separated geographically; the methods of analysis used were those described by Silliman (1943) and Fry (1949). The individual estimates showed considerable variation but averages were in fairly good agreement, and a rounded value for the instantaneous natural mortality rate of 0.20 was accepted. The instantaneous rate of fishing mortality was then obtained by subtracting 0.20 from the instantaneous total mortality rate obtained from samples taken from different regions and in different years.

Estimates of fishing mortality from each region varied considerably from year to year, owing to the sampling problems involved. This variability was reduced somewhat by grouping estimates by four-year periods. The resulting estimates by groups of years and by regions are shown in Table 3.

Estimates of gear density for comparison with the fishing mortality estimates from age data were computed by dividing the average annual amount of gear fished in the sampled region during the sampled pe-

Table 3

Fishing mortality estimates from age composition data, and corresponding estimates of gear density computed on the basis of year-class decline

Statistical Areas	Years	Average Gear Fished Annually	Bottom Area in Square Miles	Gear Density	Average Total Mortality	Fishing Mortality
10	1951—54	33400	2770	12.1	0.39	0.19
10	1955—58	33300	2770	12.0	0.63	0.43
13	1951—54	62600	3500	17.9	0.50	0.30
13	1955—58	52200	3500	14.9	0.42	0.22
20—21	1951	20400	4330	4.7	0.39	0.19
24—28	1950—54*	131000	23590	5.6	0.80	0.60
24—28	1955—58	122000	23590	5.2	0.41	0.21
32	1950—54**	6300	4370	1.4	0.49	0.29
32	1955—58	9700	4370	2.2	0.45	0.25

* 1952 omitted ** 1951 omitted

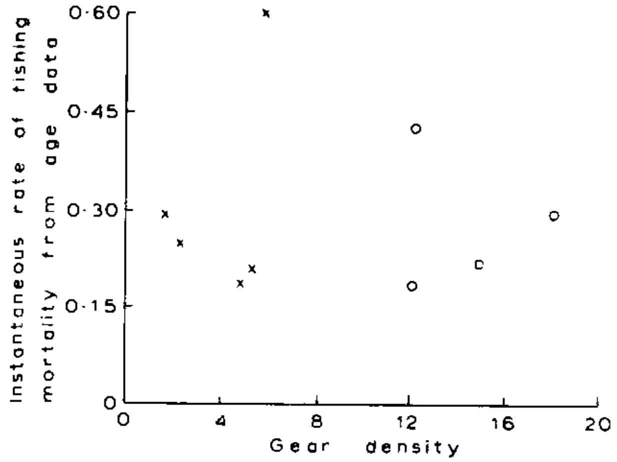


Figure 3. Correlation between gear density and fishing mortality estimates from age data based on year-class decline. X Area 3 experiments, O Area 2 experiments.

riod by the appropriate amount of bottom area. The resulting data are also shown in Table 3. The relationship between gear density and fishing mortality as estimated by age data is shown in Fig. 3. The wide scatter of points shows such a poor relationship between the two variants that a coefficient of correlation was not computed.

Considerable variability was observed in the original data, as was mentioned above. These variations could have been sufficient to have masked the relationship between fishing mortality rates and gear density. This problem was largely overcome in the tagging data by dividing the number of recoveries by the catch in the same year.

New estimates of total mortality were computed from the original data (International Pacific Halibut Commission, 1960) using the catch curve method to minimize this influence. The same groups of years and areas were used so that the same estimates of gear density would apply. The equations used were those suggested by Chapman and Robson (1960). The ages used were 9—18 in Area 2 samples and 12—21

Table 4

Fishing mortality estimates from age composition data based on catch curves and corresponding estimates of gear density

Statistical Areas		Years	Gear Density	Fishing Mortality
10	....	1951—54	12.1	0.38
10	....	1955—58	12.0	0.13
13	....	1951—54	17.9	0.23
13	....	1955—58	14.9	0.16
20—21	....	1951	4.7	0.13
24—28	....	1950—54*	5.6	0.16
24—28	....	1955—58	5.2	0.13
32	....	1950—54**	1.4	0.14
32	....	1955—58	2.2	0.12

* 1952 omitted ** 1951 omitted

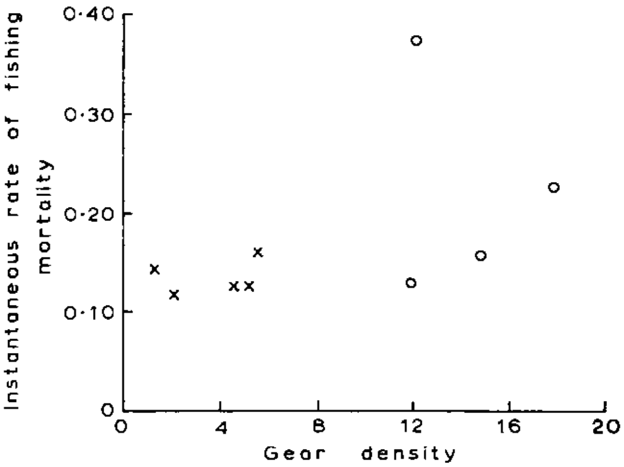


Figure 4. Correlation between gear density and fishing mortality estimates from age data based on catch curves. X Area 3 experiments, O Area 2 experiments.

in the Area 3 samples. Natural mortality was again assumed to be 0.20 and this value was subtracted from the estimates of total mortality to obtain the desired estimates of fishing mortality. The resulting values are given in Table 4 and plotted in Fig. 4. A coefficient of correlation of 0.497 was computed, with 7 degrees of freedom. Ninety-five percent confidence intervals of $-0.395 \leq 0.497 \leq 0.935$ were computed by the z test (Snedecor, 1956). Although this value is not significantly different from zero correlation, there is some suggestion of a relationship.

A test for proportionality between the two variants yielded an F value of 0.94 which is not significant at the 95 percent level of confidence ($p \sim 0.35$). Here, as with the tagging data, the power of this test is probably insufficient to eliminate the alternative possibilities.

Discussion and Conclusion

The presence of a significant correlation plus a suggestion of proportionality between gear density and fishing mortality based on tagging data is evidence favoring but not proving the validity of both methods of estimation. More important, refinements in either or both methods should result in higher correlations. Thus, this method of analysis may provide a means of systematically increasing the precision of fishing mortality estimates.

Failure to find a correlation between gear density and estimates of fishing mortality from year-to-year decline in year-class strength was attributed to variability resulting from marked annual changes in availability of fish. Although the correlation between gear density and the estimates of fishing mortality obtained from the same data by the catch curve method was not significantly different from zero, there was a strong suggestion of a relationship which may be improved by further refinements in the method of analysis.

It is apparent from the great amount of variability in both the age and tagging data, that it would be unwise to pick one as being superior to the other at this time. Furthermore, the estimates of gear density used above are based on assumptions concerning the distribution of fish and fishing which must be verified before the validity of the method can be accepted. This is particularly true since the above analyses depend to a considerable extent upon the comparability of Area 2 and Area 3 gear densities.

Summary

Tagging data have consistently indicated a low rate of utilization of halibut in western Area 3, in contradiction to indications from age data and from catch statistics. To explain these differences, studies were undertaken to test some of the assumptions required in using tagging data as a measure of utilization.

Double-tag experiments were conducted to test for tag loss and it was tentatively concluded that Type-A loss of large strap tags was 0.02. Annual Type-B losses of large and small strap tags were 0.03 and 0.07, respectively.

Live-box experiments in which tagged halibut were held for two-week periods were conducted to test for tagging mortality. Results have failed to demonstrate the presence of a significant tagging mortality during the first two weeks after tagging.

To reconcile the difference between the apparent mortality rates derived from age and tagging data, gear density estimates were computed for the several statistical areas. This required the estimation of the amount of area over which the fish and fishing are presumably distributed, and if accurately done these data should be proportionate to the fishing mortality rate.

Gear density and fishing mortality estimates from tagging data were significantly correlated and proportional. These results provide a basis for believing that the tagging data provide a measure of fishing mortality if it can be shown that the required assumptions are satisfied.

Gear density and fishing mortality estimates obtained from age data based on the year-to-year decline in year-classes gave no correlation. When similar estimates were computed, using the catch curve method, a correlation coefficient of 0.497 was obtained which was not significantly different from zero correlation at the 95 percent confidence level, although a relationship was strongly suggested.

Although gear density figures showed better agreement with fishing mortality estimates from tagging data than with those from age data, judgement as to the best source of fishing mortality estimates must be withheld until the assumptions upon which the gear density estimates are based can be tested.

Acknowledgements

The suggestions and criticisms of my associates on the Commission's staff have been helpful in preparation of this report. I especially want to thank Gordon J. Peltonen, who supplied the data on tagging mortality, and William L. High, who provided the data on gear density.

References

BELL, F. HEWARD and ALONZO T. PRUTER (1958). Climatic temperature changes and commercial yields of some marine fisheries. *J. Fish Res. Bd Cannada*, 15 (4): 625—683.

BEVERTON, R.J. H. and S. J. HOLT (1957). On the dynamics of exploited fish populations. *Fish. Invest., Lond.*, Ser. 2, 19.

BLACK, EDGAR C. (1958). Hyperactivity as a lethal factor in fish. *J. Fish. Res. Bd Canada*, 15 (4): 573—586.

British Columbia Fisheries Department (1935). Rep. Comm. Fish. for the year ending Dec. 31, 1935. 122 p.

CHAPMAN, D. G. and D. S. ROBSON (1960). The analysis of a catch curve. *Biometrics*, 16 (3): 355—368.

COLLYER, ROBERT D. and PARKE H. YOUNG (1953). Progress report on a study of the kelp bass, *Taralabrax clathratus*. *Calif. Fish Game*, 39 (2): 191—208.

FRY, F. E. J. (1949). Statistics of a lake trout fishery. *Biometrics*, 5 (1): 27—67.

International North Pacific Fisheries Commission (1961). *Ann. Rep.*, 1960. (In press).

Inter-American Tropical Tuna Commission (1958). *Ann. Rep.*, 1957.

International Pacific Halibut Commission (1957). Regulation and investigation of the Pacific halibut fishery in 1956. *Int. Pacif. Halib. Comm.*, Rep. No. 26, 27 p.

International Pacific Halibut Commission (1960) Utilization of Pacific halibut stocks: yield per recruitment. *Int. Pacif. Halib. Comm.*, Rep. No. 28, 52 p.

JACKSON, C. H. N. (1939). The analysis of an animal population. *J. Anim. Ecol.*, 8: 238—246.

MYHRE, RICHARD J. (1960). Loss of tags from marked halibut (*Hippoglossus stenolepis*). Thesis (Ms.). Univ. Washington.

PARKER, ROBERT A. and EDGAR C. BLACK (1959). Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). *J. Fish. Res. Bd Canada*, 16 (1): 95—106.

PELTONEN, GORDON J. (M.S.) Manuscript in preparation.

RICKER, W. E. (1948). Methods of estimating bio-statistics of fish populations. *Indiana Univ. Publ., Sci. Ser.* 15, 101 p.

RICKER, W. E. (1958). Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd Can.* 119, 300 p.

SCHEFFER, VICTOR B. (1950). Experiments in the marking of seals and sea lions. *Spec. Sci. Rep. U.S. Fish. Wildl. Serv.*, 4, 33 p.

SILLIMAN, R. P. (1943). Studies on the Pacific pilchard or sardine (*Sardinops caerulea*). A method of computing mortalities and replacements. *Spec. Sci. Rep. U.S. Fish Wildl. Serv.*, 24, 10 p.

SNEDECOR, GEORGE W. (1956). *Statistical methods.* Iowa State College Press, 534 p.

THOMPSON, W. F. and W. C. HERRINGTON (1930). Life history of the Pacific halibut, (1) Marking experiment. *Rep. Int. Fish. Comm.* No. 2, 137 p.

THOMPSON, W. F. and RICHARD VAN CLEVE (1936). Life history of the Pacific halibut, (2) Distribution and early life history. *Rep. Int. Fish. Comm.* No. 9, 184 p.

9.

The Tagging and Marking of Marine Animals in Australia

Collated By*

J. M. THOMSON**

I. Types of Tag

Twelve different tags or marks have been applied to fish and other marine animals in Australian waters and some have been attached by more than one method. One or more individuals of seventy-one species have been tagged or otherwise marked; two species in numbers in excess of 20,000, four in excess of 10,000 but fewer than 20,000, and seventeen in excess of 1,000 but fewer than 10,000. The remaining species have been tagged in numbers fewer than 1,000.

(a) Strap Tag

Made in monel metal or German silver, three sizes of strap tag have been used. The majority were 35 mm long, 3.0 mm wide, and 0.6 mm thick. Besides these, a smaller number of "fingerling" tags 21 mm × × 2.0 mm × 0.3 mm and some larger tags 58 mm × × 6.5 mm × 0.6 mm have been used. All were applied by means of specially made pliers (Fig. 1). The nose-pieces of these were incised to hold the tag of appropriate size. On one side, at the point where the opening in the strap tag would lie, there is a groove into which the tongue of the strap tag would project after passing through the hole so that it is clenched immovably.

The great majority of strap tags were placed on the operculum except in the case of leatherjackets (*Monacanthidae*) where they were placed ventrally immediately behind the ventral spine, on some barracouta (*Thyrsites atun*) where they were clenched on the dorsal fin, and on some trout (*Salmo trutta* and *S. gairdneri*) where they were clenched about the lower jaw. When used as jaw tags the straps were at first applied and rounded off as described by Shetter

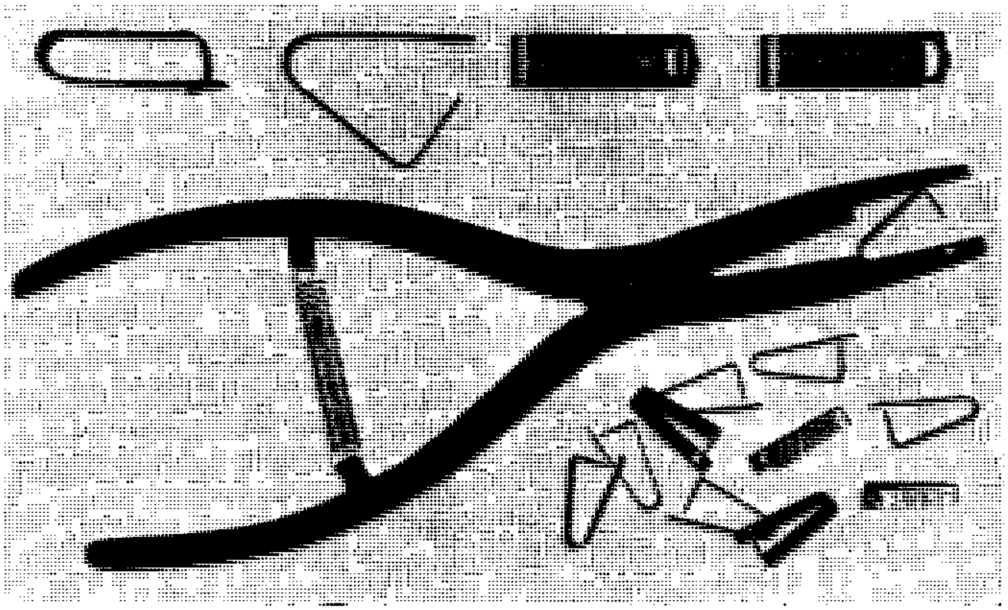


Figure 1. Strap tags and clenching pliers.

---

* From the publications listed, from catalogued data, and from information supplied by Dr A. Nicholls (trout), Dr B. Malcolm (Australian salmon and Tommy-ruff), Dr D. Kurth (flathead and flounder), Dr K. Sheard (western crayfish), Mr A. M. Olsen (southern crayfish, scallop, and school shark), Mr J. S. Hynd (pearlshell), Mr R. Cowper (barracouta and gummy shark). Particular thanks are due to Mr A. Dunbavin Butcher, Director of Fisheries and Wildlife in the state of Victoria, to Mr N. V. Harris, Superintendent of Fisheries in the state of New South Wales, and to Mr A. J. Fraser, Director of Fisheries in the state of Western Australia, who made available information on tagging carried out by officers of their respective departments.

** Division of Fisheries and Oceanography, C.S.I.R.O., Cronulla, N.S.W.

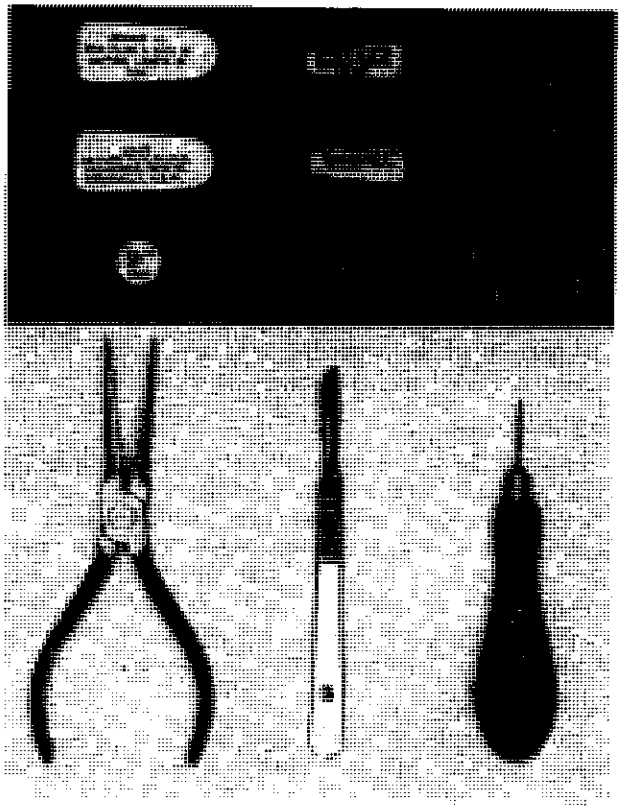


Figure 2. Internal tags (above left) Petersen disks (centre), transparent backing disks (above right); pliers, scalpel, awl and silver wire (below).

(1936). Later it was found that rounding was unnecessary (Nicholls 1957). One arm of the strap tags bore a serial number; the other the letters C.S.I.R. or later C.S.I.R.O., to indicate the tagging organization.

(b) Petersen Disk

These disks were of 16 mm diameter and 1 mm thick. They were attached in pairs, one disk on either side of the tissue pierced. One of the pair was stamped with a serial number and the letters C.S.I.R. (Fig. 2); the other was a blank useful only as a guard to prevent the attachment wire working back through the tissue. The first disks used were of white plastic; later the backing disk was made of clear celluloid. Subsequently, because a number of returned disks showed peculiar scratches and indentations suggesting that the white disks had attracted undesirable attention from other fish, a grey disk was substituted for the white.

When applied to a thin tissue such as the dorsal fin of school and gummy sharks (*Galeorhinus australis* and *Mustelus antarcticus*) the wire was passed through a hole previously pierced by an awl. Thick tissue such as the fleshy base of the dorsal fin or the caudal peduncle was pierced by a hollow-stemmed needle in whose base the silver attachment wire was inserted. On passing to the far side the needle was completely removed leaving the wire projecting and prevented from passing right through by the numbered disk previously threaded upon it. The blank tag was then threaded on the wire; any great excess of wire was cut off and the remainder twisted into a knot by a pair of sharp-nosed pliers. The disk was cemented on mollusc shells (Fig. 6).

(c) Hydrostatic Tag

The type used was as described in the anonymous (1953) Guide to Fish Marks, the dimensions being 45 mm in length and 4 mm in diameter. The tags were attached by means of silver wire bridles either at the base of the caudal fin or on the caudal peduncle by a hollow-stemmed needle.

(d) Silver Tape Tag

A flat piece of silver tape bearing a number was attached to a small number of Australian salmon (*Arripis trutta*) and trout and a few thousand scallops (*Pecten meridionalis*). They were very similar to the numbered tags used to identify museum specimens and, on the salmon and trout, were attached in the usual way by means of a silver wire either to the operculum, the jaw, or the base of the tail, through a hole pierced by an awl. When tried on scallop shells this tag was not as longlasting as the cemented Petersen disk.

(e) Internal Tag

The internal tags used were of white plastic with a serial number and instruction for return printed in black (Fig. 2). The tags were inserted into the body cavity through an incision made in the body wall by means of a scalpel (Fig. 3). Three sizes have been used, appropriate to the size of fish. The largest were 50 mm long and 23 mm wide at the broader end. The medium size were 34 mm × 13 mm and the smallest 33 mm × 10 mm. This tag has been used in several species, particularly sharks, salmon, snapper (*Chrysophrys auratus*) and Tommy-ruff (*Arripis georgianus*).

(f) Spiral Tag

These were plastic spirals, sold commercially as leg rings for poultry. No printed message was attached and no serial number, the plan being to use differently coloured rings in different areas. The tag was attached by ringing the caudal peduncle. Only barracouta were tagged in this way.

(g) Safety-pin Tag

These consisted of sterling-silver safety-pins, each bearing an aluminium plate; the pins, measuring

Figure 3. Making incision in school shark to insert internal tag. Note Petersen disk on dorsal fin.

approx 19 mm × 3 mm, were attached to the flesh between the two dorsal fins. A few were used on barracouta.

(h) Streamer Tag

The streamer tag consists of a length of plastic tube which is attached to the fish below the second dorsal fin by means of an aluminium dart which is inserted into the flesh of the back. The first version of this tag had a separate message tape inside the clear tube. The later version had a stouter plastic head and the opaque red nylex tube had a black inscription stamped along its length. The first version was attached by inserting the head under the skin. It was feared that many of these worked out. Subsequently the second type was provided with an arrow head, the barb of which was hooked under a vertebral spine (Fig. 4). Tuna (*Thunnus thynnus maccoyii*, *Neothunnus macropterus*, and *Thunnus germo*) were tagged in this way.

(i) Dart

This tag is similar to the streamer tag, but has a flat piece of plastic tape attached to a plastic arrowhead. It has heen used on southern crayfish (*Jasus lalandei*).

(j) Clip and Disk Tag

This was of the type used by Godsil (1938) on tuna and basically was a strap tag with a disk attached.

(k) Fin-clips

The well-known method of marking by fin clipping has been used in Australia only in studies on the imported salmonids, the brown and rainbow trouts.

(l) Telson-punch

Prior to the use of dart tags, cattle ear-punches of different shapes were used in marking western crayfish (*Panulirus longipes*) and southern crayfish (*Jasus lalandei*). The punch mark remained discernible over several moults, but with each moult the outline became more indefinite, so that the original shape became unrecognizable. In later work, combinations of punches in telson and uropods were used.

(m) Whale Marks

The majority of marks used were standard Discovery marks (Rayner 1940). A modified mark (Chittleborough and Godfrey 1957) was also developed but there are indications that it penetrated too far into the body.

II. Tests of Suitability

These were confined mostly to species which were tagged in large numbers. The difficulty in holding large scrombrid fishes prevented any test experiments with the tunas. The tests carried out were of two types; either a test of short duration whose purpose was to determine whether the fish showed obvious signs of distress or discomfort as a result of the fixing of the tag, or longer tests to observe whether tags

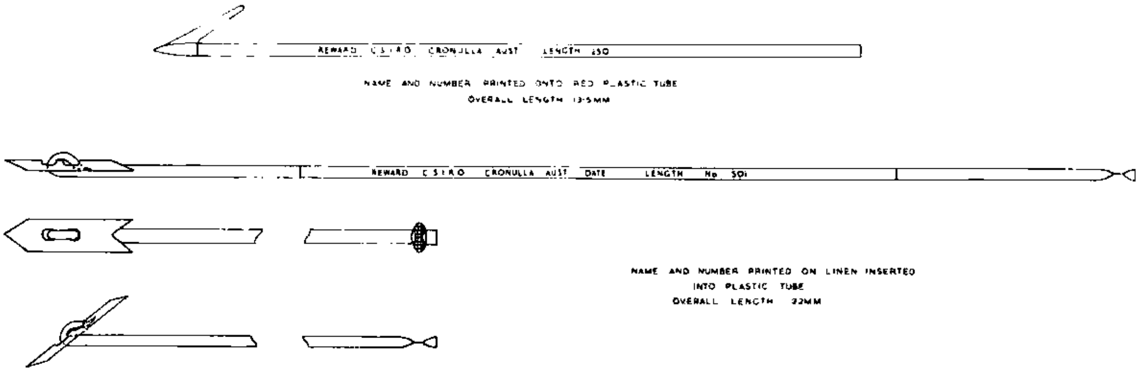


Figure 4. Sketch of streamer tags used on tuna.

were shed, or whether ill effects became apparent with time.

Short duration experiments were carried out with the species shown in Table 1.

Table 1
Species of fish and types of tag tested in short-term studies

Species	Type of Tag	Observation
Sea mullet (*Mugil cephalus*)	Medium strap on operculum	No interference with gill movement; no effect on balance of fishes over 15 cm. Fishes under 10 cm definitely unbalanced and unable to swim normally.
	Small strap on operculum	Fishes less than 7 cm unbalanced.

Tests of longer duration are reported in Table 2. The early success with the strap tag on mullet led to its use on other species. However, some fish, particularly black bream (*Acanthopagrus australis*), were returned with the tag almost lost from the operculum and others with split opercula, suggesting that the tag may have worked out or been torn out. The aquarium test showed that this resulted from the procedure of leaving an eighth to a quarter of the loop of the tag projecting beyond the operculum edge to allow for growth. Tags that were clipped with the minimum of projection beyond the edge of the operculum did not work out in aquarium tests, and from such firmly attached tags long-term recoveries have been made even with black bream, though each produced an invagination in the edge of the operculum. However, aquarium tests may be misleading: three species of fishes were tagged with hydrostatic and Petersen tags and held in the aquarium for over three months without deleterious effect. But estuarine fishes recovered in the field, and particularly those bearing hydrostatic tags, had nasty wounds about the wire. Because of this, and also because both hydrostatic tags and Petersen tags without the fish attached were recovered from nets in which they were entangled, use of these two types of tag was discontinued in the Lake Macquarie investigation (Thomson 1959), after about 200 Petersens and 120 hydrostatics had been released.

Table 2
Species of fish and types of tag tested in long-term studies

Species	Type of Tag	Observation
Sea mullet, Luderick (*Girella tricuspidata*) Black bream	Strap, hydrostatic and Petersen	All appeared satisfactory except straps when left projecting from edge of operculum; in such cases tags worked out
Trout	Strap	Marked proportion worked out over several weeks; but no observation given of projection beyond opercula.
School shark	Petersen disk	Appeared satisfactory in pond-held sharks.
	Barbed disk	All lost in pond; not used in field.
Southern crayfish	Punch marks	Shape of punch lost after several moults, but combination of positions on telson and uropod discernible.

Figure 5. Dorsal fins of school shark showing that Petersen disks work out.

Results in the field also led to the substitution of internal tags for Petersen disks in the case of sharks because the disks were found to work out of the fin, as described by Olsen (1953) (Fig. 5).

Field staff are unanimously agreed that opercular strap tags are the easiest to apply on all but very large fishes whose opercles resist penetration. The rapidity of attachment of this type of tag lessens the time out of water, a point which is important to survival in the warm temperate and sub-tropical conditions of the Australian inshore.

III. Publicity and Incentives

To ensure the return of discovered tags, the existence of the tagging programme and its objects were publicised as widely as possible. Notices such as that

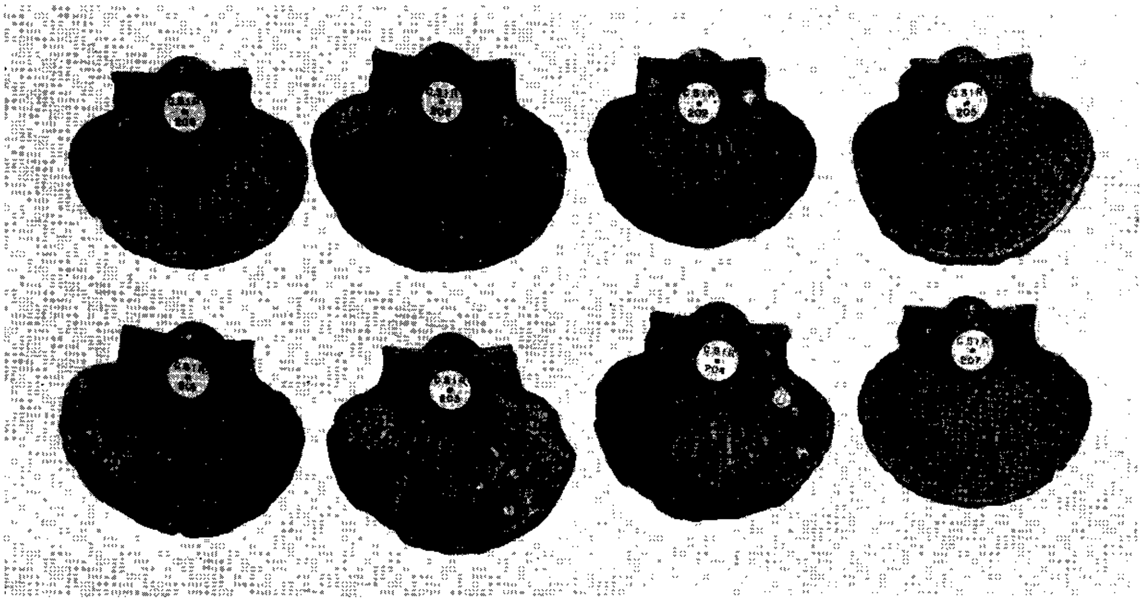


Figure 6. Petersen disks cemented to scallop shells.

hown in Figure 7 have been displayed at all fisheries nspectors' offices, and at all fish markets and storage depots to attract the attention of commercial fishermen, and the angling public has been alerted by the display of notices at boat-hiring premises and at favourite fishing spots such as jetties, etc. An appeal for co-operation in the return of tags on trout was included on the licence issued to anglers. In some of the more restricted fisheries, such as that for Australian salmon or the estuarine fishery in Lake Macquarie, each licensed fisherman was interviewed personally to appeal for his co-operation.

TAGGED FISH

REWARD TO FINDERS

Look HERE and HERE

1. Measure this length.

2. Take a few scales from here.

3. Send tag with a record of the length of the fish and the place and date of capture, and the scale samples to C.S.I.R.O., DIVISION OF FISHERIES, P.O. BOX 21, CRONULLA, N.S.W., or to the nearest Fisheries Inspector. If finder prefers to return whole fish, market price will be paid besides reward. Please help this Fish Conservation programme. Returning tags helps tell when and where fish move and how fast they grow. 4/- reward will be paid for each tag returned with desired information.

Figure 7. Reward notice used in Lake Macquarie investigations.

Periodic publicity was given to the investigations by press releases and radio news flashes about any interesting returns. The weekly newspaper columns of angling experts provided contact with sports fishermen, and the Australian Fisheries Newsletter reached the commercial fishermen.

To provide an incentive beyond that of mere interest, a reward has been paid for each tag returned. In the period 1938—1948 this was 2/— (about 20 cents) per tag; it was increased to 4/— (about 40 cents) after 1948. In the investigation of gold-lip pearlshell, the incentive offered was the exchange of double the tagged shell's weight in good pearlshell. A point featured in the publicity concerning the investigations was that the fish themselves should be returned wherever possible. In such cases the market price of the fish and the cost of postage or cartage was also reimbursed. In practice, relatively few of the tagged fish found by fishermen were returned, the tag alone being sent with the fishermen's "guesstimate" of length or weight. In about 25% of cases scales were also included. Every tagged fish that was detected in the markets was made available for biometric and other work.

IV. Comparative Return of Tags

(i) Hydrostatic Tag

Table 3 shows the comparative rate of recovery of various types of tags in a single fishing area (Lake Macquarie, New South Wales). It might be concluded from these figures that hydrostatic tags are noticed and reported in greater proportion than opercular strap tags or Petersen disks. However, it is considered that this tag is neither more conspicuous nor better retained than the others, but that it is recovered more frequently because it is most easily entangled in a net.

In other words, it is suggested that the fishing mortality rate for fishes bearing hydrostatic tags is greater than for the population as a whole. This would invalidate the use of hydrostatic tag returns to estimate populations but not to track movements or to obtain direct measures of growth.

Table 3

Comparative return of tags, Lake Macquarie, 1954—56

Species and Tag	No. Reported	% Reported	Av. Days Freedom
Sea mullet			
Hydrostatic	10	17.0	181
Strap	151	5.2	258
Petersen disk	1	5.5	60
Flat-tail mullet			
Hydrostatic	3	17.3	117
Strap	218	5.5	140
Luderick			
Hydrostatic	10	53.0	549
Strap (opercle)	55	4.3	119
Petersen disk	1	3.0	243
Tarwhine			
Strap (opercle)	362	14.9	87
Petersen disk	2	1.9	5
Yellow-fin leatherjacket			
Strap (ventral flap)	218	17.7	114
Petersen disk	4	14.8	301
Centreboard			
Hydrostatic	1	50.0	739
Strap (ventral flap)	112	22.0	46
Black bream			
Strap (opercle)	161	7.0	110
Petersen disk	0	0	—

It is noticeable that the average days of freedom of luderick carrying hydrostatic tags were considerably greater than of fish carrying either Petersen disks or opercular strap tags. Possibly this results from poor retention of opercular tags, which are known to work out of soft opercles, and of Petersen disks which are occasionally recovered from nets without the fish which bore them. Such an advantage of hydrostatics was not revealed in the case of sea mullet and flat-tail mullet. Hydrostatic tags have not been used in greater numbers because members of the public criticised their use since the wires caused obvious wounds in the fish.

(ii) Petersen Disk

The Petersen disk cemented onto the shell has proved very useful and durable in studying epibenthic molluscs such as scallops and pearlshell. Opinion is divided on the use of these tags on fish. The application of the Petersen tag is slower than that of the opercular strap, thus increasing the time the fish is out of water, but where it is suspected that strap tags work out Petersens have been used, as in the east coast investigation on black bream during 1944—48. However, during the Lake Macquarie investigation in 1954—56 no black bream marked with a Petersen disk were returned, although a 7% return of opercular strap tags was achieved (Table 4).

Table 4

Comparative returns of Petersen disks and strap tags on black bream

Area	No. Tagged	No. Reported	% Reported	Av. Days Freedom
East Coast 1944—48				
Petersen disk	1245	71	5.7	98
Strap (opercle)	3666	22	0.6	79
Lake Macquarie 1954—56				
Petersen disk	210	0	0	—
Strap	1978	161	7.0	110

In view of the 5.7% return of Petersens in the earlier study it seems possible that the tagging technique of the later tagging crew might not have been equal to that of the earlier, and may have resulted in a higher mortality rate of Petersen-marked bream. However, it should be noted that the bream tagged and held in the aquarium showed no ill effects.

Other species of Petersen-marked fish in Lake Macquarie were also returned at a lesser rate than other types of tag. Petersens are known to work out of the dorsal fins of sharks (Olsen 1953, and Fig. 5). In Section I (b) attention was drawn to the fact that grey Petersen disks were substituted for white when experience indicated that white disks attracted attention from predators. Olsen (1953) was unable to detect any significant difference in rate of return of the two colours in the case of the school shark which, however, is a species with few predators. In school sharks returns of double-tagged fish (internal plus Petersen) were about double the returns of those tagged with Petersen alone (Table 5). This difference is consistent with the loss of disks from double-tagged fish, which was about 50%. The small mumber of fish tagged with internal tags only gave fewer returns than the double-tagged fish, but the difference is not significant.

Table 5

Comparison of Petersen disks and internal tags used on school sharks

Type of Tag	No. Tagged	% Returned
Petersen disks alone	3580	2.09
Internals alone	105	2.85
Petersens plus Internals	2150	5.81
Petersens recovered		2.84
Petersens lost		2.97

Petersen disks were returned in comparatively small proportion from Australian salmon (Table 7), except in Tasmania. There is a preponderance of disk tag returns in Tasmania because most of the fish taken there are small immature fish, taken on hand-lines. Under these circumstances the Petersen disk is readily detected, whereas the internal tag would not be observed if the undersized salmon is returned alive to the water as fisheries regulations require.

The seven barracouta returned have borne Petersen disks, five being grey, two white (Table 6).

Table 6

Tags used on and returned from barracouta

	Petersen Disk	Strap	Internal	Hydrostatic	Safety Pin	Spiral
No. tagged	2559	380	1293	130	136	100
Returns	7	0	0	0	0	0

(iii) Internal Tag

When cleaning of the fish is done at sea or on the beaches internal tags have a better rate of return. The white internal tag shows up against the viscera when the cleaning is being done and is thus easily detected. The evident superiority of the internal tag in the Western Australian and Victorian salmon fisheries results from this practice (Table 7).

Internal tags from fish marketed in the round often fail to convey information because it is usually impossible to track down the place of recapture.

Table 7

Comparative returns of strap, tape, disk, and internal tags used on Australian salmon in various areas

Area	No. Returned	% Returned
Western Australia (total)	499	20.1
Strap	268	17.6
Petersen disk	15	6.9
Internal	216	27.6
South Australia (internal)	409	9.9
Tasmania (total)	34	3.6
Petersen disk	8	8.0
Tape (jaw)	1	1.3
Internal	25	3.3
Victoria (total)	220	5.8
Strap	95	3.9
Petersen disk	19	3.7
Tape (operculum)	0	—
Tape (jaw)	16	6.9
Internal	90	15.0
New South Wales (Petersen)	50	10.0

In a species such as the Tommy-ruff which is sold in the round, approximately equal returns of internal and external tags might be anticipated. The apparent loss of internal tags (Table 8) is probably due to a lack of detection of this type of tag in the canneries, where cleaning proceeds at speed and the small internal tag could be overlooked. The only internal tag returned from cannery processed fish was recovered from a can.

Table 8

Comparative returns of internal and operculum tags from Tommy-ruff

Area	No. Tagged	No. Returned	% Returned
Western Australia			
Internal (tag)	4166	100	2.4
Operculum strap	606	20	3.3
South Australia			
Internal	6250	25	0.4

A small rate of return is to be expected in this species as the intensity of exploitation is low, particularly in South Australia where the small immature ruffs are not taken by the fishery, but are fished later when they migrate to Western Australia for spawning.

(iv) Strap Tag

The ease of application of the operculum strap tag has led to its wide use in the study of inshore fishes in Australian waters, 61054 fishes having been so marked compared with 27824 internal and 25417 Petersen disks, the other principal types of tags. In addition, 5103 straps were clenched on trout jaws. The comparative effectiveness of the strap tag varies with the species, and with the exact mode of application. In the two separate studies on black bream reported in Table 4 the disparate results with the strap tag are probably due to the fact that in the earlier series the tags were left with about a third of their length projecting to permit growth of the operculum edge, whereas in the later series the tag was clipped tightly to the operculum so that no loop projected to catch on weed or snags (see Section II). In such circumstances the operculum continues to grow, leaving an incision where the tag blocks the way.

On sea mullet the strap tag has given better results than the Godsil tag. The greater rate of return of the hydrostatic tags (Table 9) has been commented upon in Section IV (i).

Table 9

Reported recoveries of sea mullet carrying specified types of tag

	Eastern Australia 1938—1942		Lake Macquarie 1954—1956		
	Godsil Tag	Strap Tag	Strap Tag	Hydrostatic	Petersen
No.	4	224	151	10	1
%	0.4	6.4	5.2	17.0	5.5

The return of opercular straps on Australian salmon was better than that of Petersen disks, but not as good as the return of internal tags (Table 7). Whether this indicates loss of straps or lesser detectability is uncertain. In Victorian waters the opercular strap on snapper has been returned at a better rate than internal tags (Table 10).

Table 10
Comparative returns of internal and strap tagged snapper

Area	No. Reported	% Reported	Av. Days Freedom
Victoria			
Internal	7	0.3	215
Strap (opercular)	114	2.8	464
Lake Macquarie	760	20.1	59

In other inshore fishes (Table 3) the strap tag has provided better returns than the Petersen disk, though not as good as the hydrostatic, whose possibly atypical rate of recapture is mentioned in Section IV (i).

The strap tag used on the jaw has given good returns with trout, though the silver tape (Section I (d) gave better results for rainbow trout (Tables 11 and 12).

Table 11
Comparative returns of tag types used on brown trout

Area	No. Reported	% Reported	Av. Days Freedom
Tasmania			
Silver tape	8	11.0	336
Jaw strap small	35	2.5	925
Jaw strap medium	136	16.4	400
Jaw strap large	66	12.5	935
Victoria			
Internal	2	5.7	237

Table 12
Comparative returns of tag types used on rainbow trout

Type of Tag	No. Reported	% Reported	Av. Days Freedom
Silver tape	68	55.7	281
Jaw strap small	56	3.9	143
Jaw strap medium	118	43.9	529
Jaw strap large	137	32.7	506

(v) Streamer Tag

Only a few of these have been returned. Of 219 of the earlier type released (Section I (h)) only one has been returned, but nine out of 381 (2.3%) of the later type have been returned.

(vi) Dart Tag

The dart tag has so far been used only in an experimental area to test its efficacy. Sixty-one dart-tagged crayfish were released in 1960 and 14 were recovered 12 months later. Another 1492 were tagged in the summer of 1961 and will be fished for in the summer (January) of 1962. The recovery of the 14 dart tags indicates that properly applied, the dart tag is retained through ecdysis.

(vii) Telson Punch

Of the crayfish marked by telson punches, 9.1% of western crayfish and 18.9% of southern crayfish have been recovered, the average days' freedom being 40 and 455 respectively. The results from the southern crayfish show that telson punches remain discernible after several moults, but they become less distinct with each moult and any distinction on the shape of the punch becomes obscured. A combination-pattern of two or more punch holes in various positions on the telson and uropods gives a better criterion, though even these are obscured or lost after several moults.

V. Summary

Of the 12 types of tag or mark used on fish and other marine animals the internal tag has given most satisfaction in those species which are cleaned on the beaches or at sea. For medium and small fish sold in the round the opercular strap tag is preferred, except in the case of fish with soft opercles. Hydrostatic tags have been returned at a rate which may be in excess of the normal fishing mortality; also they and Petersen disk tags are not favoured owing to the wounds produced on a high proportion of fish. Petersen disks are known to work out of shark fins. For rapidity of application the opercular strap tag is best.

The most suitable tag may vary with age of the fish, as in the Australian salmon, because of the different nature of the fishery operating on the young and old age groups.

The modified streamer tag with a plastic head is the most promising tag used on tuna in Australian waters.

In crayfish, telson punch marks persist over several moults but become more obscure with each ecdysis; the dart tag, now being tested, seems most promising.

Publicity has been provided by angling columns in newspapers, in the Australian Fisheries Newsletter which reaches all commercial fishermen, by radio newsflashes, by notices posted at wharves, boat hire premises and other spots frequented by fishermen, and by personal contact.

References

ANONYMOUS 1953. A guide to fish marks, 2nd edition. *J. Cons int. Explor. Mer*, **19**: 241—89.

CHITTLEBOROUGH, R. G. and GODFREY, K. 1957. Review of whale marking and some trials of a modified whale mark. *Norsk Hvalfangsttid.*, **46**: 238—48.

GODSIL, H. C. 1938. Tuna tags. *J. Cons. int. Explor. Mer*, **13**: 217—20.

NICHOLLS, A. G. 1957. The Tasmanian trout fisbery. I. Sources of information and treatment of data. *Aust. J. Mar. Freshw. Res.* **8**: 451—75.

OLSEN, A. M. 1953. Tagging of school shark (*Galeorhinus australis* Macleay) in south-eastern Australian waters. Aust. *J. Mar. Freshw. Res.*, **4**: 95—104.

RAYNER, G. W. 1940. Whale marking: progress and results to December 1939. *'Discovery' Rep.*, **19**: 245—86.

SHETTER, D. S. 1936. The jaw-tag method of marking fish. *Pap. Mich. Acad. Sci.*, **21**: 651—53.

THOMSON, J. M. 1959. Some aspects of the ecology of Lake Macquarie, N.S.W. with regard to an alleged depletion of fish. X. The movements of fish. *Aust. J. Mar. Freshw. Res.*, **10**: 375—**87.**

10.

Bering Sea King Crab *(Paralithodes Camtschatica)* Tagging Experiments

By

FRED C. CLEAVER*

Introduction

The king crab is found in cold waters of the North Pacific Ocean, the Bering Sea, and the Okhotsk Sea. It occurs in the eastern Bering Sea where bottom water temperatures are at times below 0° Centigrade, but it is not abundant north of 59° North latitude, and is generally not the object of fishing north of 58°. Another (smaller) species, *P. platypus*, becomes common at higher latitudes.

The average size in the commercial catch for eastern Bering Sea in 1941 was 7.3 pounds with a maximum of about 14 pounds (Wallace, Pertuit and Hvatum, 1949). Because only the larger crabs are taken, this had not changed much by 1960. In the Pacific Ocean south of the Alaska Peninsula 20-pound specimens are frequently found.

Fishing is done in waters of less than 100 fathoms. The 100-fathom contour extends from Unimak Pass at the western tip of the Alaska Peninsula in a northwesterly direction, passing westward of the Pribilof Islands. The bottom becomes gradually shallower to the eastward and is smooth and free from obstructions. Otter trawling can be done anywhere with little danger of damage to the gear. The bottom of the southeastern Bering Sea is a moderately flat, smooth shelf.

Most of the catch is taken with large mesh tangle nets which are highly selective for the larger crabs. The irregular shape and many spines of the king crab cause them to tangle readily in the nets. Otter trawls are also used in the fishery.

Ice usually covers much of the fishing ground by February and may remain until late April or early May. Fishing with otter trawl gear is possible the entire year, but activity has been very limited except during the late spring and summer months. In recent years there has been no winter fishery.

The fishery for king crab (*Paralithodes camtschatica*) in the southeastern Bering Sea was begun by Japan about 30 years ago. Following World War II Japan and the United States jointly exploited the stocks, and in 1959 and 1960 the Union of Soviet Socialist Republics also engaged in the fishery. Because of earlier concern over the effect of fishing on this species the International North Pacific Fisheries Commission, of which Canada, Japan and the United States are members, undertook to study the stocks of king crab. The work reported here was done by the United States Bureau of Commercial Fisheries for the Commission with the coöperation of Japan. Japanese scientists have also conducted studies of the king crabs in the eastern Bering Sea as well as in waters near Japan.

The overall purpose of this investigation is to determine the effect of fishing upon the yield of the stock. To accomplish this, studies are being made of various features of the life history of the crab and of the fishery. Much of this is not particularly germane to a discussion of tagging and will not be considered here. The objective of this paper is to examine the design and analysis of tagging experiments in the king crab studies.

The work has been done by a small group at the Seattle Biological Laboratory of the Bureau. From 1956 to 1958 I was directly responsible for the investigations. Mr. Takashi Miyahara, who is now leader of the king crab program, supplied the data that I am using here.

The tagging was designed to study the limits and degree of intermixing of the southeastern Bering Sea king crab population, growth, and rates of mortality. Size frequency data were collected to test the accuracy of the results of the growth analysis. Quantitative trawling was undertaken to provide an alternate method of calculating fishing mortality.

Tagging Methods

The king crab is in some respects a very satisfactory animal for tagging. It is resistant to damage by handling or suffocation and if treated with reasonable care, can be caught at depths of 100 fathoms or more and released in good condition. The commercial fishery commonly takes the crabs in otter trawls, holds them alive in flooded compartments aboard ship for a week or longer, and discharges the catch with little mortality. The major difficulty lies in avoiding loss of the tag when the crab casts its shell during molting. This problem seems to have been solved fairly well by using a tag of the type first employed by the Japanese more than 20 years ago.

This tag is essentially a piece of soft plastic tubing which is threaded through the arthral muscle at the

---

* U. S. Dep. of the Int., Fish and Wildlife Serv., Bur. of Com. Fish., Biol. Lab., Seattle 2, Washington, U.S.A.

junction between the carapace and abdomen. The ends are knotted and hang behind the crab with a numbered label. It has been called a "spaghetti tag" since the material resembles wet, cooked spaghetti in texture. Initially, we were seriously concerned over the effect of placing the tag in this manner. The arthral muscle is highly vascular and appears to be a major route of blood transport from the body to the heart. However, crabs which were held in live tanks following tagging showed no ill effects. Because the presence of sea water appears to be necessary to blood coagulation, the crabs were returned to the sea as quickly as possible.

We have tagged only crabs possessing firm shells and not recently molted. When newly molted and soft, the crabs are easily damaged and tagging is not deemed to be desirable because of the low recovery rates anticipated.

Returns

The degree to which we failed to obtain tags from recaptured crabs is unknown. However, it is believed that the loss from this source is relatively small. The fishery is unique in that almost all of the catch is landed at a few factory ships. Until the entry of the Soviet factory ship, generally about 80 percent of the catch was processed by the Japanese mothership *Tokei Maru*. The Japan Fishery Agency assigns a scientist to the ship who has been very conscientious in collecting recaptured tags from the fishermen. The Soviet operation has also returned numerous tags, but we are not familiar with the recovery procedure. We believe that nearly all of the tags recovered by United States fishermen were returned.

Design and Analysis of Marking Experiments

Mortality rates

To find the rates of mortality we proposed to calculate the total annual mortality rate from the rate of tag disappearance over a period of years. The part due to fishing was to be estimated by two methods: (1) recoveries after 1 year of freedom for 1956, 1957 and 1958 releases and (2) estimating numbers of crabs in the area by trawling and comparing this estimate with the catch. If we can estimate fishing mortality reasonably well, it is then convenient to estimate the mortality from causes other than fishing.

The first successful tagging took place in the summer of 1955, and tags were released each year in 1956, 1957, 1958, 1959 and 1960. Because the fishery takes only male crabs which are 13 cm or more in carapace length, only the releases of these larger male crabs are discussed. Actually, few crabs as small as 13 cm are retained commercially. For convenience, we have used carapace length to record size. The irregular shape of the carapace makes width difficult to measure with precision. The returns are not complete for the larger more recent releases, so the results shown below are of a tentative nature. No attempt has been made to adjust for size-selective fishing, molting, changes in fishing, or a variety of other factors which should be treated in a careful analysis. The data presented serve to illustrate the methods employed and the progress of the work.

Table 1 shows the total numbers released and returned for the first three years of tagging with plastic tube tags. The returns for 1960 are not complete. Numbers tagged in 1958, 1959 and 1960 are listed in the annual reports of the International North Pacific Fisheries Commission for these years. They are not used here because they do not provide a sufficiently long series for analysis.

Table 1

Recovery of male crabs over 13 cm in carapace length released in the southeastern Bering Sea

Release year	Number Released	Number recovered 1955	1956	1957	1958	1959	1960
1955	1099	30*	48	30	16	7	4
1956	2545	—	42*	125	82	56	31
1957	5780	—	—	34*	136*	166*	67*

* Not used in calculations.

The data in Table 1 were used to calculate survival rates. Following Jackson's method (Ricker, 1958) the mean annual survival from the 1955 tagging was 0.56 and from the 1956 tagging it was 0.64. For comparison with an unweighted estimate, the recovery data were converted to logarithms which transformed the series to good approximations of straight lines with slopes corresponding to 0.52 survival for 1955 and 0.60 for 1956. The 1957 tagging was not used because of the short series and the anomaly between the 1958 and 1959 recoveries. The low recovery in 1958 is believed to be due to low availability caused by the distribution of tagging in 1957.

Now let us consider means of estimating annual fishing mortality. We obtained an approximation of fishing mortality by examining tags recovered after one year of freedom. This was compared with an independent estimate derived from the number of crabs calculated to be on the fishing grounds and the catch reported by the fishing companies. Thus, we have two separate estimates of fishing mortality.

The first method of estimating fishing mortality is by tagging. Before using the returns to derive this estimate, it is necessary to be assured that the tags are well mixed through the stock. Because tagged

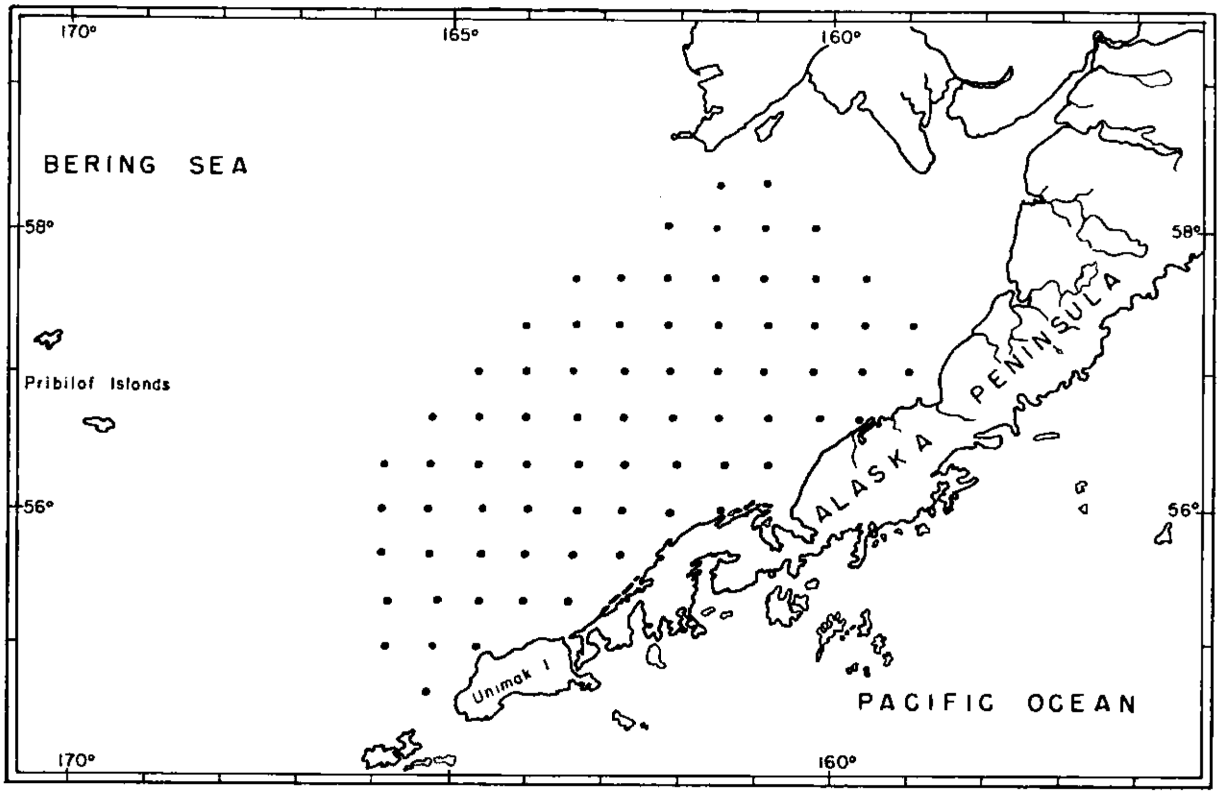


Figure 1. King crab station pattern.

crabs do not appear to become thoroughly distributed within a year after tagging, all of the releases cannot be used. Two patterns of release were employed. In the first, a pattern of stations 20 miles apart were fished. All of the crabs caught were tagged and released where caught. An illustration of this pattern is given in Fig. 1. Following this, mass tagging was done where crabs were most abundant. The mass taggings account for most of the crabs released. These were not distributed through the stock. However, the crabs released on the station plan were systematically distributed throughout the area in which crabs are found. Therefore we reason that the distribution of those tagged on station should be approximately the same as that of the stock as a whole. From the distribution of the fishery on different grounds this seems to be generally true. If it is true, it immediately accomplishes good mixing of tags through the stock.

In Table 2, only station releases were used, and only those recoveries made in the first spring and summer fishery following the year of tagging were considered. As mentioned earlier, the fishing was done almost entirely during the spring and summer months. The releases have been adjusted for recoveries within the year of tagging. The table shows that for 1956 and 1958 about 4 percent of the tags were recovered by the fishery, but for 1957 only about 1 percent. Again, the 1957 recoveries appeared to reflect a lower availability. For all three years we would expect that loss of tags, mortality of tagged crabs, and similar factors would cause these data to indicate a fishing rate lower than actually occurred.

Table 2

Recoveries in following year of crabs tagged on station

Year of tagging	Male crabs released on station	Recoveries in following summer	Percent re-covered
1956	750	28	3.7
1957	348	3	0.9
1958	2617	96	3.7

The second method used to estimate fishing mortality was by comparing the numbers of crabs on the grounds with the catch in 1957, 1958 and 1959. Total numbers of male crabs of commercial size were calculated from otter trawling catches. The area covered by the trawl was used with the numbers caught to compute the average density per unit area. This was then expanded to the total area covered. The results are shown in Table 3. These estimates reflect the entry of the first large mode mentioned in the discussion of growth. The catch of crabs by the fisheries in these years may be found in Table 4.

Table 3
Estimated number of male crabs (over 13 cm) in southeastern Bering Sea

Year	Number
1957	14,435,000
1958	20,563,000
1959	25,145,000

Table 4
King crab catch in eastern Bering Sea, 1953—1959, in thousands of crabs*

Year	Japan	U. S.	Total
1953	1276	361	1637
1954	1061	328	1389
1955	1129	313	1442
1956	1079	294	1373
1957	1171	107	1278
1958	1130	1	1131
1959	1292	—	1292**

* Source: International North Pacific Fisheries Commission Statistical Yearbooks for 1958 and 1959.

** Does not include catch by U.S.S.R. or incidental catch in bottom fish fishery.

Tables 3 and 4 provide the data to estimate directly the annual fishing mortality. For 1957 it was 0.089, for 1958, 0.055, and for 1959, 0.051.

The confidence intervals for the population estimates are quite broad, but interestingly enough, the mortality estimates for the three years are all between 5 and 10 percent. Moreover, they are probably high, since in calculating the density of crabs we assumed that all of the crabs which were between the otter boards were caught, and that our station pattern covered the entire area of the stocks. These assumptions are not entirely fulfilled. When the results of this method are compared with those from tagging, it appears that the fishing rate was less than 10 percent, and perhaps as low as 5 percent.

If for each year we use a mean of Jackson's and the line slope method of estimating annual survival (for the 1955 tagging 0.54 and 0.62 for the 1956 tagging), we then have total annual mortality rates of 0.46 and 0.38. When these are used with an annual fishing rate of 0.05, maximal annual natural mortality rates of 0.43 and 0.35 are derived for the 1955 and 1956 taggings respectively. If the higher estimate of 0.10 is used for the fishing mortality factor, the estimates of natural mortality become 0.40 and 0.31, which are similar to the rates derived using 0.05 for fishing. The estimate of natural mortality is not greatly changed whether the upper or lower estimate of fishing is used.

Mixing

Tagging showed no interchange between the stocks south of the Alaska Peninsula and those of the Bering Sea. Within the range of the species in the southeastern Bering Sea, there appears to be but one stock. Consideration of hydrography, distribution and fishing studies leads us to believe that there is only one major breeding group; it is almost continuous along the north side of the Peninsula. Release of larvae and mating take place here. The fishery concentrates on these mating adults, for the most dense aggregations of prime male crabs are found here. However, a group of crabs tagged at a single location might never become distributed randomly through the stock. In Table 1 the tags released in 1957 were evidently not fully available to the fishery before 1959, or perhaps later. The stock is highly segregated by sex, size and condition. The large hard-shelled males, the adult females and the very small of both sexes tend to be concentrated inshore from the nonbreeding crabs which include the large molting males. A large prime crab tagged on the breeding grounds would probably never return to the molting concentrations found northwest of the Alaska Peninsula, because the molting frequency of the larger crabs is low.

Growth

In some respects the growth studies of king crab (and crustaceans generally) are complicated by the lack of permanent annular marks on the animal, and the irregular nature of the growth. Carapace size remains constant for long intervals and growth occurs suddenly. The intervals between ecdyses vary with size, sex and age. A detailed study has been made of the Bering Sea king crab (D. D. Weber and T. Miyahara, 1959). In this study the mean growth rate was derived by using the amount of growth per molt as shown by tagged crabs, combined with observations of molting proportion.

Molting of the larger male crabs takes place in the spring months and appears to be limited to no more than a single molt per year. In order to establish the frequency of molting it is necessary to distinguish between shells that are perhaps 3 months old and those that are 15 months old or older. The shells of the recently molted crabs can be generally recognized as they are cleaner and show less scratching and erosion. While the decisions are subjective, they are in good agreement with data from recovered tagged crabs for which it is possible to determine whether or not they molted while free. This method does not insure that a larger crab would not molt later in the year, or molt more than once annually as the small crabs do. However, for large crabs it seems to be unimportant because they are seldom observed as soft-shelled crabs or with bright new shells between midsummer and midwinter.

Sampling (at the stations described above under mortality studies) was employed to determine the proportion molting for each year.

The results of this sampling showed that almost all of the crabs less than 11 cm had molted within the year of sampling. The proportion molting dropped gradually at first with increasing size, then more and more rapidly, until fewer than 10 percent of the crabs over 17 cm were found to be molting each year.

Mean growth in carapace length during one molt was approximately 16 mm and nearly stable for crabs from 11 to 16 cm in carapace length. A 16 cm crab would molt to 17.6 cm. Few of the crabs become greater than 19 cm, so the bulk of the commercial stock is included in the size range for which increase at molting is known.

A model was constructed using tagging and molting data to calculate the annual average size of a group of crabs initially 11 cm in length. The growth is shown in Table 5.

Table 5

Calculated growth of a group of king crabs initially 11 cm in carapace length, from model studies

Year	Modal length (cm)	Mean length (cm)
N	11.0	11.0
N+1	12.6	12.5
N+2	14.2	13.9
N+3	15.8	15.0
N+4	15.8	15.8
N+5	15.8	16.4
N+6	17.4	16.8

The spread in length of the group increased with time. It was estimated that after six years, with an average length of 16.8 cm some individuals might be as small as 14.2 cm or larger than 20 cm.

The rate of growth was also examined by studying the size frequency of male crabs found on the fishing grounds from 1955 through 1959 (Weber and Miyahara, 1959). The male crabs found on the fishing grounds were generally larger than 5 cm and smaller than 20 cm in carapace length. We were fortunate in 1955 when a distinct mode appeared at about 8 cm which we could follow in successive years. It was still evident in 1960. In 1957 when this mode had reached about 11 cm, another group, less strong but still quite identifiable, appeared near 8 cm. By 1959 the first mode mentioned was near 14.5 cm. The average progression of these modes through 1959 was approximately 15 mm per year.

This compares quite closely with the modal growth shown in Table 5. The results of the study summarized in Table 5 indicate, however, that the growth of an age-group as a whole is somewhat less than that found by following unique modes in their progress through the population. This difference arises because in any given year all male crabs do not molt. Those which fail to molt tend to skew the mode to the left and then mean length becomes smaller than the modal length.

Summary

The purpose of this paper is to consider the design and analysis of tagging experiments with the southeastern Bering Sea king crab. Migration, growth and mortality rates are of primary interest. These are discussed in a preliminary manner. Although a completed manuscript on growth is in press, the work on migration and mixing has not reached the same stage and serious analysis of mortality rate data has yet to be undertaken. The time series of tag returns has been too short to permit careful analysis. For this reason the results given here are tentative trial estimates, and have not been adjusted for the high degree of size selectivity by the fishery, changes in fishing intensity, differential availability because of variation in molting frequency by size, and similar factors. A study of these factors is being made. The material that has been presented may be summarized as follows:

1. The use of growth data from tagged crabs combined with molting proportions appears to give reliable results. The average growth in carapace length by crabs of 11 cm is 15, 14, 11,8, 6 and 4 mm in succeeding years. This does not conflict with the results of size frequency studies.
2. Tagging shows that the southeastern Bering Sea has but one stock of king crabs, which does not mix with the crabs south of the Alaska Peninsula.
3. The tagging experiments promise to yield series of data which are suitable for reasonably accurate calculation of mortality rates. The estimates suggest that the annual fishing rate has been between 5 and 10 percent and that the annual natural mortality on this basis is between 31 and 43 percent.

References

International North Pacific Fisheries Commission 1958—1961 Annual report for the year 1957, 1958, 1959, 1960.

International North Pacific Fisheries Commission. 1959—1960. Statistical yearbook 1958, 1959.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. Fish Res. Bd. Canada, Bull. 119, 300 p.

WALLACE, M. MARVIN, CAMILE J. PERTUIT and ARTHUR R. HVATUM. 1949. Contribution to the biology of the king crab (*Paralithodes camtschatica Tilesius*). Fish. Leafl. 340. Wash. 50 p.

WEBER, DOUGLAS D. and TAKASHI MIYAHARA. 1962. Growth of the adult male king crab *Paralithodes camtschatica* (Tilesius). *Fish. Bull. U.S.*, 62 (200).

11.

Marking Fingerling Salmon with Trace-Elements and Non-Radioactive Isotopes

By

P. S. TREFETHEN and A. J. NOVOTNY*

The Bureau of Commercial Fisheries at its Seattle Laboratory** is conducting experiments to develop a permanent mark that can be applied to fingerling salmon quickly, easily and economically, and that can be employed to mark the entire production of a hatchery or specific spawning area. The evaluation of hatchery or spawning area contribution to a fishery has depended upon the recovery of fish marked by clipping one or more fins. While fin-clipping has produced some data for evaluation, the method is time-consuming, expensive, requires the handling of each fish, and usually results in only a portion of the output being marked.

The use of trace elements or non-radioactive stable isotopes would eliminate the disadvantages of fin-clipping and would enable biologists to mark entire productions for identification.

The specifications of a perfect mark might be defined as follows:

(1) Not injurious to the fish.
(2) Has no effect on usual behavior patterns.
(3) Has no harmful effect on metabolism.
(4) Can be applied without handling the fish.
(5) Easily and readily applied.
(6) Can be applied to large numbers quickly and easily.
(7) Readily distinguishable to observers.
(8) Marked and unmarked population differences indistinguishable by predators.
(9) Inexpensive to apply.

With the exception of not being externally visible and easily distinguishable to observers, trace elements and non-radioactive stable isotopes appear to be a perfect mark.

Experiments by biologists have indicated that certain mineral salts can be assimilated into the bone matrix of most vertebrates during juvenile development with no harmful effect. These salts crystallize and remain with the organism in detectable amounts throughout its life cycle with little ion exchange. During their early life history in a freshwater environment, Pacific salmon assimilate certain elements necessary for sustained health and vigor. The radioisotopes of these elements are being used in some countries for permanently marking juvenile fish, and it appears reasonable to believe that contiguous non-radioactive (or stable) isotopes and certain trace elements could be used as a permanent mark for salmon fingerlings.

The present study is still in the primary phases, being only some five months old. Experiments are in progress to determine practical elements and isotopes that can be used in a marking program.

The first part has been the cation toxicity studies. We have one good guide on this. Shaw and Grushkin (1957) clearly demonstrated that the cation toxicity to aquatic organisms is directly correlated to the insolubility of the sulfide of the cation. We have checked this with sockeye salmon, and thus far the correlation holds true. Toxicity studies are still being continued. This phase is important for the study of cation metabolism in ionic solutions, since it determines lethal and permissible concentrations. If certain cations are toxic at low concentrations in solution, we then place emphasis on a dietary introduction study.

The actual determination of the retention of a cation can best be done (in most cases) by using the radioactive isotope of that cation in controlled closed system laboratory studies. Accurate information as to the most successful method of introduction can best be obtained in this manner also.

Once a cation has been demonstrated to be a bone-seeking retentive element, the next phase involves a study of introducing the non-radioactive isotopes. They will be introduced to test lots of fish by addition to their diet or by ionic solution. In the latter method, the fish are placed in a solution of the trace element for 24 to 48 hours. Chinook salmon (*Oncorhynchus tshawytscha*), blueback salmon (*O. nerka*) and rainbow trout (*Salmo gairdneri*) are being subjected to the medium. The chinook and blueback salmon will be released at their normal migration period. It will be necessary to hold fish (such as the rainbow trout) after the last introduction, and sample periodically until vestigial detection has been reached.

The marked fish will be identified by different procedures. Samples of the osseous tissue will be taken and reduced to an ash. The trace elements will be identified by either colorimetric analysis or neutron activation of the ash. The method chosen will depend on its sensitivity for a particular trace element.

Utilizing colorimetric analysis as a technique, one trace element mark would suffice for this, since a

---

* Bur. of Com. Fish., Seattle, Wash., U.S.A.

** Financed through the Columbia River Fisheries Program Office.

destructive analysis of the bone must be made. Neutron-activation analysis can be done on a non-destructive basis, and many trace elements can be detected in one sample by regulating activation time and reactor flux.

Fortunately, the most promising trace elements are the lanthanide series, and they are detectable by neutron-activation to quantities as low as 5×10^{-13}gm.

Durbin et al. (1956) have demonstrated that the average biological halflife of the entire lanthanide series in bone is 2.5 years.

In the case of the stable isotopes, only those which can be detected by neutron activation will be employed. The availability of enriched stable isotopes which can be produced cheaply is currently a problem which may not be resolved until the demands from industry become greater.

In practice, the elements or isotopes used would not be naturally available in either the freshwater or marine environment, and would thus be a product of the original introductory site when detected in a fish. Samples can be taken at any time during the life history and the analysis of osseous tissues will reveal their true origin. There appear to be sufficient trace elements and stable isotopes to initiate marking programs through a regulatory agency such as is being done now in the fin-clipping program.

Summary

The assimilation of certain trace elements and non-radioactive (or stable) isotopes into the osseous tissues of fingerling salmon is the basis of research now in progress. Elements have been selected which are not naturally available in the fishes' environment. They are introduced to the fish in their diet and through the water in their holding tanks.

Toxicity of the substances is being studied. Samples of osseous tissue will be taken and reduced to an ash. The trace elements and stable isotopes will be identified by colorimetric analysis or neutron activation.

References

SHAW, W. H. R., and B. GRUSHKIN 1957. The toxicity o ions to aquatic organisms. *Arch. Biochem.*, **67** (2): 447—452.

DURBIN, P. W., et al. 1956. Metabolism of the lanthanons in the rat. *Proc. Soc. Exp. Biol.* N. Y., **91**: 78—85.

12.

Use of Tagging Data in Subarea 4 Cod Growth Investigations

By

A. CARL KOHLER*

Introduction

Tagging experiments provide the only opportunity at present of measuring the growth of individual fish in the wild state over an accurately determined period of time. This method of estimating growth can be particularly valuable for aquatic animals which do not lay down age rings in bony structures (e.g., Lindner, 1953). However, for Atlantic cod in Subarea 4 there exists a reliable method of growth determination, using length and age data (Kohler, 1961). Thus, it is possible to compare growth data based on tagging with independently collected growth information from age-length sampling. The validity of estimating growth parameters for wild fish from tag returns is dependent on the premise that the tag does not affect the growth of the fish, or, if it does, that this effect can be accurately estimated. As a first step in this study, data from laboratory growth experiments on tagged and untagged cod were analysed.

Growth of Tagged and Untagged Cod in the Laboratory.

A controlled experiment to determine factors affecting variation in cod growth was carried out by Kohler (1959, 1961). In order to have a record of growth of some of the individual fish, a number in each tank were tagged at the beginning of the experiment. The tag used was a Petersen disk threaded on a double loop of 15 lb test monofilament nylon line. The doubled nylon line was inserted through the dorsal musculature between the first and second dorsal fins and knotted to form a loose loop with the disk tag dangling from it. Records of growth of tagged and untagged fish, living under identical conditions for a year, were thus available. Fork length in millimetres and weight in ounces were recorded for each individual every 3 weeks during the experimental period from 22 August 1957 to 4 September 1958. The data on initial numbers, average size of cod and rate of feeding during the experiment are shown in Table 1. Details of feeding and other conditions in the tanks are given by Kohler (1959, 1961).

The growth in length and weight of tagged and untagged cod in the four tanks is shown by 3-week periods in Fig. 1. Differences in growth of the two groups are not consistent from tank to tank. The picture is affected by mortalities resulting in removals and replacements of fish (indicated in Fig. 1) which presumably had different growth potentials. However, some general conclusions may be drawn. In tanks No. 4 and 7 the untagged fish had accumulated more in length and weight than the tagged ones at the end of the respective holding periods. In these two tanks the rate of accumulation of length increments increased more steadily than that for weights. The data for tank No. 5, collected for only 21 weeks due to removal of untagged fish, did not show such a clear trend. Although in the initial period the untagged fish accumulated more in length and weight, these differences did not follow through. Subsequent accumulation of length increment remained the same for both groups, while at the end of the period total weight increments were almost equal. Fish in tank No. 6 gave results that were the reverse of those for tanks No. 4 and 7. Tagged fish showed considerably greater growth in length and weight than the untagged ones.

With such diversity of growth among the tanks, it seems evident that the differences cannot be attributed to the effects of tagging. The tagged fish

Table 1
Initial sizes, numbers and rates of feeding of tagged and untagged cod in tanks

Tank no.	Relative size of fish	Initial numbers and average sizes						Feeding rate (weight of herring consumed)
		Tagged			Untagged			
		No. fish	Length (mm)	Weight (oz)	No. fish	Length (mm)	Weight (oz)	
6	Small	4	361	19.3	13	348	14.7	Maximum (x)
5	Large	5	430	28.2	2	415	23.0	Maximum (y)
4	Small	7	360	15.8	9	355	16.1	Intermed. (0.72 x)
7	Large	3	414	27.2	4	407	25.6	Intermed. (0.82 y)

---

* Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B.

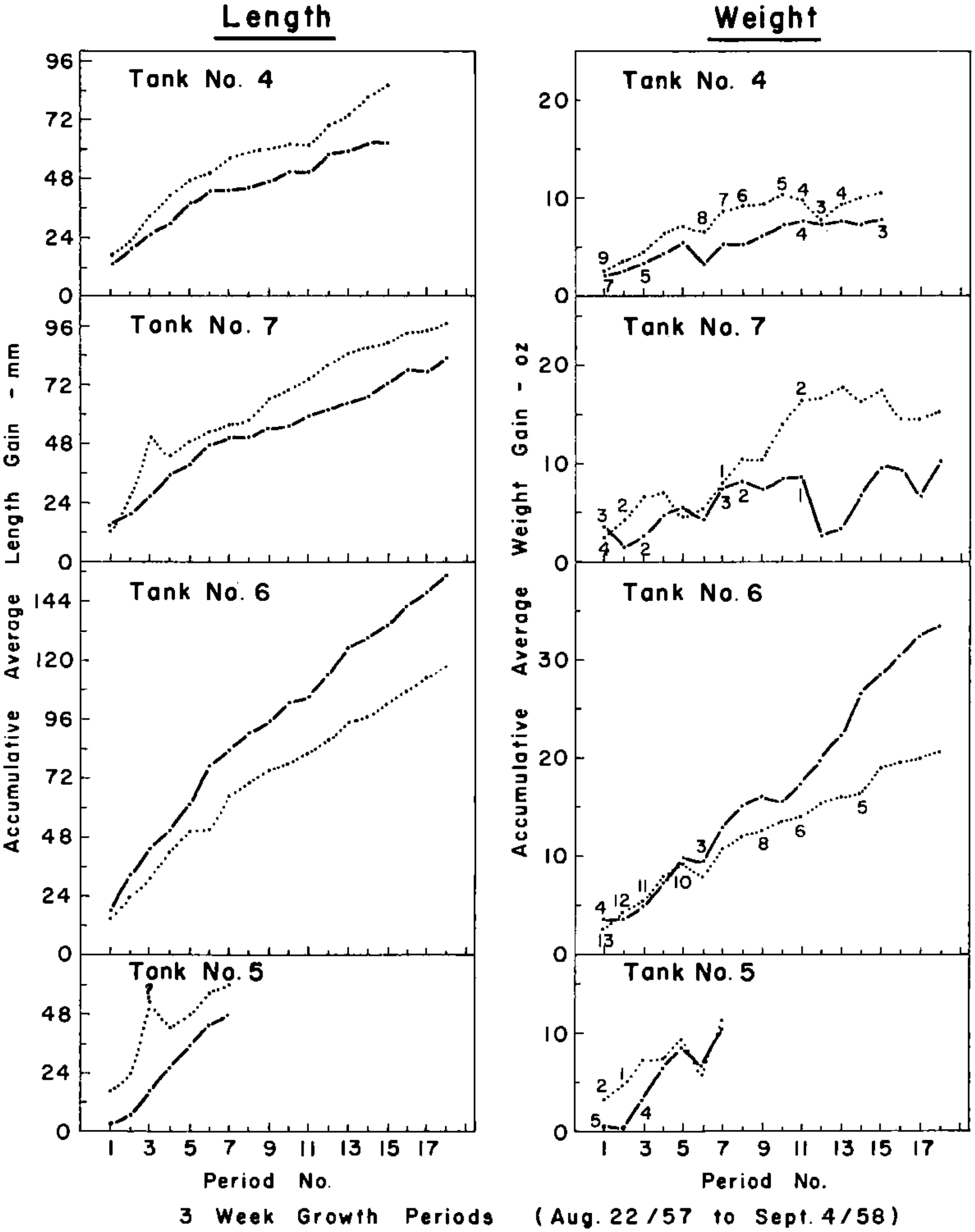


Figure 1. Growth of tagged (·—·—·—·) and untagged (.......) cod under controlled laboratory conditions. Changes in numbers of fish in tanks are shown in the right-hand series.

in all tanks grew well, and overall results for the experiment did not show consistent differences between the two groups. In small groups of cod, such as are compared here, the intrinsic growth potential no doubt differs greatly among the individuals concerned, and this is probably the main factor accounting for the differences in growth between groups.

Growth of Gulf of St. Lawrence Cod from Tagging Data

Data on growth variations as indicated by age-length sampling are available for Gulf of St. Lawrence cod (Kohler, 1961), and were compared with tagging growth data for the same species and area. Information from taggings carried out in 1955 and 1956 was examined. The 1955 tags were put on in the months of June to September, while the 1956 tags were applied during the months of June to August. Details of methods of tagging, types of tags and areas of recapture have been reported by McCracken (1959). Growth of individuals was estimated by comparing lengths in centimetres at tagging and recapture. Only measurements made by Fisheries Research Board personnel were used in this study, in order that no error would be introduced due to inconsistent measuring techniques. Because of seasonal variation in

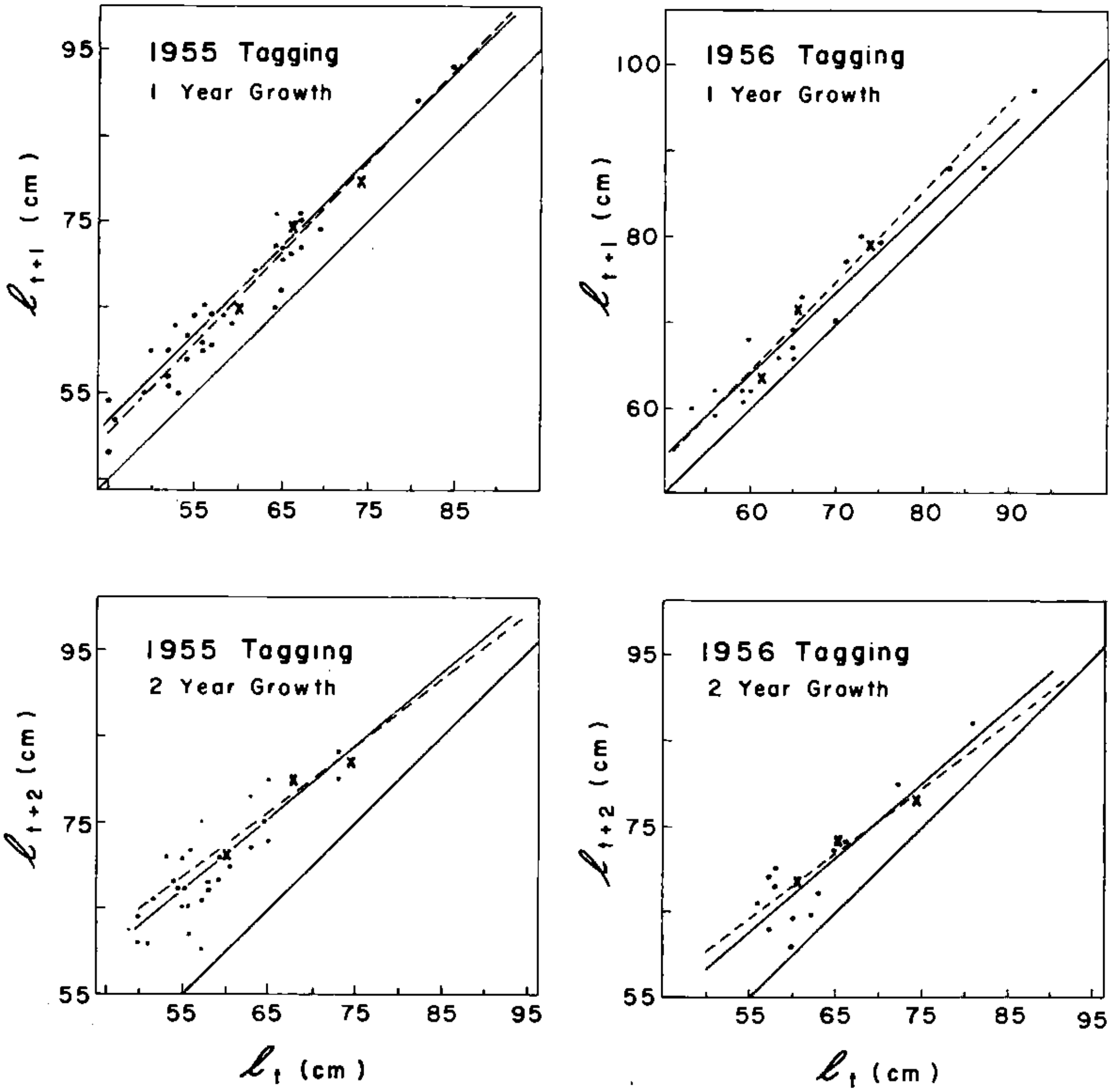


Figure 2. Growth of Gulf of St. Lawrence cod for one- and two-year periods. Dots and solid lines indicate tagging data; crosses and dashed lines indicate age-length data for corresponding ages and time intervals, ages 6—9 for 1 year growth and 6—10 for 2 year growth. The 45° diagonal from the origin, where $l_t = l_{t+1}$ or l_{t+2}, is also shown.

growth of cod, data for fish at liberty for 11 to 13 months and 23 to 25 months only were selected. These were taken to represent growth of cod at large for one- and two-year periods after tagging.

This information was then plotted in the form of four "Walford" (1946) graphs for recaptures of cod one and two years after the 1955 and 1956 taggings (Fig. 2). In the same graphs growth represented by mean lengths of year-classes from age-length data was plotted. These data were for ages (mostly 6—10 years), lengths and time intervals corresponding to those for the respective sets of tagging data. Since they are averages they occupy only the middle portion of the range of lengths covered by the individual specimens in the tagging data. They were taken from commercial age-length sampling data previously analysed in Table 2 of Kohler, 1961 (p. 23). In order to facilitate comparison of growth data from the two sources, straight-line "Walford" transformations were fitted to the data by the least squares method. Values for constants in equations (1) and (2) shown below for growth over one- and two-year periods are recorded in Table 2. The resulting lines were plotted in the appropriate graphs in Fig. 2.

Where l_t = length (in cm) at age "t"
and l_{t+1} = length (in cm) at age "t + 1"
and l_{t+2} = length (in cm) at age "t + 2"
$l_{t+1} = al_t + b$ (1)
$l_{t+2} = a'l_t + b'$ (2)

Table 2

Values for constants of Walford transformations and Bertalanffy growth curves for Division 4 T cod, from tagging and age-length data

Growth interval	Type of data	a	b	K	L_∞
1955—56	Tagging	1.01	5.8	—0.01	—582
(1 year)	Age-length	1.04	3.5	—0.04	— 88
1956—57	Tagging	0.96	6.6	0.04	164
(1 year)	Age-length	1.03	2.9	—0.03	— 98
		a′	b′	K	L_∞
1955—57	Tagging	0.84	20.7	0.17	129
(2 year)	Age-length	0.76	26.6	0.28	111
1956—58	Tagging	0.87	14.9	0.14	114
(2 year)	Age-length	0.77	21.7	0.26	94

Examination of the data points and fitted lines in the four graphs indicated good agreement between tagging and age-length data, especially where the data points were concentrated. Such a comparison has previously been used for validating growth from haddock age determinations (Kohler, 1958), and has been mentioned by Ricker (1958, p. 199) as being useful in determining the confidence to be placed in either method for determining growth.

Growth variations already demonstrated from age-length data and by measurements of growth rings in otoliths (Kohler, 1961) also appear in the tagging data. In order to demonstrate this point the same fitted lines shown in Fig. 2 were re-plotted in Fig. 3 in two graphs showing one- and two-year growth of cod, respectively. In the top graph, representing increments for one year, the 1955—56 period is seen to be above the 1956—57 period. The bottom graph shows two years of growth, and it is obvious that the 1955—57 average increments

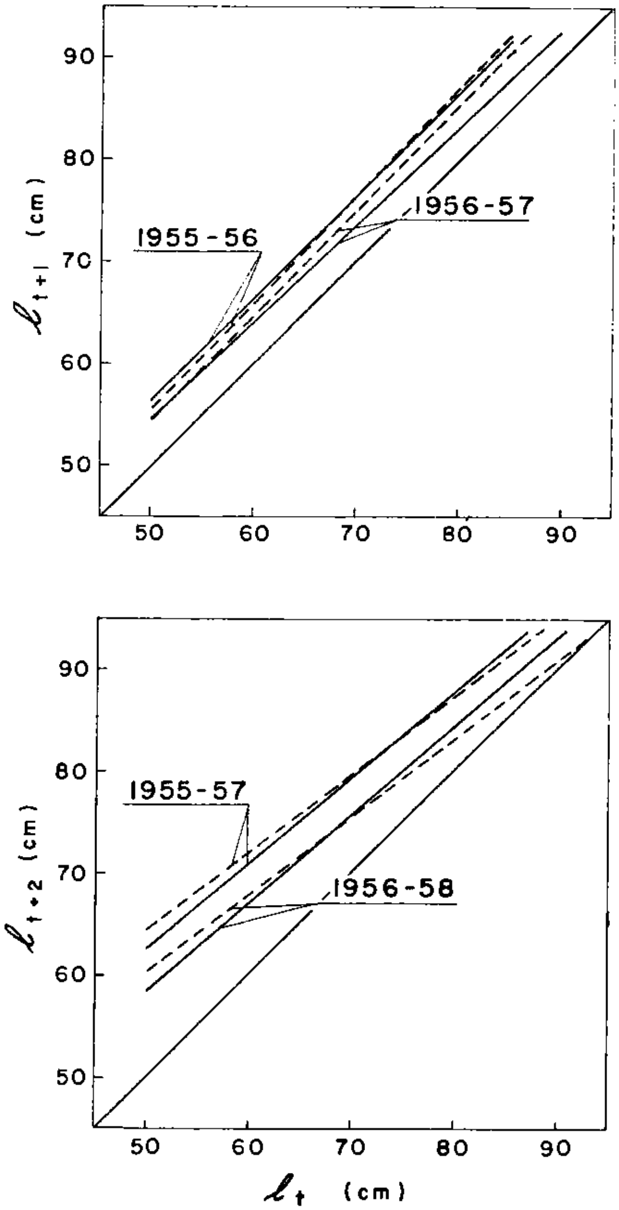


Figure 3. Comparison of tagging and age-length lines for various sampling years and time intervals. Lines are those fitted to data shown in Figure 2. Tagging lines are solid and age-length lines are dashed. The 45° diagonals from the origin are included.

were much higher, as shown by both tagging and age-length data, than those for 1956—58.

In this connection K's and L ∞'s of the Bertalanffy growth equation were calculated (Table 2) as suggested by Beverton and Holt (1959) in order to examine variations in their values corresponding to those found in the Walford plots (Figs. 2 and 3). One complicating factor here is that the data are for growth of fish in the middle of the size and age range of the population. Hence calculations for three of the four one-year growth periods give minus values for K and L ∞, indicating that the inflection point in growth has not been passed. However, in these cases, the value "a" from the Walford transformation and from which K is calculated is so close to 1.0 that relatively small variations in the data would serve to change K from a plus to a minus value.

The values of K and L ∞ for two years of growth are all positive and allow for comparison among themselves. It has already been demonstrated (Fig. 3) that tagging and age-length data agree in showing greater length increments in the 1955—57 period than in the 1956—58 period. However, upon referring to Table 2 this difference is not evident in data for K and L ∞ values. In fact K values for tagging for the two periods are numerically closer than K values for tagging and age-length data for either single period, and the same applies for L ∞ values. Thus in these cases where both values for rate of approach (K) to L ∞ and asymptotic length (L ∞) change, it is difficult to compare year-to-year changes in growth by comparing the two parameters. No doubt the availability of more information in the size range closer to L ∞ would clear up some of the anomalies, as such data would give better estimates of K and L ∞ for the later years of life of the fish.

Discussion

The study indicates that tagging growth data are useful for growth estimations. Because of the effort and expense in planning and following up a tagging experiment this is not an economically feasible way of following growth of cod from year to year. However, when these experiments are being performed for other reasons, the fringe benefit provided by accumulation of growth data is considerable. In these cases the information is useful as a general indicator of growth rate at the particular time. More important than this is the use of these data for corroborating and supplementing the information accumulated from sampling cod for lengths and ages.

Summary

Comparable data on growth of tagged and untagged cod, available as a by-product of a controlled growth and feeding experiment in the laboratory, were analysed. Differences in a year's growth between groups of tagged and untagged fish were inconsistent and could not be shown to be due to tagging.

An analysis of growth data from cod taggings in the Gulf of St. Lawrence in 1955 and 1956 was carried out to determine the usefulness of such data in cod growth studies. Four sets of data, two for fish recaptured after one year and two for fish recaptured after two years, were examined. "Walford" transformations fitted to the tagging growth data and to corresponding commercial age-length data showed good agreement. Indications of year-to-year fluctuations in growth of Gulf cod noted in previous growth studies were confirmed by the analysis of growth of tagged fish.

Use of sporadic returns of tagging growth data was considered to be impractical for routine following of yearly growth variations in Subarea 4 cod populations. However, growth data from tagging were demonstrated to be useful when available for corroborating and supplementing cod growth information obtained from sampling lengths and otoliths.

Acknowledgements

Dr. L. M. Dickie, Dr. J. L. Hart and Dr. W. R. Martin reviewed the manuscript and made suggestions for improvement. Their very useful criticisms were greatly appreciated. Thanks are due to a number of individuals who have contributed to the tagging program. These include Dr. F. D. McCracken who has guided the program as a whole, Messrs. P. M. Powles and C. J. Bayers who carried out the 1955—56 tagging in the Gulf of St. Lawrence, Mr. D. N. Fitzgerald who made special efforts to collect returns and Mrs. C. R. Garnett who was responsible for processing returns. The co-operation of fishermen and fish plant personnel in returning tags and recapture information is also gratefully acknowledged.

References

BEVERTON, R. J. H. and S. J. HOLT. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Foundation Colloquia on Ageing. Vol. 5. The lifespan of animals, edited by G. E. W. Wolstenholme and M. O.'Connor, 142—77, J. & A. Churchill, Ltd. Lond.

KOHLER, A. C. 1958. The validity of otolith age determinations for haddock (*Melanogrammus aeglefinus* L.) from the Lockeport, N. S. area. *J. Fish. Res. Bd Can.*, **15**: 1229—38.

KOHLER A. C. 1959. Growth and parasites of cod during a year in captivity. *Progr. Rep. Atl. Cst. Sta.*, No. 72: 3—7

KOHLER, A. C. 1961. Variations in the growth of Atlantic cod (*Gadus morhua* L.). McGill Univ. Thesis, 106 pp.

LINDNER, M. J. 1953. Estimation of growth rate in animals by marking experiments. *Fish. Bull.*, U. S., **54**: 65—69.

McCRACKEN, F. D. 1959. Cod tagging off northern New Brunswick in 1955 and 1956. *Progr. Rep. Atl. Cst. Sta.*, No. 72: 8—19.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd Can.*, No. 119.

WALFORD, L. A. 1946. A new graphic method of describing the growth of animals. *Biol. Bull., Woods Hole*, **90**: 141—47.

13.

Estimation of Mortality Rates of Gulf of St. Lawrence Cod from Results of a Tagging Experiment

By

L. M. DICKIE*

It is notoriously difficult to obtain reliable estimates of fishing and natural mortality rates solely on the basis of catch and effort statistics. Similarly, while returns from tag releases reflect the effects of these mortality rates, tagged fish are liable to losses of other sorts as well. In certain circumstances, however, combinations of fisheries statistics and tag returns may be used to improve the quality of mortality estimates obtained from either source alone. This paper describes a set of returns of cod captured and tagged by various means and released in two consecutive years. Comparison between rates of return of various releases over a period of several years yields an estimate of the relative proportions of initial losses and non-reporting, termed by Ricker (1958) the Type A errors. Further comparisons of the tag returns with each other and with the fishing effort also permit estimation of the sustained tagging mortality and tag loss rates, termed Type B errors, as well as improved estimates of the fishing and natural mortality rates.

The Tag Experiments

Tagged cod were released in the northern Gulf of St. Lawrence during the summers of 1955 and 1956. Two types of tags, Petersen yellow disks and Lea hydrostatic tags, were used, both attached through the dorsal musculature with stainless steel wire. In 1955 the cod for tagging were all captured by handlines. In 1956 both handlines and otter trawls were used. The total numbers of cod caught, tagged and released by the various methods are described in Table 1.

Table 1
Numbers of fish tagged by each method in the 1955 and 1956 experiments

Year	Tag used	Originally handline (HL)	captured by otter trawl (OT)	Total tagged
1955	Petersen yellow disk (YD)	2,638	—	3,846
	Lea hydrostatic (LH)	1,208	—	
1956	Petersen yellow disk (YD)	483	917	1,992
	Lea hydrostatic (LH)	—	592	

Further details of the catching, handling and tagging procedures and the types of tags used are given by McCracken (this Symposium, no. 16). Tags have been returned in each year since release. Canadian returns are from recaptures in the summer, autumn and early winter by both hook-and-line fishing and by small otter trawlers fishing in the northern part of ICNAF Division 4 T. French, Italian, Portuguese and Spanish returns are from recaptures in the spring by large otter trawlers fishing in southern 4 T and 4 Vn (McCracken, 1959). Research-boat surveys confirm that this distribution of the fleets represents effort devoted to fishing on a migratory stock when it is concentrated at the northern and southern ends of its migration route, rather than on the fringes of a population distributed over a wide area (Y.M.L. Jean, personal communication). In the following account, therefore, it has been assumed that, despite differences in season and area, the tags returned by various fishery components represent recaptures from fishing on a single stock of fish.

McCracken (contr. no. 16) notes that there are differences in the percentage returns among countries, sizes tagged, tag types, original methods of capture, gear used for recapture, and between years of release and recapture. In the following account adjustments are first made for apparent differences in the relative efficiency of returns among countries. There is no significant difference in apparent total mortality rate among sizes, so the returns are combined over all sizes. The remaining differences are utilized to establish the relative magnitudes of Type A and B errors and to calculate the fishing mortality rates, except that no attempt is made to partition these mortality rates between types of fishing gear because this aspect of the return information is incomplete. Fishing mortality rates are calculated by quarters of the year* using a method suggested by Paloheimo (1958).

---

* Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B.

* Throughout this report quarters of the year are calculated starting with February 1 rather than January 1. Thus February + March + April = quarter I; May + June + July = quarter II; August + September + October = quarter III; November + December + January of following calendar year = quarter IV

Table 2

Landings and tags returned from the 1955 and 1956 Gulf of St. Lawrence cod tagging experiments by countries, and the ratios of tags returned per '000 metric tons landed, together with a comparison of these ratios for European fishermen with the ratio for Canadian fishermen

Returns in:	1956				1957				1958				
Country	Cod landings*	Released in 1955	1956	No. returns/ landings	Cod landings*	Released in 1955	1956	No. returns/ landings	Cod landings*	Released in 1955	1956	No. returns/ landings	Average
Canada	62.4	392	not included	6.28	67.3	276	209	7.21	57.2	168	104	4.76	
France	28.0	32		1.14	8.4	2	4	0.71	12.0	5	6	0.92	
Portugal	5.8	29	—	5.00	2.8	13	10	8.21	2.9	8	7	5.17	
Spain	8.1	15	—	1.85	10.4	10	18	2.69	14.4	8	4	0.83	
Ratios													
Canada/France ...				5.51				10.2				5.17	6.94
Canada/Portugal .				1.26				0.88				0.92	1.02
Canada/Spain				3.39				2.68				5.73	3.93

* Landings are given in thousands of metric tons, round fresh weight. For Canada they are total landings for Division 4T for the year; for European countries they are annual landings for 4T plus landings from 4V for the months of February, March and April.

Corrections for Differences in the Relative Rate of Returns among Countries

In Table 2 are set out the annual tag returns for 1956, 1957 and 1958 by Canada, France, Portugal and Spain, from each year's tagging, together with the total catch of cod made by each country in the same year and area. We make the reasonable assumption that during the migrations following tagging, tagged cod mixed with the untagged population. If this is true then in any year the proportion of tags recaptured to total cod caught should be the same for all countries, and if the same proportion of recaptured tags is recovered from the catch and returned, the ratio of returns to total cod caught should also be the same. The latter ratios are therefore calculated and the results for each of the European countries compared with the ratios for Canada as a standard.

Experience with the returns of tag releases from many experiments does not always inspire confidence in our ability to get a complete record of the recaptures. However, widespread publicity, relatively high rewards and frequent contacts between official collectors and fishermen have given remarkably high percentage returns from some Canadian tag experiments (McCracken, contr. no. 16, for Lockeport taggings), suggesting that the numbers of recaptures which are not returned must be a small fraction of the total. During the period of these experiments Portugal has also made special efforts to increase the return of tags. The relative success of the publicity and collection by both these countries is therefore confirmed by the fact that during the period 1956 through 1958, when the bulk of the returns were made, the average ratio of tags returned to total cod captured was the same for Canada and Portugal. The table shows, however, that the ratio for Canada and Portugal is four times that for Spain and seven times that for France. Few tags were returned by Italy, and landings have not yet been reported in the same detail as for other countries, so that data for Italy were not included in the table. It is concluded that a high proportion of the tag recaptures by France, Italy and Spain are not returned.

On the basis of the above comparisons, the numbers of tags returned by Spain have been multiplied by four and those returned by France and Italy have been multiplied by seven. Their adjusted returns have been added to actual numbers returned by Portuguese and Canadian fishermen as a first estimate of total recaptures. These adjusted returns have been used throughout the remainder of the paper.

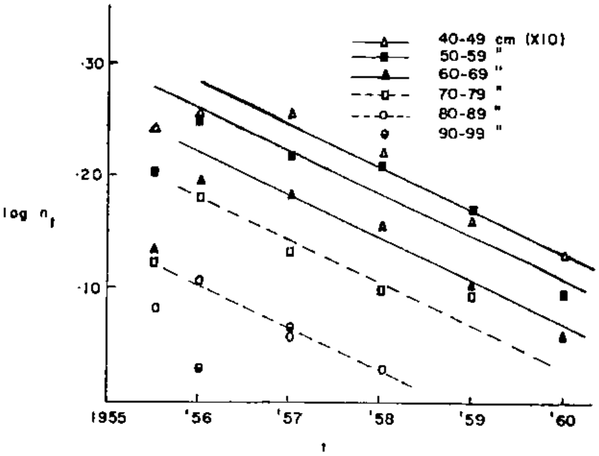


Figure 1. Logarithm of annual returns of the 1955 Petersen yellow disk tagged cod, in 10-cm length classes.

Effects of Size at Tagging on Returns

The lengths of the tagged cod ranged from 30 to 130 cm. However, the proportion of different sizes tagged and released was approximately the same as their occurrence in the catches. As a result, the bulk of released fish were between 40 and 80 cm. The logarithm of the adjusted returns of each 10-cm length group was plotted against year of recovery. The slopes of lines joining the logarithm of successive annual returns give estimates of total mortality rate by length groups (Ricker, 1958).

Figure 1 shows the slopes for the 1955 Petersen disk tag returns and illustrates a feature common to returns from each tagged group: slopes for the different sizes in each tagged group are the same. We conclude that there are no detectable trends in the apparent total mortality rates with size. McCracken noted some differences in percentage returns by size-group and we might *a priori* expect to find that different sizes of fish were not equally vulnerable to capture. However, on the basis of the results of this experiment, we can only conclude that numbers of returns are too small, compared with the normal variations in rates of return, to permit a meaningful study of such differences by size. In the subsequent analysis we have treated tagged cod of all sizes as equally vulnerable to mortalities.

Methods of Analysis

Beverton and Holt (1957) and Ricker (1958) review earlier methods available for analysis of tag returns. They point out several sources of variations in the rate of recapture and return of tags and how these may be expected to affect estimates of the mortality rates. Following their lead we may rewrite the basic catch equation in the form

$$n_t = PRN_t \frac{F}{F+X} (1-e^{-(F+X)t}) \qquad (1)$$

where n_t = the numbers of tagged fish returned during time t

N_t = the number of tagged fish present at the beginning of time t

F = instantaneous rate of fishing during time t

= qf, where f = effective fishing effort
q = catchability coefficient

X = instantaneous rate of non-fishing mortality during time t

= $M + M'$ where M = instantaneous rate of natural mortality during time t

M' = instantaneous rate of extra "natural" mortality of tagged fish from deaths or loss of tags during time t

($Z = F + X$ = the apparent total mortality rate of tagged fish)

e = base of natural logarithms

R = the fraction of the tagged fish which survive or retain their tags up to the beginning of time $t = 0$

P = the fraction of total recaptures during time t which are returned.

Ricker (1958) classes the product PR in this equation as Type A error, and points out that it affects the estimate of fishing mortality rate but not of the total mortality rate. The term M′ is classed by Ricker as Type B error, which, by adding to M, affects the estimate of the total mortality. Various methods for estimating the magnitude of these errors have been suggested.

Considering Type A errors first, it is apparent that if two groups of tags or types of tags are at large at the same time we may write the catch equation for the larger group of releases and returns in logarithmic form as follows:

$$\begin{aligned} \log n_t &= \log PR + \log N_t \\ &\quad + \log \frac{F}{F+M} (1-e^{-(F+M)t}) \\ &= \log PR + \log N_t + \log A. \end{aligned}$$

Similarly for the smaller group of releases and returns we may write

$$\log n_t = \log P'R' + \log N'_t + \log A.$$

If the sustained total mortality rates from these two groups are the same, then by subtraction we obtain

$$\log n_t - \log n'_t = \log PR - \log P'R' + \log N_t - \log N'_t \qquad (2)$$

That is, the difference in the position of parallel lines drawn through logarithms of returns of two groups of tags reflects the difference in numbers tagged initially, and the difference in the magnitudes of the Type A errors. If the product PR is assumed equal to unity we obtain from equation (2) a value for $-\log P'R'$ which is a measure of the relative Type A error for the second group of tags. If tag experiments are appropriately designed, various combinations of tag types and procedures may be made to yield information on the magnitudes of the Type A errors.

Estimation of the magnitudes of Type B errors may also be made by comparing returns from various tagged groups with each other and with the amount of fishing effort, using a method of analysis suggested by Paloheimo (1958). Disregarding Type A errors for purposes of exposition, and putting $t = 1$, we may note with Paloheimo that if the exponential term $e^{-(F+X)}$ of equation (1) be expanded as a power series, then by retaining terms to the second order only we obtain the approximation

$$n = FN\left(1 - \frac{F+X}{2}\right)$$

from which $F = \frac{n}{N} \div \left(1 - \frac{F+X}{2}\right)$ (3)

If the period t is chosen to be rather short, $\frac{F+X}{2}$ is small and F differs little from $\frac{n}{N}$. In such a case we may rewrite equation (3) as

$$F = \frac{n}{N} \div \left(1 - \frac{\frac{n}{N} + X}{2}\right) \qquad (4)$$

From the data on hand it appears that these conditions for the use of equation (4) may be met if instead of setting t equal to periods of a year, we deal with tag returns by quarters of the year. In the analysis presented below we have therefore calculated several sets of F_t, using observed quarterly n_t, but assuming different quarterly values for X_t and employing different values of initial $N_t = PR\,N_o$, where N_o is the number of fish tagged and values are assigned to PR from the consideration of relative Type A errors.

Calculations of this sort result in various sets of F_t for a given set of n_t, depending on the magnitude of both Type A and B errors which have been used. A choice of appropriate Type A and B errors may then be made by noting that $F_t = qf_t$ and calculating the correlation coefficients between F_t and f_t, assuming constancy of q.

Changes in the value of the correlation coefficient are not a sensitive test of the different hypotheses of errors, particularly when these are underestimates. This follows from the fact that successive values of F_t in any set are related rather than independent. The effect of a change in the relative size of N_t at the beginning of the set thus tends to be accelerated uniformly throughout the set. Underestimates of the error terms result in estimates of initial N_t which are large relative to n_t. They therefore have little influence on the size of the F_t, hence its correlation with f_t. However, if returns are available over a sufficiently long period for the tagged population to be significantly reduced, small changes in the parameters give rise to large changes in the F_t calculated from the later returns. Errors in the selection of values for the Type A and Type B errors will then become rapidly magnified in the calculated F_t and lead to a rapid lowering of its correlation with f_t.

Given an increasing arithmetic series of possible values for the correction terms, it is evident that if the other assumptions are reasonably well met the correlation coefficients will change little for the initial values of the series, up to and including the "best" values. Beyond this, however, larger values for the correction terms will lead to rapidly decreasing correlations. The "best" values will then be those immediately preceding the set which results in a marked fall in the correlation coefficient. In some cases it may be advisable to use only parts of the sets of F_t and f_t to detect the interval of correction terms first leading to a marked decrease in the correlation. In the following analyses, however, most of each set of F_t has been used.

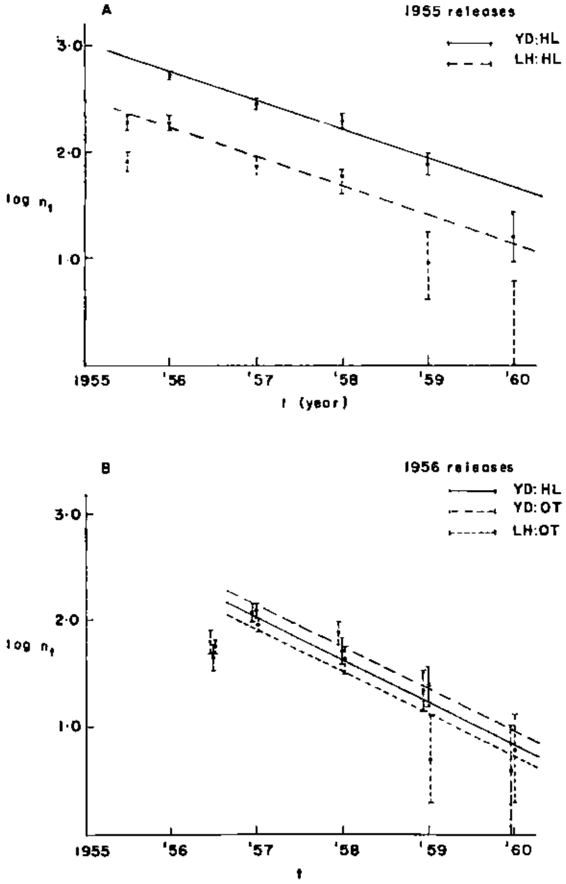


Figure 2. Logarithm of annual recoveries from tag releases in 1955 (A), and 1956 (B), with 95% confidence limits from Poisson frequency distribution. Lines have been fitted by eye.

Results

Apparent total mortality rates

The logarithms of the annual (adjusted) recoveries from the two groups of tags released in 1955 — Petersen yellow disks on cod caught by handlines (YD:HL), and Lea hydrostatic tags on cod caught by handline (LH:HL) — are plotted in Fig. 2A. Logarithms of annual recoveries of the three groups released in 1956 — YD:HL, YD:OT and LH:OT — are plotted in Fig. 2B. The numbers of tagged fish in commercial catches may reasonably be considered to follow the Poisson distribution. We have therefore calculated approximate 95% Poisson limits for the annual recoveries as suggested by Ricker (1937); these limits are also shown in Fig. 2. Straight lines have then been fitted by eye to the logarithms of successive annual returns of each tag group. Disregarding returns during the year of release, the line fitted to the 1955 YD:HL lies within the confidence limits for the first four years' returns, and a parallel line fitted to the LH:HL falls within the confidence limits for the first three years' returns. It appears that for this period there is no reason to reject the hypothesis that average annual total mortality rates for the two groups were constant and the same, although there appears to have been a subsequent decrease. The period of constancy fulfills the conditions required by equation (2) for estimating the relative magnitude of the Type A errors. A similar conclusion may be drawn for the slopes of lines through the logarithms of recoveries of the three 1956 tag groups, although in this case an hypothesis of uniform total mortality could be used to describe returns in all years following the season of tagging.

In both years' taggings the points describing 1958 returns are above the average total mortality lines, while those for 1959 and 1960 are all below them. This suggests that annual mortalities are not actually uniform, although the differences are so small that the annual returns could not be used to establish the source of the mortality difference. The similarity in pattern for the two years' experiments suggests that it may reflect changes in the rate of fishing from year to year. More striking, however, is the major difference in the apparent total mortality rate (slopes) in the releases in the two years, suggesting Type B errors. The possibility of these types of variation is examined in more detail below, making use of the fact that there have been greater differences in the seasonal than in the annual fishing effort.

Type A errors

Since total mortalities within releases of the same year are the same, the relative magnitude of Type A errors may be examined by comparing differences in positions of lines between the groups, using equation (2). Table 3 summarizes for the 1955 release the data on actual numbers released and the calculated numbers returned, based on the position of the total mortality lines in 1958 (Fig. 2A)

Table 3
Summary of data for 1955 releases

Group tagged	N_0	log N_0	Calc. $^{n}t_3$	log $^{n}t_3$	—log P'R'	P'R'
1955: YD:HL	2,638	3.42	166	2.22		
LH:HL	1,208	3.08	48	1.68		
Difference		0.34		0.54	0.20	0.63

According to equation (2), if PR = 1 then

$$\begin{aligned} -\log P'R' &= \log n_{t_3} - \log n'_{t_3} - (\log N_o - \log N'_o) \\ &= 0.54 - 0.34 \\ &= 0.20 \end{aligned}$$

from which P'R' = 0.63.

That is, correcting the 1955 returns for the difference in initial numbers tagged, the LH:HL tags were returned only 63% as commonly as the YD:HL. This difference may be compounded of differences in relative initial survival rate and relative efficiency of return.

The 1956 returns may be similarly compared. However, in that year some of the tagged cod released were YD:HL, while the remaining two groups were caught by otter trawls, YD:OT and LH:OT. The comparison between the YD and LH returns cannot therefore be made until a correction is introduced for the difference in method of original capture. This may be accomplished by comparing returns of 1956 YD:HL and YD:OT, as in Table 4.

Table 4
Summary of data for 1956 releases

Group tagged	N_0	log N_0	Cal. $^{n}t_2$	log $^{n}t_2$	—log R	R	Adjusted log n_{t_2}	Adjusted n_{t_2}
1956								
YD:OT	917	2.96	57.5	1.77			1.92	83.2
YD:HL	483	2.68	43.7	1.64			1.64	43.7
Difference		0.28		0.13	0.15	0.71		126.9

Since the type of tags in this comparison is the same, it is evident that all tags should be equally visible. Therefore, in the product PR the efficiency of returns of the recaptures (P) must be the same. The whole difference in rates of returns must be due solely to differences in initial survival. Substituting in equation (2), therefore, we have

$$
\begin{aligned}
\log R - \log R' &= \log n_t - \log n' - (\log N_t - \log N_t') \\
&= 0.13 - 0.28 \\
&= -0.15.
\end{aligned}
$$

Putting $R' = 1$ we then have

$$
\begin{aligned}
-\log R &= 0.15 \\
R &= 0.71.
\end{aligned}
$$

That is, initial survival of otter-trawl-caught fish was only 71% of that of handline-caught fish.

To compare YD with LH returns for 1956 in the same manner as in 1955, it is therefore necessary to increase the known returns of otter-trawl-caught fish by $(100-71)/71 = 41\%$. This is shown for the YD:OT tags in Table 4. Correcting the LH:OT tags similarly, we may compare the 1956 returns of YD and LH tags (Table 5).

Table 5

Further comparison of data for 1956 releases

Group tagged	N_0	log N_0	Cal. n_{t_2}	Adjusted n_{t2}	log Adjusted n_{t2}	—log P'R'	P'R'
1956							
YD:HL+OT	1,400	3.15	109.6	126.9	2.10		
LH:OT	592	2.77	32.4	45.7	1.66		
Difference		0.38			0.44	0.06	0.85

From equation (2), putting $PR = 1$, we again have

$$
\begin{aligned}
-\log P'R' &= 0.44 - 0.38 = 0.06 \\
P'R' &\approx 0.85
\end{aligned}
$$

That is, the Lea hydrostatic (LH) tags of the 1956 release were returned only 85% as commonly as the Petersen yellow disks (YD).

In none of the above comparisons is it possible to calculate actual values for Type A error terms. However, from the relative values derived from comparing various groups of releases we may make an approach to separating the product PR into its components, thereby arriving at estimates of the order of magnitude of errors from different sources, as well as their minimum actual values. Thus, in the 1956 comparison it was found that the method of capture was of major significance, otter-trawl capture reducing returns to only 70% of those from handline capture. In the second 1956 comparison, changing tag type gave relative returns of LH tags which were only 85% of the YD, apparently due to lowered efficiency of returning the recaptures. The 1955 and 1956 tags were of the same type and indistinguishable to fishermen. The component of P'R' due to non-return of recaptures must therefore have been the same for both releases. Setting $R' = 1$ for the 1956 releases, we have a maximum estimate of relative P' for LH tags of 0.85 which should apply equally to 1955 and 1956 releases. Applying this to the relative P'R' for 1955 releases we have $(-\log P'R')_{1955} - (-\log P')_{1956} = (-\log R')_{1955} = 0.13$ whence $R'_{1955} = 0.74$. That is, initial survival of LH tags in 1955 was at most only 75% of the initial survival rate of the YD tags treated in the same way. We have no information to suggest why there should have been such a difference but it is significant that the order of attachment of the two types of tags was not randomized in the release, a higher proportion of the LH tags being applied at the beginning of the release (June), and YD alone being used during September at the end of the tagging. It is possibly significant for future experiments that this difference is associated with an effect on returns comparable to that from changing the method of capture in the 1956 experiments.

The positions of the total mortality lines on which the above comparisons are based were not accurately determined. The actual values used in the above comparisons are thus subject to errors, of which we have no good measure. However, the results do give several estimates of the order of magnitude of components of the Type A errors. They may therefore be used to provide trial values of the product PR or P'R' in the subsequent analyses.

Type B errors

The slopes of the logarithms for annual recoveries for the 1955 and 1956 releases, shown in Fig. 2, are different. They suggest total mortalities of

$$
\begin{aligned}
Z_{1955} &= 0.65 \\
Z_{1956} &= 0.90.
\end{aligned}
$$

Since the tag releases were apparently mixed in the same population, it is reasonable to suppose that the true natural mortality rate was very nearly the same. A major share of the difference in apparent total mortality may therefore be due to Type B errors.

In assessing the possible importance of this error we have used the method of Paloheimo (equation (4)) to calculate quarterly F_t from the quarterly tag recoveries, assuming first of all that there were no Type A errors; that is, we have used the uncorrected N_0 in the calculations. Various values of annual X have been assumed, distributed evenly among quarters. The results of the calculations are given in Table 6 for three values of annual X: 0.15; 0.30; 0.45; for 1955; and 0.30; 0.45; 0.60; for 1956. The resulting series of F_t have then been compared with estimates of the quarterly fishing effort, f_t, which is shown in the last column of Table 6.

Catch per unit effort data for the Gulf of St. Lawrence cod fishery are available from unpublished records of the Biological Station, St. Andrews, N. B. For the small Canadian otter trawlers (26—50 GT)

Table 6

Fishing mortality rate calculated from tag returns for 1955 and 1956 releases, assuming different rates of non-fishing mortality (X) but no initial tagging mortality, and complete reporting of recaptured fish; together with relative fishing effort for the same period

Quarters	1955 releases							1956 releases							Calculated fishing effort
	N_t Calculated number of tagged fish at beginning of each time t, (N_t) when N_0 (YD:HL) = 2,638 N_0 (LH:HL) = 1,208			n_t No. of returns	$F_t = \frac{n_t}{N_t} \div \left(1-\frac{\frac{n_t}{N_t}+X_t}{2}\right)$			N_t Calculated number of tagged fish at beginning of each time t, (N_t) when N_0 (YD:HL) = 483 N_0 (YD:OT) = 917 N_0 (LH:OT) = 592			n_t No. of returns	$F_t = \frac{n_t}{N_t} \div \left(1-\frac{\frac{n_t}{N_t}+X_t}{2}\right)$			
	P'R' = 1.00 X = 0.15	1.00 0.30	1.00 0.45		0.15	0.30	0.45	P'R' = 1.00 X = 0.30	1.00 0.45	1.00 0.60		0.30	0.45	0.60	
1955															
IV	3600	3346	3220	47	0.013	0.015	0.016								3.1
1956															
I	3421	3059	2833	371	0.117	0.134	0.149								40.4
II	2932	2483	2180	162	0.058	0.070	0.082								26.2
III	2665	2148	1795	183	0.073	0.093	0.114								21.2
IV	2387	1815	1463	31	0.013	0.018	0.023	1692	1620	1386	21	0.013	0.014	0.017	4.2
1957															
I	2269	1654	1278	79	0.036	0.051	0.068	1550	1429	1173	117	0.082	0.091	0.114	19.4
II	2108	1458	1068	132	0.066	0.099	0.140	1325	1167	901	89	0.072	0.084	0.113	22.7
III	1902	1225	829	119	0.066	0.106	0.165	1144	958	693	100	0.095	0.117	0.169	24.3
IV	1716	1071	628	22	0.013	0.022	0.038	965	762	504	15	0.016	0.021	0.033	11.0
1958															
I	1631	972	541	95	0.061	0.107	0.206	881	667	420	74	0.091	0.125	0.211	28.5
II	1478	810	397	91	0.065	0.124	0.276	746	526	293	56	0.081	0.120	0.230	29.2
III	1335	664	269	61	0.048	0.100	0.274	638	417	200	36	0.060	0.096	0.216	21.2
IV	1226	557	183	3	0.002	0.006	0.018	557	339	139	3	0.006	0.009	0.024	3.6
1959															
I	1178	514	161	27	0.024	0.056	0.195	514	300	95	22	0.045	0.081	0.286	65.0
II	1108	451	118	33	0.031	0.079	0.348	455	247	61	12	0.028	0.053	0.238	22.9
III	1035	387	74	22	0.022	0.061	0.374	411	209	41	8	0.020	0.041	0.236	19.4
IV	975	338	46	3	0.003	0.009	0.072	374	179	28	9	0.025	0.055	0.421	3.0

fishing in northern 4 T they give catch per unit effort in terms of total cod catch per trip. Catch per trip is used in this paper rather than catch per hour (which is also available) since it is available for a rather larger sample of the fishing fleet, and during the period considered it appears that there has been no significant change in the length of time fished per trip nor in the seasonal distribution of the fishing effort. The European fleet fishes the same stock of fish, but at a different time and place, and no comparative fishing studies have yet been made. Therefore, it has been further assumed that European catch per unit effort in the first quarter was the same as average c/f for the Canadian small otter trawlers during the preceding three quarters. Total effort by quarters has been calculated by dividing these indices of quarterly c/f into total quarterly cod landings reported in the ICNAF Statistical Bulletins for the same areas and periods.

Figure 3 shows the plot of quarterly F_t for total 1955 tag returns against f_t, assuming annual X = 0.30.

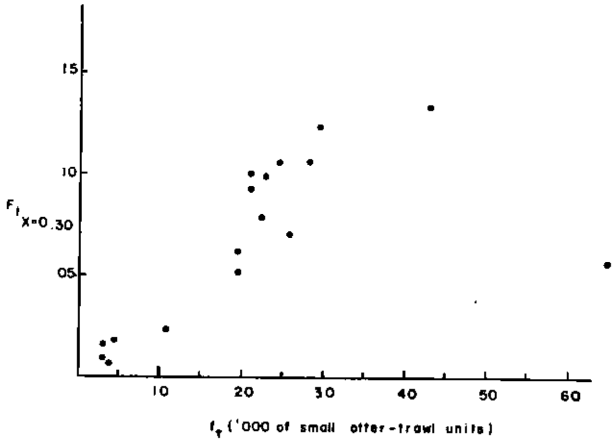


Figure 3. Relation between quarterly fishing mortality rate, F_t, calculated from returns of tags released in 1955, assuming the sustained non-fishing mortality (X) = 0.30, but no Type A errors, and effort, f_t, calculated from records of catch per unit effort and total quarterly landings by small Canadian otter trawlers.

One point falls down and to the right of the general array. This point represents the tag returns and the effort calculated for the European fleet during the first quarter of 1959, and occurs in approximately this position for plots of returns from both the 1955 and 1956 tag releases.

During the first quarter of 1959 ice conditions in the Gulf of St. Lawrence prevented the fleet from fishing on the stock in 4 Vn and southern 4 T until later in that year than was usual for them. It appears quite possible, therefore, that although their total catch was high, the change in conditions resulted in much of their fishing effort being devoted to a different stock than formerly. In our comparisons of F_t and f_t for various values of X, it was found that changes in the position of this point alone contributed a major share to variations in the magnitude of the correlation coefficients. It was therefore decided that the effects of changing the X were more faithfully reflected by the correlation coefficients if this possibly aberrant point were rejected than if it were left in.

Omitting the point for 1959, first quarter, the correlation coefficients (r) for F_t on f_t have been calculated for different values of X, using the total n_t from all groups of tags released each year, starting with the beginning of the fourth quarter of the year of release through 1959. The results are as follows:

1955 release	1956 release
$r_{X=0.15} = 0.91$	$r_{X=0.30} = 0.80$
$r_{X=0.30} = 0.94$	$r_{X=0.45} = 0.83$
$r_{X=0.45} = 0.17$	$r_{X=0.60} = 0.22$

It is apparent that the best fit for the 1955 data is obtained with an X = 0.30, while that for 1956 is with X = 0.45, apparently reflecting the presence of the Type B errors. These results confirm the conclusion that Type B errors were significantly higher in 1956 than in 1955.

Such high levels of the non-fishing mortality components in both years suggest that there may still be a large component of Type B error in the 1955 releases. It should be noted, however, that since Type A errors have not been accounted for in this initial comparison, the initial N_t used was too large throughout. Therefore the correlation between F_t and f_t would not have decreased markedly until the trial value for Type B errors became large enough to compensate partially for the Type A errors as well. That is, X values which yield the best correlation coefficients must contain overestimates of the true value of Type B errors, although the relative values between releases of 1955 and 1956 should not be seriously affected.

Calculation of mortality rates

Values for the actual fishing mortality rates may be derived following the above described techniques, but using various hypotheses of Type A and Type B error in combination. A second set of calculated F_t values has been so calculated and is shown in Table 7. In this case we have accepted the "best" X values derived in the preceding section, and combined them with various values for PR or P'R'. The results are described by the following table:

1955 releases	1956 releases
X = 0.30	X = 0.45
$r_{P'R'=1.00} = 0.94$	$r_{PR=1.00} = 0.83$
$r_{P'R'=0.90} = 0.93$	$r_{PR=0.80} = 0.83$
$r_{P'R'=0.60} = 0.89$	$r_{PR=0.70} = 0.81$
$r_{PR=0.85,\ P'R'=0.51} = 0.65$	$r_{PR=0.60} = 0.68$

A test for the homogeneity of each of these series (Rider 1939) indicates that the final value in each case is significantly different from the other three. In the case of the 1955 tag release we may therefore reject the hypothesis that there was an initial loss of all tags of 15% in addition to the 40% loss assumed for the Lea tags alone. In the 1956 release it appears that a reduction of 30% in the effective initial survival of only otter-trawl-caught cod (which comprised 75% of the total) gives an upper limit to the magnitude of the Type A error.

The above comparisons have resulted in two independent sets of estimates of the fishing mortality rates on the Gulf of St. Lawrence cod stock during the period of the tagging experiments. It remains to compare these sets. For the comparison we again make use of correlation coefficients. If the two tag releases were to give identical estimates of fishing mortality, the F_t for the 1955 releases, plotted against F_t for the 1956 releases during the same period, should fall along the 45° diagonal (i.e., a slope of 1.00), with a correlation coefficient of 1.00.

As a base line for assessing the effects of Type A and Type B errors on the mortality estimates we have first calculated this regression line for the 1955 and 1956 sets of F_t when only Type B errors are considered, i.e., when $X_{1955} = 0.30$ and $X_{1956} = 0.45$, and no corrections are made for P or R (Hypothesis 1). These results may be compared with plots of the F_t's for the case where $P'R'_{1955} = 0.60$ and $PR_{1956\text{-}OT} = 0.80$, 0.70 and 0.60. The results are given in Table 8.

It is apparent that Hypothesis 2 which postulates that Type A error reduced the effective total 1955 releases to the equivalent of total YD:HL plus only $60\,^0/_0$ of the LH:HL releases, and the total 1956 releases to the equivalent of all HL releases plus $80\,^0/_0$ of the OT releases, in addition to the

Table 7

Fishing mortality rate calculated from tag returns for 1955 and 1956 releases, assuming given values of non-fishing mortality (X) and various rates of initial tagging mortality, and incomplete reporting of recaptured fish

Quarters	1955 releases: N_t Calculated number of tagged fish at beginning of each time t, when N_0 (YD:HL) = 2,638, N_0 (LH:HL) = 1,208			n_t No. of returns	$F_t = \frac{n_t}{N_t} \div \left(1 - \frac{\frac{n_t}{N_t} + X_t}{2}\right)$			1956 releases: N_t Calculated number of tagged fish at beginn. of each time t, when N_0 (YD:HL) = 483, N_0 (YD:OT) = 917, N_0 (LH:OT) = 592			n_t No. of returns	$F_t = \frac{n_t}{N_t} \div \left(1 - \frac{\frac{n_t}{N_t} + X_t}{2}\right)$		
	P'R' = 0.90 X = 0.30	0.60 0.30	PR = 0.15 + P'R' = 0.51 0.30		P'R' = 0.90 X = 0.30	0.60 0.30	PR = 0.15 + P'R' = 0.51 0.30	R = 0.80 X = 0.45	0.70 0.45	0.60 0.45		R = 0.80 X = 0.45	0.70 0.45	0.60 0.45
1955														
IV	3243	2932	2492	47	0.015	0.017	0.020							
1956														
I	2963	2675	2267	371	0.139	0.155	0.186							
II	2393	2125	1746	162	0.073	0.082	0.101							
III	2064	1816	1456	183	0.097	0.110	0.140							
IV	1740	1509	1175	31	0.019	0.022	0.028	1374	1270	1128	21	0.016	0.018	0.020
1957														
I	1584	1370	1060	79	0.053	0.062	0.081	1208	1115	989	117	0.108	0.118	0.134
II	1394	1196	907	132	0.103	0.122	0.164	968	886	773	89	0.102	0.112	0.130
III	1166	982	714	119	0.112	0.134	0.190	781	708	607	100	0.146	0.162	0.191
IV	967	797	548	22	0.024	0.029	0.043	603	538	448	15	0.027	0.030	0.036
1958														
I	876	718	487	95	0.119	0.148	0.226	525	467	386	74	0.161	0.183	0.226
II	721	574	361	91	0.140	0.179	0.301	399	347	275	56	0.161	0.187	0.242
III	582	445	248	61	0.115	0.153	0.293	304	257	193	36	0.134	0.160	0.219
IV	481	354	172	3	0.007	0.009	0.018	238	196	138	3	0.013	0.016	0.023
1959														
I	443	326	157	27	0.065	0.086	0.196	210	172	120	22	0.117	0.145	0.215
II	385	277	120	33	0.093	0.132	0.333	167	133	87	12	0.079	0.100	0.158
III	325	225	80	22	0.073	0.107	0.333	138	108	66	8	0.063	0.082	0.137
IV	280	188	53	3	0.011	0.017	0.061	116	89	51	9	0.086	0.113	0.206

Type B error, gives best agreement. Evidently various other combinations of A and B error terms could give a slightly better approximation to the ideal of a high r with a slope of 1.00. But examination of the array of average annual F_t values indicates that further manipulation of the data with Type A and B errors of this general order of magnitude would not appreciably affect the estimate of fishing mortality rate. Hypothesis 4 is included in the set to indicate the effect on F_t of including estimates of Type A error corrections which were rejected in the earlier comparisons.

Table 8

The agreement between sets of F_t based on 1955 and 1956 releases, under various hypotheses

Hypothesis no.	Magnitude of Type A error correction	r	slope	1957-59 average annual $F_{(1955)}$	1957-59 average annual $F_{(1956)}$
1	No Type A error	0.73	0.87	0.24	0.28
2	1955 initial LH tags reduced to 60% c.f. 1956 initial OT tags reduced to 80%	0.81	0.92	0.37	0.37
3	1955 initial LH tags reduced to 60% c.f. 1956 initial OT tags reduced to 70%	0.81	0.80	0.37	0.44
4	1955 initial LH tags reduced to 60% c.f. 1956 initial OT tags reduced to 60%	0.72	0.54	0.37	0.59

On the basis of the foregoing information on the tagging procedures and fishing, we conclude that in this cod tagging experiment mortality estimates which do not take into account both Type A and B errors may significantly underestimate the rate of fishing on the cod stock. From the comparisons shown in Table 8 it seems reasonable to conclude that an average annual value of F = 0.40 is near the true value for this fishery during the period 1957 to 1959.

Given this result, it is tempting to continue the calculations to provide estimates of the remaining parameters of the catch equation. Thus, from the plots comparing quarterly F_t with f_t, and noting that $F_t = qf_t$, we may estimate the catchability coefficient q, when effort units are expressed in terms of trips by small Canadian otter trawlers. For Hypothesis 2 of Table 8 we have

$$q_{(1955)} = 4.76 \times 10^{-4}$$
$$q_{(1956)} = 4.65 \times 10^{-4}$$

These values of q may be used to calculate the approximate fishing mortality rate in other years for which effort data can be similarly derived.

Finally, we may, given an estimate of total mortality from some other source, derive values for M and M′. One such estimate of $Z = 0.50$ for Gulf of St. Lawrence cod stocks was calculated for the period 1955 to 1958 in the report of the ICNAF Mesh Assessment Working Party (Document 20, 1961 Annual Meeting). Subtracting our estimate of F we have directly $M = 0.10$. From the foregoing estimates of X we get $M'_{(1955)} = 0.20$; $M'_{(1956)} = 0.35$.

To the extent that the logic of these manipulations of the tag return data is formally correct, we are justified in concluding that the introduction of correction terms results in estimates of the mortality rates which more faithfully reflect true values for the fishery than was possible without such corrections. However, it will be apparent that the correlation coefficients used to detect the trends of the major departures from various hypotheses of tag errors are not sensitive enough to provide a measure of the reliability of the sampling errors in either the original data or in the correction terms introduced; nor at the moment have we attempted to use any other measure of these errors. Pending further study of this rather formidable statistical problem, we are left with the conclusion that the estimates derived by the use of the correction terms are more nearly of the correct order of magnitude than are those derived without their use. In lieu of a more satisfactory treatment, they may be taken as provisional "working" values for these important population parameters.

Summary

Returns over several years from cod tagged with either Petersen yellow disk or Lea hydrostatic type tags and released in tag experiments begun in 1955 and 1956 indicated that the average annual total mortality rate was constant for releases within a particular year, although it was different between the two years' releases. Comparisons among the various groups of releases within and between year of release suggest that Type A and Type B errors (Ricker, 1958) had major effects on returns. Measures of the relative order of magnitude of the Type A errors are obtained from comparisons of the proportion returned per unit time, corrected for differences in initial numbers tagged. Type B errors are estimated from differences in the rate of return between years, relative to the fishing effort.

Although total annual mortality rates were relatively constant, there were significant seasonal differences which appear to be highly correlated with changes in estimated seasonal fishing effort. Quarterly fishing mortality rates are calculated from tag returns using different hypotheses of Type A and Type B errors. The results for each year's releases are compared with the fishing effort and with each other. Closest agreement is obtained between the series derived from the two years' releases when intermediate levels of Type A and Type B errors are included; the resulting estimates of fishing mortality are appreciably higher than when such errors are neglected. Pending a more careful statistical treatment, these higher fishing mortality rates and the catchability coefficients and natural mortality rates associated with them appear more likely to reflect the true rates than do the uncorrected data.

Acknowledgements

I am indebted to a number of people for their assistance during preparation of this report. Dr. W. R. Martin, scientist-in-charge of the groundfish investigations at the Biological Station, St. Andrews, suggested the study and reviewed the findings with me at various stages in the analysis. The tagging experiments were designed by Dr. F. D. McCracken and carried out under his guidance. He discussed them with me and kindly made the results available for this additional analysis. Mrs. I. Thompson carried out most of the rather lengthy sets of calculations. Mr. J. E. Paloheimo made a number of helpful suggestions during analysis and preparation of the manuscript. It is a pleasure to acknowledge my indebtedness to these people and to thank them for the parts they played.

References

BEVERTON, R. J. H. and S. J. HOLT. 1957. On the dynamics of exploited fish populations. *Fish. Invest.*, Lond., Ser. 2, **19**.

McCRACKEN, F. D. 1959. Cod tagging off northern New Brunswick in 1955 and 1956. *Progr. Rep. Atl. Cst. Sta.*, No. 72: 8—19.

McCRACKEN, F. D. 1962. Comparison of tags and techniques from recoveries of Subarea 4 cod tags. *This Symposium*, No. 16.

PALOHEIMO, J. E. 1958. Determination of natural and fishing mortalities of cod and haddock from analysis of tag records off western Nova Scotia. *J. Fish Res. Bd Can.*, **15**: 1371—81.

RICKER, W. E. 1937. The concept of confidence or fiducial limits applied to the Poisson frequency distribution. *J. Amer. statist. Ass.*, 32: 349—56.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res.* Bd Can., No. 119.

RIDER, P. R. 1939. *An introduction to modern statistical methods.* New York, John Wiley and Sons, Inc., 220 pp.

14.

Sonic Fish Tracking

By

PARKER S. TREFETHEN*

The need for knowledge by fishery agencies of fish movements has long been recognized and many techniques, such as disc tags, streamer tags, dyes, and tattoos, have been devised to obtain this important information. Valuable data have been accumulated by these methods for population studies, catch evaluation, timing of migrations, and delays during migration, but none of these tags are able to produce minute-by-minute information on fish movements in specific areas or on the behavior and orientation of fish in response to specific stimuli in their natural environment. Detailed information on behavior of fish is necessary for understanding migrations and predicting changes in migratory routes, for providing adequate fish passage facilities for certain species of fish, and in the management of a fishery.

In the absence of a suitable tag for observing detailed movement patterns of fish, the Bureau of Commercial Fisheries undertook a programme to develop special equipment that could be employed to observe adult salmon as they migrated upstream. Dr. Gerald Collins initiated this research and investigated the possibility of utilizing mechanical noisemakers or radio transmitters attached to a fish, but these techniques were unsatisfactory and it became apparent that underwater sound was the only feasible method that could be employed.

The Seattle Development Laboratory of Minneapolis-Honeywell Regulator Company under contract to the Bureau designed a sonic tag and produced receiving equipment that would "home" automatically on the tag's signal and track the fish to which the tag was attached. The first usable tag was an aluminum capsule 0.86 inches in diameter and 2.37 inches long, and weighed from 0 to 2 grams in water. This was a self-contained battery-operated unit that produced a pulsed 132 kc signal detectable for eight hours, and had a tracking range of 250 feet.

This tag was employed for three years to observe fish behavior, but after its initial use it became obvious that the life and tracking range of this tag was too short and its operation too unreliable for prolonged experiments. During this three-year period, however, the advances in sonic and electronic engineering and in subminiaturization of electronic parts made it possible to design and produce a tag with more desirable characteristics.

The basic tag now in use was designed for us by Automated Controls Company, Alderwood Manor, Washington. It is capable of producing a tracking signal for 24 to 60 hours in fresh water at a range of 500 to 1200 feet; in salt water the range is reduced to about one-third. The dimensions have been decreased to 1.8 inches long and 0.6 inches in diameter, while the weight has been increased by only 6 grams. The frequency of the signal, 132 kc, and the pattern of the signal from the tag are similar to those of the tag previously employed.

The new tag is constructed in two units: (1) the transducer-oscillator unit which contains the resonating zirconium-titanate crystal, printed circuits and necessary electronic components to stabilize the signal in varying temperatures; and (2) the battery unit which contains the power supply. By using different types of miniature batteries and by varying the number of cells in a battery unit the duration of signal can be controlled without altering the dimensions. By increasing the length of the battery unit and utilizing a longer battery, the duration can be increased to over 5 days and the range to over 1500 feet.

The components of each unit are assembled to fit within buterate-plastic shells that, when joined, form a completed tag. This tag is waterproof and capable of withstanding water pressures at depths of more than 100 feet. Attachment to a fish is made with a hog-ring device that is cemented to the tag and clamped into the fish behind its dorsal fin.

This tag has been successfully employed to track fish in salt and fresh water, in shallow water and deep forebays of dams and in rapidly flowing water that is not extremely turbulent. We have found that adult migrant salmon appear to prefer water less than 30 feet deep, that they tend to follow a shoreline and that there is a difference in their behavior between daylight and darkness. Fish have been tracked up to 15 hours, but the duration was usually limited by personnel endurance rather than by the equipment.

We have demonstrated that individual fish can be kept under constant observation in their natural environment with specialized sonic equipment. To accomplish this, it was necessary to employ a tag that is larger than tags used in the usual tagging programmes. Because of its size, and the method of application, its effect on natural behavior patterns is an important consideration in the analysis of the

---

* Bureau of Com. Fish., Seattle, Wash., U.S.A.

results. We have attempted to minimize the effect of handling while attaching the tag, by keeping the fish under water at all times. About one out of four fish tagged in this manner reacted to the procedure by swimming rapidly around a tagging box for several seconds; the others showed no visible reaction. The fish was then held up to four hours to eliminate the effect of the tagging.

The sonic properties apparently do not affect the behavior of adult migrant fish. Tagged and untagged chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Salmo gairdneri*), tagged with a sonic tag and placed in fast flowing and in quiet water, exhibited no visible differences in their behavior patterns. Several investigators have concluded that fish, when subjected to frequencies between 0.005 and 70 kc, became quickly adjusted to the new sound after an initial "start" and accepted it as part of the large volume of noise normally encountered in their environment.

Another factor that might have affected the validity of the information being collected was the weight of the tag and its drag as it was carried through the water. In so far as possible we streamlined the tag to reduce the drag, but it remained relatively large and the weight was foreign to a fish. A series of tests, designed to compare the movement of tagged and untagged fish through different water conditions in a fisheries behavior laboratory, were conducted to examine the effect of the tag being employed and, also, the effect of a smaller tag that weighed 12 to 15 grams. No effect was observed between tagged and untagged fall-run chinook salmon and blueback salmon of the Columbia River. An apparent effect was observed on spring-run chinook salmon, but we are not certain that the observed behavior is the result of the sonic tag and handling, for in other types of experiments the behavior of spring chinook salmon appears very erratic. More experiments are necessary before we can assume that the tag does not affect behavior of spring chinooks.

Throughout our behavior experiments we have utilized receiving equipment that has been only slightly modified from the original design. This automatic tracking system is servo-powered, utilizing four receiving or detecting barium titanate transducers and four receiver channels for tracking a tagged fish. Two of the transducers are used for tracking in azimuth and two are for tracking in elevation. A 132 kc sound source (sonic tag) in the common axis of a pair of transducers produces a signal in each transducer. As it is moved from the common axis toward the axis of either transducer the output from one rapidly increases toward a maximum, while the output of the opposite transducer decreases. The two signals are used to balance each other in a difference amplifier and the sharply defined null provides sensitivity to vertical and horizontal angular displacement from the common axis. These detecting transducers are clustered around the echo-ranging transducer and when the tag is in the null, or common axis, the ranging system is aimed at the tagged fish. The exact position of the fish is determined by echoes from sound impulses emitted by the ranging unit. These echoes are transformed into electrical energy and displayed on a calibrated cathode-ray tube that shows distance and direction; the depth of the fish can be calculated.

The four receivers, each of which is connected to one of the four detecting transducers, use a t-r-f-circuit with a band pass of ± 1 kc. For accurate and dependable operation a delicate balance between the receivers must be maintained and a signal level of 5 microvolts is required at the receiver grids.

In view of electronic developments since the original design of the tracking system, our equipment is obsolete and improvements must be made to increase the dependability and accuracy of our observations on fish behavior. In a new tracking system, a single channel would replace the four-channel receiver to eliminate the delicate balance necessary between channels for accurate tracking. A front-end switching unit would separate azimuth and elevation signals received from a sonic tag and activate an improved servo-system to aim echo-ranging equipment at a tagged fish. A high-gain circuit would be employed but the bandpass would be decreased to about 500 cycles or less. This would effectively increase the range of our present tag by eliminating some of the signals or noise now received with the 1 kc band pass. A reduction in noise will also increase the duration that the tag signal can be detected.

New equipment will include a tunable receiver capable of detecting signals over a wide range of frequencies. This will allow us to select a tag frequency most suitable to the water condition, and minimize signal attenuation in turbulent water and in a marine environment. This type of receiver will eliminate the precise adjustment of tag signal that is now necessary before use and enable us to continue tracking a tagged fish regardless of any frequency shift that might be caused by temperature or pressure changes. The ability to utilize lower frequencies will enable us to reduce the size of the sonic tag by nearly one-half, while maintaining the present characteristics. Also, it is conceivable that several tags of different frequencies could be employed at the same time, so that more than one fish could be tracked in a specific area.

We have emphasized the development of automatic tracking equipment in anticipation of long-term fish behavior studies when fish might be tracked for days or weeks. It is possible, however, to develop a simpler system that could be mechanically positioned by aurally differentiating signal strength; thus, with two or more systems fish could be tracked by triangulation. However, this type of equipment would probably be limited to specific areas from stationary observation points.

The ability to utilize sonic equipment to observe in detail the behavior of individual adult salmon has been adequately demonstrated. Although we will continue to use the present tracking system to accumulate data on salmon behavior, efforts are being directed toward the design and production of new equipment to realize fully the potential of this research tool. A new tracking system design will be based on our experiences coupled with the latest advances in sonic and electronic engineering. The increased accuracy, reliability, and sensitivity will enable us to consider the use of this tool in a marine environment for extensive observations on salmon and other species of fish, some shellfish and marine mammals.

In our development programme we have accumulated considerable experience in the use of sonic equipment in small boats. We gladly offer our assistance in the installation and operation of equipment, the interpretation of data or in tagging-tracking operations. We are hopeful that other fishery agencies will utilize this research tool and contribute basic as well as practical information on behavior patterns of aquatic animals.

Summary

An early sonic tag used for 3 years has been replaced by an improved device. A new plastic tag now in use is 0.6 inch in diameter, 1.8 inches long, and weighs 4—6 grams in water. A continuous 132 kc signal can be traced at a distance of 500 to 1200 feet for 24—60 hours. The range can be increased to over 1500 feet for more than 5 days by increasing the length of the tag.

The tag is constructed in two sections: (1) the transducer oscillator unit and (2) the battery unit. It withstands water pressure at depths of over 100 feet. Fall-run chinook salmon (*Oncorhynchus tshawytsha*) and blueback salmon (*O. nerka*) are not affected by the sonic or physical properties of the tag.

15.

Some Investigations of Haddock Movements

By

RODNEY JONES*

Introduction

One way of investigating fish movement is by the tagging and recapture method. In a recent paper (Jones, 1959) there is a description of some haddock tagging experiments and a method of analysis of the results. It was found that to a large extent haddock appear to move independently of one another, and it is desirable to reconcile this with the other known facts about haddock biology. In particular, it is necessary to reconcile random movement with the fact that there is a wide variation in the mean lengths of haddock from adjacent areas and that these differences tend to become greater rather than smaller as the fish grow older.

Tagging and Movement

The simplest way of demonstrating a set of tagging recapture records is by means of a diagram showing the positions of liberation and recapture, and the period at liberty of each fish returned. Such a diagram can he very useful, but it shows nothing of the actual movements of the fish as they travel from the release to the recapture positions; only the end points of each journey are fixed, and we require to deduce something about the rest of the journey. To do this it is first necessary to decide whether the fish are moving independently of one another or not. If on encountering each other the fish tend to remain together then it is easy to see that in time a series of random encounters will lead to the formation of shoals. This is the case with herring, hut probably less so with haddock. The comparatively uniform distribution of haddock as shown by trawling records suggests that it is not a shoaling fish but that it is more likely that the individuals move more or less independently of one another. Aggregation on good feeding or spawning grounds could still occur by chance and does not have to be explained by postulating a true shoaling habit.

The simplest case is when the individuals are moving quite independently of each other, and the net effect is then simply one of dispersion. To allow for the fact that haddock do show some migratory tendencies, the simplest assumption that can be made is that the movement of a haddock at any instant is the resultant of two components: (i) a directional tendency (V) and (ii) an undirected or random component (a^2) which measures the way in which the movement of an individual at any instant departs from the overall direction. If (i) is large and (ii) is small, the fish will tend to move in a particular direction. On the other hand, if (i) is small and (ii) is large, the individuals will disperse, possibly to a sufficient extent to mask their mean direction of travel. Estimates of these components of movement can be obtained from tag returns by using the following two formulae:

$$V = \frac{\Sigma r \cos \theta}{\Sigma\ t}$$

$$\text{and } a^2 = \frac{1}{n}\left[\sum \frac{r^2}{t} - \frac{(\Sigma\ r \cos \theta)^2}{t}\right]$$

where, for each fish returned:

r = apparent "straight line" distance travelled,
t = number of days free,
θ = individual direction of travel measured from the average direction of travel.
n = number of returns.

These equations can be interpreted as follows:—

In the first equation, the quantity $r \cos \theta$ measures the displacement of a fish along the mean direction of travel of the group as a whole. Thus for a single fish the quantity $\frac{r \cos \theta}{t}$ is simply the mean daily travel of the fish in that direction. The quantity "V" is therefore a measure of the mean daily travel of the group as a whole. The significance of the quantity a^2 is more difficult to define. It measures the rate of movement, excluding any directional component, and is in units of miles^2/day. This is because it is dependent on both the swimming speed of the fish and also on the average distance travelled between each change of direction (Beverton and Holt, 1957). A given rate of dispersion could be the result of a number of fish swimming rapidly with frequent changes of direction or more slowly with less frequent changes. It is not possible from the distribution of returns alone to discriminate between these alternatives, and instead one obtains a parameter (a^2) dependent both on swimming speed and on mean distance travelled between each change of direction.

---

* Marine Laboratory, Aberdeen, Scotland.

One feature of interest arose from the application of these formulae to North Sea haddock tag data. When there is a marked variation in the values of V for different fish the estimate of a^2 obtained from the formula can be grossly overestimated. This can easily happen if there are just one or two fish which happen to undertake extremely long migrations in comparatively short periods of time. In extreme instances such returns can be ignored, but often it is not possible to do this objectively. Values of a^2 obtained from tagging results can therefore be quite variable, and the haddock tagging data gave results that ranged from 2 to 20 miles^2/day, a variation that is too great for some purposes. More reliable estimates of a^2 are required, as they can be important when making assessments of the effects of movements across boundaries. It is useful therefore to see if there are any other ways of estimating the parameter a^2, and one way of doing this is described below.

Growth and Movement

It is known, from a study of the mean sizes of North Sea haddock, that the size of 0 group fish is nearly uniform throughout the northern North Sea, but that at later ages the distribution of sizes is such that areas of high and low growth rate can easily be distinguished (Thompson, 1929). For a given age the smallest haddock are found in the deep northern North Sea basin, and the largest off the east coast of Scotland, and in the region of the Great Fisher Bank and to the south-east of it. The size differences between the slow and fast growing areas are also found to increase with age.

If a section ABC is drawn from the fast growing Scottish east coast area, to the slow growing northern area (Fig. 1), it is found that the gradient in mean size at age is not constant along this line, but has a maximum at an intermediate point B. How is the persistence of this gradient to be reconciled with the degree of dispersion shown by tag returns? This question can be partly answered by reasoning along the following lines. If the fish at position B are moving quite independently of one another, they disperse in all directions. At the same time, the position B becomes occupied by fish that were previously situated around it. Fish coming in a direction parallel to the size contours are the same size as those that have just left. Those that approach at right angles to the size contours consist of larger fish coming from one direction and smaller fish coming from the other. If as a first approximation one supposes that the size gradient at the position is linear, and that the numbers approaching from either direction are equal, it follows that the mean length of the two groups when they meet is the same as the mean length of the group that has just dispersed. The fact that some growth occurs during this interval does not invalidate this argument and can be allowed for by saying, as a first approximation, that the mean size of the fish at B after a short interval is the same as it would have been if there had been no mixing. By reasoning in this manner it is possible to understand how a size gradient can persist, even when there is a considerable amount of mixing.

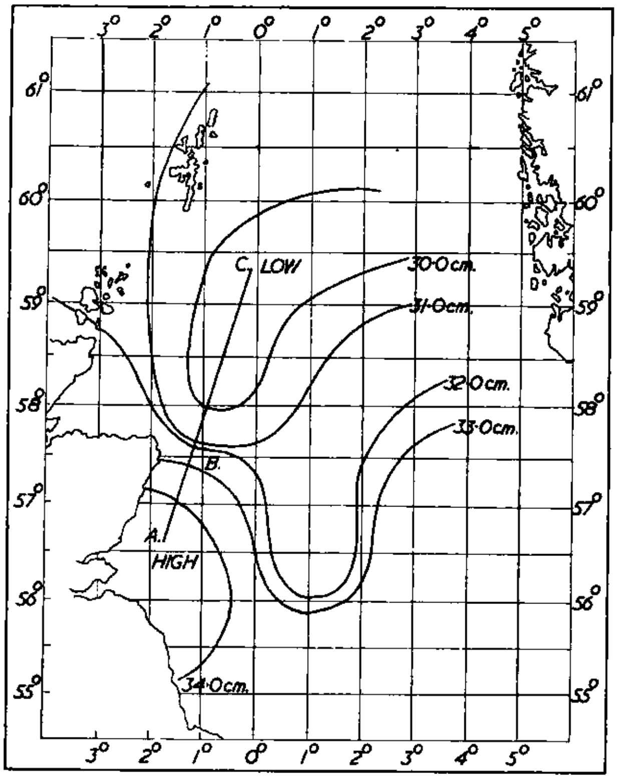


Figure 1. The mean lengths of three-year old haddock in different parts of the North Sea.

At the ends of this section, this argument does not hold. At one end is the Scottish coastline. This means that, when mixing occurs, there is an influx of smaller fish from the seaward direction, but no compensating influx of larger fish from the opposite direction. The net effect of mixing there is to make the mean length less than it would have been in the absence of movement. In the deep northern North Sea basin the effect of mixing is to introduce fish of a larger size from all around, so as to increase the observed mean length.

These considerations lead to the conclusion that the effect of mixing along a size gradient is to reduce the apparent magnitude of the gradient at the ends, but not necessarily in the middle. This is, in fact, in agreement with the observed gradients along the section ABC.

If it were possible to measure the "true gradients" at all points (i. e. the gradients that would be observed in the complete absence of movement), it ought to be possible to calculate how much random movement was necessary to account for the observed ones. Although this cannot be done, it is still possible to calculate a rate of movement from other criteria.

It has been explained how, in the centre of the section, movement may have scarcely any effect on the mean size. It will have one effect, however, and that is to increase the variance of the individual fish lengths there. A group of individuals disperses from a point and is replaced by individuals of various sizes from all round. The net effect is to increase the variance of the fish lengths at the original position by an amount that depends on the variation in the mean sizes around it. The actual rate of increase of this variance depends partly on the degree of mixing (i. e. the value of a^2) and partly on the actual (i. e. observed) size gradient. It is also necessary to allow for an increase in variance due to natural variations in the growth rates of different fish. A formula relating these variables is derived in a later section, and will be used below to derive further estimates of the coefficient of random dispersion.

Application of Theory

The formula can be written simply as:

$$V_t = \frac{a^2 g_t^2}{2} + I$$

where V_t is the rate of increase in variance at age t, g_t is the maximum observed gradient in the mean lengths at age "t", a^2 is the coefficient of diffusion, and I is the natural rate of increase in variance due to variations in individual growth rates. V_t and g_t can be estimated from observed growth data, and a^2 and I can then be calculated from the formula, provided independent estimates of V_t and g_t^2 can be obtained from at least two areas.

Two areas for which data are available are the Buchan Deeps (statistical square C13) and the area north of latitude 59° N. In the former the gradient 'g_t' in the mean length of 3 year old haddock is 0.07 cm/mile; in the latter area it is more difficult to assess, but is approximately 0.017 cm/mile.

Estimates of the variance of individual haddock lengths, at different ages, have been made from data collected by F.R.S. "Explorer" in the North Sea in 1957. Estimates were obtained of the "within haul" variances of the lengths, for a considerable number of hauls, and mean values are given in Table 1 for the Buchan Deeps area, and the area north of latitude 59° N. If these data are plotted, the rates of increase of variance with age can be obtained from the slope of each curve. For 3 year old fish these estimates of V_t are

Northern North Sea
$2\ cm^2$ per year = $0.0055\ cm^2$ per day
Buchan Deeps area
$3\ cm^2$ per year = $0.0082\ cm^2$ per day

Table 1
Showing the relationship between age and the variance of the lengths of North Sea haddock

Age	Northern North Sea	Buchan Deeps Area
1.5	1.5	2.5
2.0	2.3	3.5
2.5	3.2	5.0
3.0	4.2	6.4
3.5	5.2	8.0
4.0	6.1	9.3
4.5	7.2	10.7

Substitution of these values into the above formula gives:

Northern North Sea $0.0055 = 0.00014\ a^2 + I$
Buchan Deeps area $0.0082 = 0.0025 a^2 + I$

By subtracting one equation from the other, I is eliminated, and an estimate of a^2 can be obtained. Substitution of this value in either equation then leads to an estimate of I. The results are:

$a^2 = 1.1$ miles² per day
$I = 0.0054\ cm^2$ per day, or $1.97\ cm^2$ per year.

This value of a^2 (1.1 miles² per day) is at the lower end of the range of 2 to 20 miles² per day obtained from tagging experiments. It must be remembered, however, that these two ways of estimating a^2 are quite different, and that either method could be subject to considerable sampling variation. Alternatively, it is not impossible that tagged fish move more than untagged fish, and this would account for the higher values of a^2 obtained from tagging experiments. Many more data will be required, however, to discriminate between these alternatives.

Summary

Estimates of the coefficient of dispersion of haddock have been made by two methods. Those made from tag returns ranged from 2—20 miles²/day, but there is a possibility that this method of estimation can sometimes lead to considerable overestimates. An estimate based on the way in which the variance of haddock lengths increases with age was much lower (1.1 miles/day). It has yet to be decided which estimate is the better, but many more data will be required to determine this.

Theoretical Section

The effect of movement on the variance of the mean lengths:

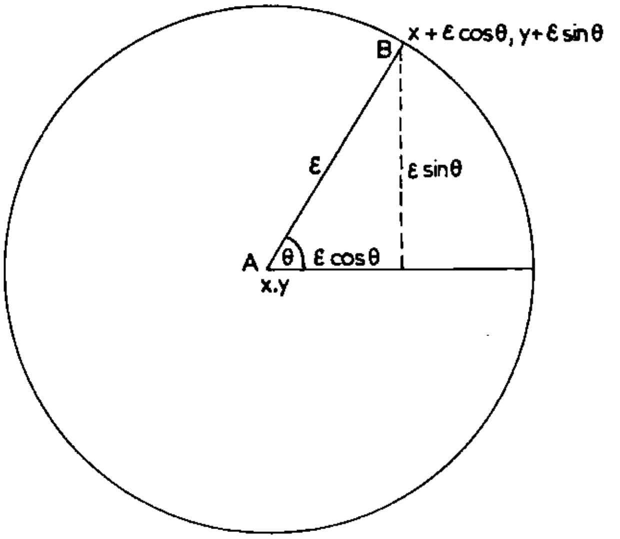


Figure 2. Locus of all possible positions of a fish at an instant of time previous to its being at point A.

The theoretical approach adopted in this section is a direct application of the approach used by Skellam (1951).

In Fig. 2 is shown a circle of radius "ε" with a centre "A". This central position represents the co-ordinate position x, y and it is supposed that there are a number of fish of age t years situated there. As these fish are moving at random, they will, during a short time interval "w", move off in all directions through a mean distance "ε". At age t + w, they will therefore be distributed around the circumference of the given circle. This argument can equally be applied in reverse. If there are a group of fish of age t years at position A, then at a previous age, t—w years, they must have been distributed around the circumference of the same circle.

Let the mean length of fish aged t years at position x, y be denoted by M (x, y, t). Consider any point B on the circumference of the circle. This will have co-ordinates x + ε cos θ, y + ε sin θ, so that at age t years the mean length of fish there will be M (x + ε cos θ, y + ε sin θ, t). It will be supposed that the variance of the length frequency distribution of this group, and in fact of any group on the circle, is σ^2_t.

At a subsequent age, t + w, the centre of the circle will be occupied by a certain proportion of the fish that were previously situated around the circumference. The variance of their lengths will then be $\sigma^2_t + \sigma^2_m$ where σ^2_m is the variance between the mean lengths of the fish around the circumference. This can be determined as follows:

First, σ^2_m can be rewritten in the form:

$$\sigma^2_m = E(M^2) - [E(M).]^2$$

now $M^2 = [M(x + \varepsilon \cos\theta, y + \varepsilon \sin\theta, t)]^2$

so that

$$E(M)^2 = \frac{1}{2\pi} \int_{-\pi}^{\pi} [M(x + \varepsilon\cos\theta, y + \varepsilon\sin\theta, t)]^2 \, d\theta.$$

If this expression for M is expanded in a Taylor's series, squared and integrated, an approximate expression for $E(M)^2$ is obtained.

It is

$$E(M)^2 = M^2 + \frac{\varepsilon^2}{2}\left(\frac{\partial M}{\partial x}\right)^2 + \frac{\varepsilon^2}{2}\left(\frac{\partial M}{\partial y}\right)^2 + \frac{M\varepsilon^2}{2}\frac{\partial^2 M}{\partial x^2} +$$
$$+ \frac{M\varepsilon^2}{2}\frac{\partial^2 M}{\partial y^2} + \ldots..$$

... + terms of Order ε^3 and higher.

where M = M(x, y, t).

Similarly, an expression for $[E(M)]^2$ can be obtained, and this is

$$[E(M)]^2 = M^2 + \frac{M\varepsilon^2}{2}\frac{\partial^2 M}{\partial x^2} + \frac{M\varepsilon^2}{2}\frac{\partial^2 M}{\partial y^2} + \ldots..$$

Subtracting this from the previous equation gives the required expression for σ^2_m

$$\sigma^2_m = \frac{\varepsilon^2}{2}\left[\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2\right] + \ldots..$$

σ^2_m represents the increase in variance of the fish at x. y, during the interval w, so that the rate of change of variance per unit time can be written:

$$\frac{\varepsilon^2}{2w}\left[\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial x}\right)^2\right].$$

In the limit, as ε and w tend to zero, this expression comes to represent the differential of variance, with respect to age.

Then, if $\varepsilon^2/_w$ is replaced by a^2 (Skellam, 1951)

$$\frac{\partial(\sigma^2)}{\sigma t} = \frac{a^2}{2}\left[\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2\right]$$

It should be noted that the coefficient a^2 has precisely the same significance as the diffusion parameter (a^2) of Skellam (1951) and Jones (1959). This formula can be further simplified if it is noted that the expression in the square bracket on the right hand side is simply the square of the maximum gradient in mean length at the position x, y. Thus, if g_t represents this maximum gradient at age t,

$$\frac{\partial(\sigma^2)}{\partial t} = \frac{a^2 g^2_t}{2}.$$

This formula gives the rate of increase of variance, in terms of movement and observed size gradient. It could incidentally apply to features other than growth. For example, if there were a gradient in mean vertebral number this formula could be used to relate the rate of change in the variance of vertebral number to movement and vertebral number gradient.

It is likely that there is one other factor that could cause the variance of the mean length to increase with age. Different individuals grow at different rates and this may cause a considerable increase in variance with age.

To allow for this, let I be the rate of increase due to natural variations in the growth rates of different individuals. Then (V_t) the observed rate of increase in variance at age t will be given by

$$V_t = \frac{a^2 g_t^2}{2} + I$$

References

BEVERTON, R. J. H. & HOLT, S. J. 1957. On the dynamics of exploited fish populations. *Fish Invest., Lond.*, Ser. 2, **19**.

JONES, R. 1959. A method of analysis of some tagged haddock returns. *J. Cons. int. Explor. Mer*, **25**: 58—72.

SKELLAM, J. G. 1951. Random dispersal in theoretical populations. *Biometrika*, **38**: 196—218.

THOMPSON, H. 1929. Haddock biology (North Sea). A brief survey of recent data, methods and results. *Rapp. Cons. Explor. Mer*, **54**: 135—163.

16.

Comparison of Tags and Techniques from Recoveries of Subarea 4 Cod Tags

By

F. D. McCRACKEN*

Introduction

Extensive cod tagging was carried out off Nova Scotia and in the Gulf of St. Lawrence in the period between 1930 and 1940 (McKenzie 1956). It was resumed in 1953 off western Nova Scotia (Division 4 X) in the region of Lockeport, N. S., and in 1955 and 1956 in the western Gulf of St. Lawrence (Division 4T). The fishery had changed rather markedly in both regions between the 1930's and 1950's. Off Lockeport hooks were still the most important method of taking cod, but small inshore boats were replaced by larger, more mobile longliners. In the Gulf of St. Lawrence otter trawling had become an important fishing method for cod, virtually replacing the hook-and-line fleet from northern New Brunswick. Also, as shown by tag recaptures (McCracken 1959), the stock of cod found in the western Gulf of St. Lawrence in "summer" was being fished off eastern Nova Scotia by a European trawler fleet in "winter".

The recent taggings were undertaken mainly to improve interpretation of stock divisions as indicated by the more mobile fishery, and to assess fishing rates as measured by tag recaptures. These were primary aims in choosing the area for tagging, type of tags and methods of capture. Since a variety of tags and methods of capture were used in areas where different methods of fishing take place, the results provide an opportunity to compare efficiency of tags and techniques.

Materials and Methods

Tag types

The Petersen disk tags, Lea hydrostatic tags, strap tags and attachments used in these experiments are shown in Fig. 1. These tags are relatively standard and thus only brief descriptions are required:

Petersen disk tags: Were about half-inch diameter, plastic disks, with centre hole, numbered on one disk, with return address on the other; colours used were a combination of (a) one red and one white disk, or (b) two yellow disks, with French or English messages.

Lea hydrostatic tags: Were the familiar yellow and blue cylinders with message enclosed, in English only.

Strap tags: Were numbered, uncolored, monel metal straps of the type used for earmarking cattle.

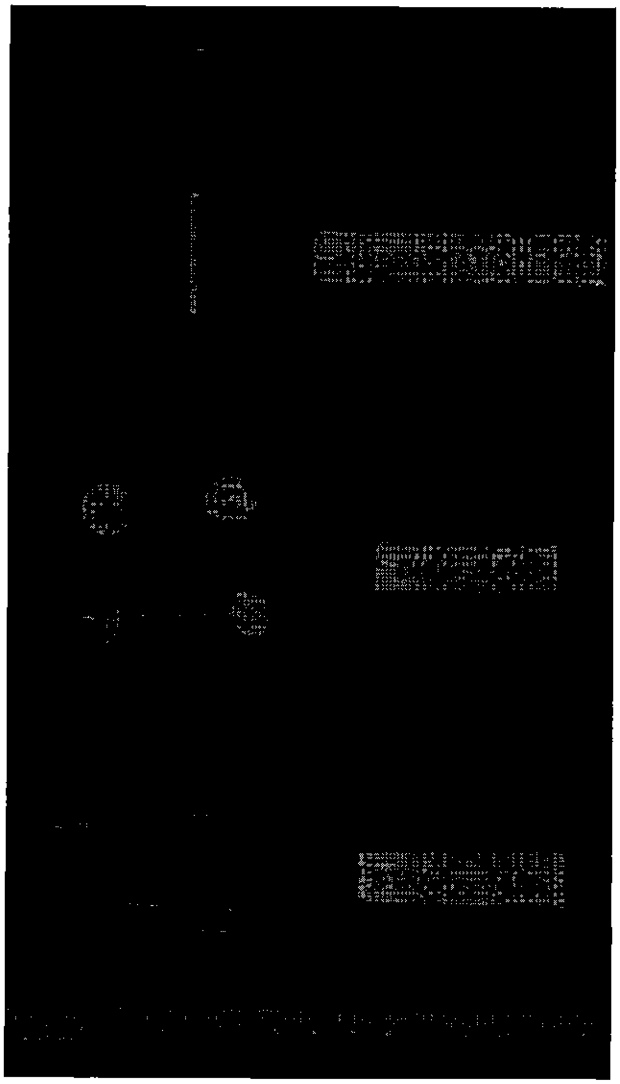


Figure 1. Tags and attachment materials used in tagging cod off Lockeport, N.S., and in the Gulf of St. Lawrence.

Attachment position and methods

Throughout all the tagging experiments Petersen disk tags were attached to the back of the fish by means of a stainless steel wire through the flesh. They

---

[*] Fisheries Research Board of Canada, Biological Station, St. Andrews, N. B.

were positioned between the first and second dorsal fins. Lea tags used in both the 1953 and 1955 taggings were attached in the same position as the disks by means of a stainless steel loop and wire. Some of those used in 1956 were attached in the same way, the remainder with a loop of monofilament nylon (about 20 lb test) through the nape. Strap tags were clamped to the ventral portion of the caudal peduncle.

Catching and handling methods

Both hook and line and otter trawl were used to capture fish for tagging. Most hook-caught cod were taken by handline although a few cod were taken for tagging by longline off Lockeport. Time of the longline sets was limited to about one to two hours. Otter trawling was carried out with a small cotton trawl (40-foot headrope) and duration of tows was restricted to about 20 to 40 minutes, depending mainly on size of catch. Attempts were made to keep catches small to avoid crushing fish in hauling.

Cod for tagging were taken from the hook or codend of the trawl and placed in a tank of running water on the deck of the vessel. Their reactions were observed for varying periods before tagging and attempts were made to pick only those fish which appeared to be in "good condition". The criteria for "good condition" included vigorous swimming, maintenance of an upright position, lack of apparent injury and lack of damage to skin and scales. The degree of culling for condition was subjective and probably varied with the person doing the tagging. However, within each experiment one person did all the tagging.

Fish were held during tagging in troughs supplied with running water, and after tagging were returned to a tank on deck. Their reactions were observed again and those showing poor condition (mainly swimming with difficulty) were discarded. All tagged fish were released at the surface.

Results from Lockeport Cod Tagging

Area and time of tagging

About 1,800 cod were tagged and released off Lockeport, N. S., between May 27 and October 20, 1953. The tagging area extended alongshore about 15 miles each side of Lockeport. Most fish were released on inshore grounds, less than 10 miles from shore and at depths between 20 and 35 fathoms. A few were released on the inner edge of Roseway Bank, about 20 miles offshore from Lockeport.

Although application of different tag types was not randomized, an attempt was made to keep the cumulative frequencies for various tags released in reasonable proportions. How effectively this was done is shown in the accompanying short tabulation:

Tag type	Number released	Percentage released, by months		
		May—June	July—August	September—October
Disk	605	30	41	29
Lea hydrostatic	991	21	56	23
Strap	263	20	33	47

Distribution of returns

Distribution of returns from the Lockeport tagging has been reported by McCracken (1956), and only a brief summary is pertinent to the analysis in this paper.

Table 1 Cod tagging summary, Division 4 X (off Lockeport, N. S) in 1953

Tag type	Capture method		Size groups (cm)							Per cent total returns
			40—49	50—59	60—69	70—79	80—89	90+	Total	
Lea hydrostatic	Handline	No. released	131	243	194	149	53	63	893	
		No. returned 1953—54	42	76	62	55	11	11	263	32
Yellow disk	Handline	No. released	40	92	66	50	21	15	284	
		No. returned 1953—54	19	46	47	28	8	8	170	60
Red and white disk	Handline	No. released	61	93	51	29	24	19	277	
		No. returned 1953—54	30	56	33	15	13	9	166	59
Strap (monel metal)	Handline	No. released	39	48	68	53	31	13	252	
		No. returned 1953—54	6	17	17	14	6	3	69	27

			No. released	No. returned	% returned
Lea	Longline		98	38	39
Disc	Longline		44	24	55
Strap	Longline		11	5	45

Most returns came from the tagging region or adjacent inshore grounds and only minor seasonal depth migrations were apparent. Almost all returned cod were taken by hook and line, either from handline or set line, but these were not recorded separately. Returns were highest in "summer", the season of tagging, and relatively low in "winter" even though cod landings from the vicinity were high in winter. In winter cod were being fished somewhat deeper than in summer, and deeper than the depths of 20 to 35 fathoms where tagging was carried out. Most returns were made by local fishermen, virtually all of whom were informed about the tagging and the information we required. In addition, one of our staff was in the area almost continually during the period when recaptures were being made.

Comparison of tag types

Return information is summarized in Table 1. It is apparent that Petersen disk-type tags produced much the highest percentage return: 60% total returns for yellow disks and 59% for the combination of red and white disks. Lea hydrostatic tags produced total returns of 32%, and the monel metal strap tags 27%. Returns of disk tags were about the same in the last 6 months of 1953 (includes the tagging period) as in 1954. Returns of hydrostatic tags

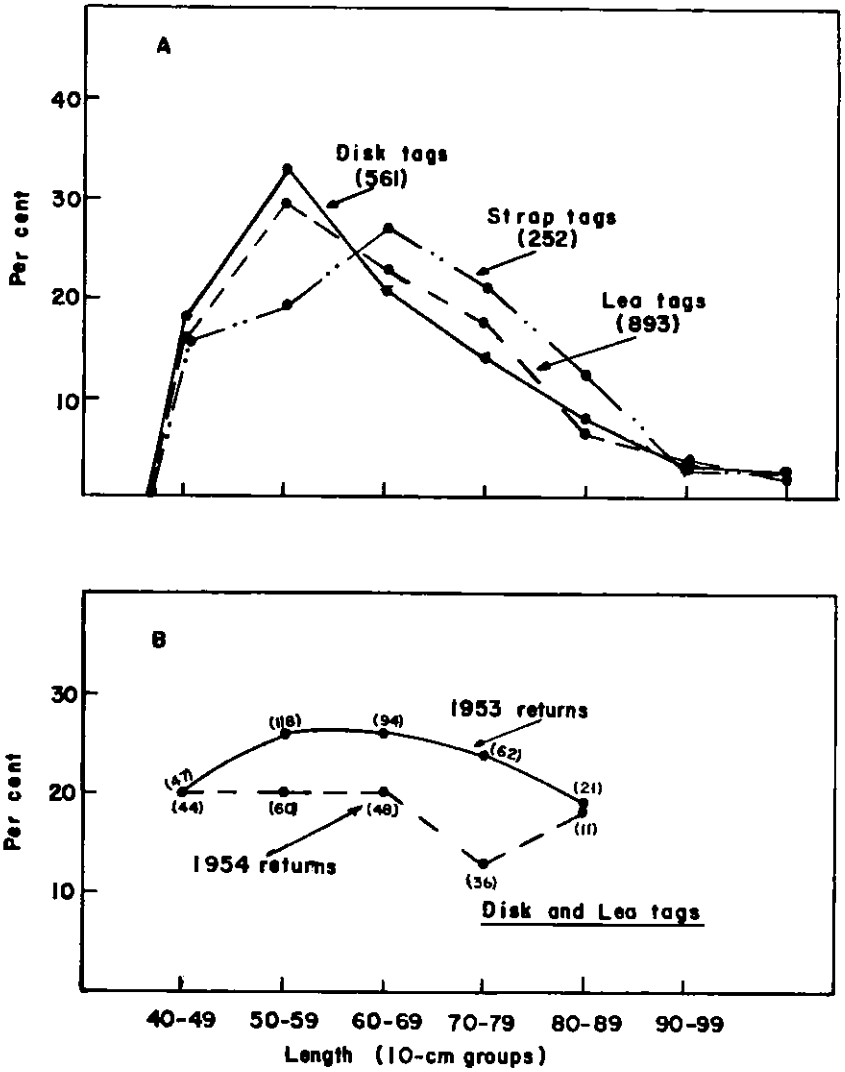


Figure 2.

A. Size composition of tagged and released cod at Lockeport, N.S.; number of fish in brackets.
B. Percentage returns in relation to size of fish at tagging for 1953 and 1954; number of fish in brackets.

decreased in 1954 to about half those of the 1953 period, while returns of strap tags in 1954 were slightly higher than in the 1953 period. Tagged fish were returned in number for only a relatively short period, about 18 months. Percentage returns of disk tags were highest throughout this period (McCracken 1956), but the time period was so short that the results do not provide a good comparison of how well tags stayed on.

Method of capture for tagging

At the beginning of the experiment some longlines were set and fish from these sets were tagged. The method was abandoned relatively early since a high proportion of the cod caught surfaced with mouth agape and operculi distended. Some of the fish caught in this way were tagged after placing them in the deck tanks and observing their behaviour. Percentage returns from these tagged fish were similar to those caught by handline (except for strap tags and only 11 of these were tagged (Table 1)). The results suggest that longline methods of capture could be used if necessary, so long as the high rate of discard for fish in "poor condition" was feasible.

Sizes tagged and recaptured

The size compositions of fish caught by handline and tagged with disk, hydrostatic and strap tags are shown in Fig. 2A. Although the size of fish released ranged between 40 and 125 cm, only those between 40 and 89 cm were considered to be numerous enough to provide consistent percentage returns. Size compositions for both disk- and hydrostatic-tagged fish were similar, with modes between 50 and 59 cm. Strap-tagged cod were slightly larger with a mode between 60 and 69 cm. Among the longline-caught cod (not shown) there tended to be fewer large fish, above 70 cm, than in the handline-caught fish.

Examination of the data revealed no differences between tag types for percentage returns by size. Throughout the size range tagged and released in quantity, 40 to 90 cm, there were no really marked differences in percentage returns by size of fish in either 1953 or 1954 (Fig. 2B). In 1953 percentage returns were slightly higher in the medium size group. In 1954 returns of the 80 to 89 cm group were low, but this may be unreal since percentage returns increased again for the less numerous larger sizes.

Results from Western Gulf of St. Lawrence Tagging

Area and time of tagging

Cod tagging in 1955 and 1956 was carried out in the western Gulf of St. Lawrence in the region of Chaleur Bay, Shippegan Gully and Bonaventure Island (McCracken 1959). All these regions are within a radius of about 35 miles from Miscou Island. In 1955 about 3,950 cod were tagged and released between mid June and the end of September in depths between 10 and 25 fathoms. In 1956 about 2,000 cod were tagged and released between early June and mid August, mainly in depths between 35 and 55 fathoms.

Although the application of different tag types was not randomized, nor was the method of capture, an attempt was made to keep the cumulative frequencies of tags released in reasonable proportion. The accompanying brief tabulation shows how well this was done:

Tag type	Capture method	Number released	Percentage, released,by months			
			June	July	August	September
		1955				
Yellow disk	Handline	2,638	17	48	18	17
Lea	Handline	1,208	31	48	21	—
		1956				
Yellow disk	Handline	483	57	1	42	—
	Otter trawl	917	48	20	32	—
Lea	Otter trawl	592	49	17	34	—

Distribution of recaptures

In contrast to cod off Lockeport, N. S., the cod tagged in the western Gulf of St. Lawrence during "summer" distributed themselves much more widely and exhibited a strong seasonal migration. "Summer" returns were mainly from the region of tagging; "winter" returns were from the deep water off eastern Nova Scotia, 150 to 300 miles from the tagging region (McCracken 1959). Returns from the tagging region were by both small otter trawlers and by small vessels fishing with hook and line. Most of the cod were landed fresh by Canadian vessels. "Winter" returns were mainly from large European otter trawlers fishing for cod to prepare as salted fish. A few returns were obtained from medium size Canadian otter trawlers fishing the eastern Nova Scotia region in "winter".

Tags from Canadian fishermen were picked up by a technician stationed in northern New Brunswick; returned from Quebec fishermen through cooperation of research organizations of that Canadian province; or sent in to us by mail directly from the finders. Many of the tags returned by European fishermen were turned in directly through the Biological Station at St. John's, Newfoundland. The remainder were returned through government agencies in the home country of the trawlers concerned.

Comparison of the results of the 1955 tagging

Tag types: Percentage returns for the two major tag types, disk and hydrostatic, were of quite different magnitudes (Table 2). Total returns for disk

Table 2 Cod tagging summary, Division 4 T (western Gulf of St. Lawrence) 1955 and 1956

Tag Type	Attachment	Capture method	No. released	Returns by year 1955	1956	1957	1958	1959	1960	Total	Per cent returned
1955 tagging											
Yellow disk message in French	Stainless steel wire, dorsal	Handline	2,400	161	318	211	139	53	17	899	37
Yellow disk, message in English	Stainless steel wire, dorsal	Handline	238	6	41	26	9	6	—	88	37
Lea	Stainless steel loop, dorsal	Handline	1,208	81	116	71	40	9	1	319	26
1956 tagging											
Yellow disk, message in French	Stainless steel wire, dorsal	Handline	483		43	100	40	12	4	199	41
Yellow disk, message in French	Stainless steel wire, dorsal	Otter trawl	917		62	85	49	15	5	216	24
Lea	Stainless steel loop, dorsal	Otter trawl	148		16	11	8	2	2	39	26
Lea	Nylon loop, dorsal	Otter trawl	444		38	47	25	4	4	118	27

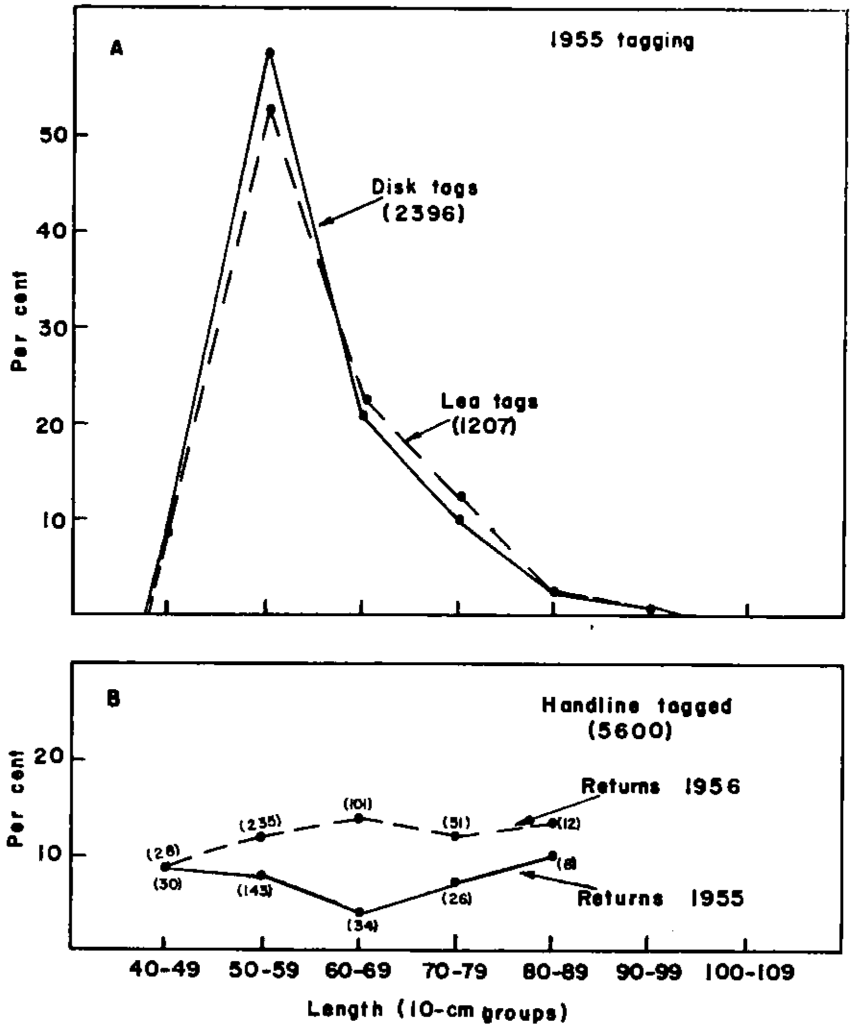


Figure 3.

A. Size composition of cod tagged and released in the western Gulf of St. Lawrence in 1955; number of fish in brackets.

B. Returns in relation to size at tagging in 1955 and 1956; number of fish in brackets.

tags were 37% and for hydrostatic tags 26%. The results are consistent with those for Lockeport tagging in relation between tags, although total percentage returns were considerably lower. Most of the disk tags had the message in French but a few with English messages were also used. Proportion of returns was the same for both message types (37%).

In contrast to Lockeport results, tags from the western Gulf of St. Lawrence were returned at a relatively high level for about four years after tagging. Disk tags continued to be returned at a high level much longer than the hydrostatic tags (Table 2).

Size comparisons: All fish for tagging in 1955 were taken by handline in depths from 10 to 25 fathoms and mainly from 15 to 19 fathoms. Although tags were not put on alternately, it is apparent (Fig. 3A) that the resulting size compositions of cod tagged by disks and hydrostatic tags were almost the same. Analysis of the returns of the two tag types by size reveals no differences between the tag types. They have thus been grouped for the purpose of this comparison. Cod were tagged in quantity between 40 and 89 cm, with a modal size between 50 and 59 cm (Fig. 3A). Percentage returns by size at time of tagging did not show a pronounced trend although they were considerably lower for intermediate sizes (Fig. 3B). During the second year following tagging (1956) percentage returns for the balance of fish remaining in the water were not strikingly different across the size range, although slightly higher for large cod than for small.

The 1956 tagging experiment

Tagging in 1956 extended the work of 1955 to deeper water (mainly 35—55 fathoms) in the region of the most important summer otter-trawl fishery. In contrast to 1955 only 25% of the fish were caught by handline for tagging. Most were taken by otter trawl and released during July and August.

Comparison of tag types, attachment and methods of capture: Only two types of tags were used in 1956, Lea hydrostatic and yellow disk tags. The yellow disks were attached through the back in the manner described previously. About 70% of the 590 hydrostatic tags were attached with nylon loops through the nape ahead of the first dorsal (Table 2). The remainder were attached with a stainless steel loop in the manner described previously. All these fish were taken by otter trawl. Lea tags with both types of attachment gave the same total percentage returns and were apparently equivalent in the length of time tags remained in the fishery.

Two groups of disk-tagged cod were released: one group of about 480 fish was captured by handline; the other group, about 900 fish, was captured by otter trawl. Returns from the two groups were at quite different levels, 41% for the handline-tagged fish and 24% for the otter-trawl-tagged fish. Although this result suggests a marked superiority for handlined fish over otter-trawled fish, the level of returns for disk-tagged, otter-trawled cod is inconsistent with other results. Thus, Lea-tagged, otter-trawled cod produced slightly higher percentage returns than disk-tagged, otter-trawled cod. This result is inconsistent with the general level of proportions returned for the two tag types, Lea having, in general, been lower than disk type. A comparison between the results for 1955 and 1956 taggings also suggests that the low percentage returns for otter-trawl disk tags is aberrant. Thus, both 1956 Lea-tagged, otter-trawled cod and disk-tagged, handlined cod produced percentage returns which were quite similar to the same tag types released in 1955. These results do not provide sufficiently good evidence to indicate that either method of capture for tagging is superior to the other.

Size comparisons : Otter-trawled cod tagged with both Lea and disk tags were similar in size, ranging between 40 and 89 cm in quantity with greatest numbers between 50 and 59 cm (Fig. 4A). Handlined cod were released in quantity between 50 and 89 cm, with a mode between 60 and 69 cm. Size composition of the latter is generally larger than the otter-trawl-caught fish.

For otter-trawled cod, combining the two tag types, percentage returns were greater for the larger fish in both the year of tagging and the year following (Fig. 4B). The much smaller number of handlined cod did not show a marked trend (Fig. 4C), although there is a suggestion that in the first year percentage returns were lower for the largest fish. This result contrasts with that for handlined cod released in 1955 and for otter-trawled cod released in 1956. Size composition of 1956 handlined cod was larger than either of the other two sets of releases and this may have been partly responsible for the difference. In addition, the handlined cod of 1956 were released in a region where fishing was mainly by otter trawl, and thus the larger cod may not have been so vulnerable to the fishery.

Comparisons with Combined Tagging Data

Proportion returned by size for different gears

As shown previously, the cod tagged off Lockeport were caught by hook and returns were also mainly by hook. Percentage returns remained about the same across the size range tagged (Fig. 2B). In the Gulf of St. Lawrence where returns were made by both otter trawl and hook and line, percentage returns by size differed with the kind of gear. For about 25% of the returns the gear was unknown and these were disregarded in the analysis.

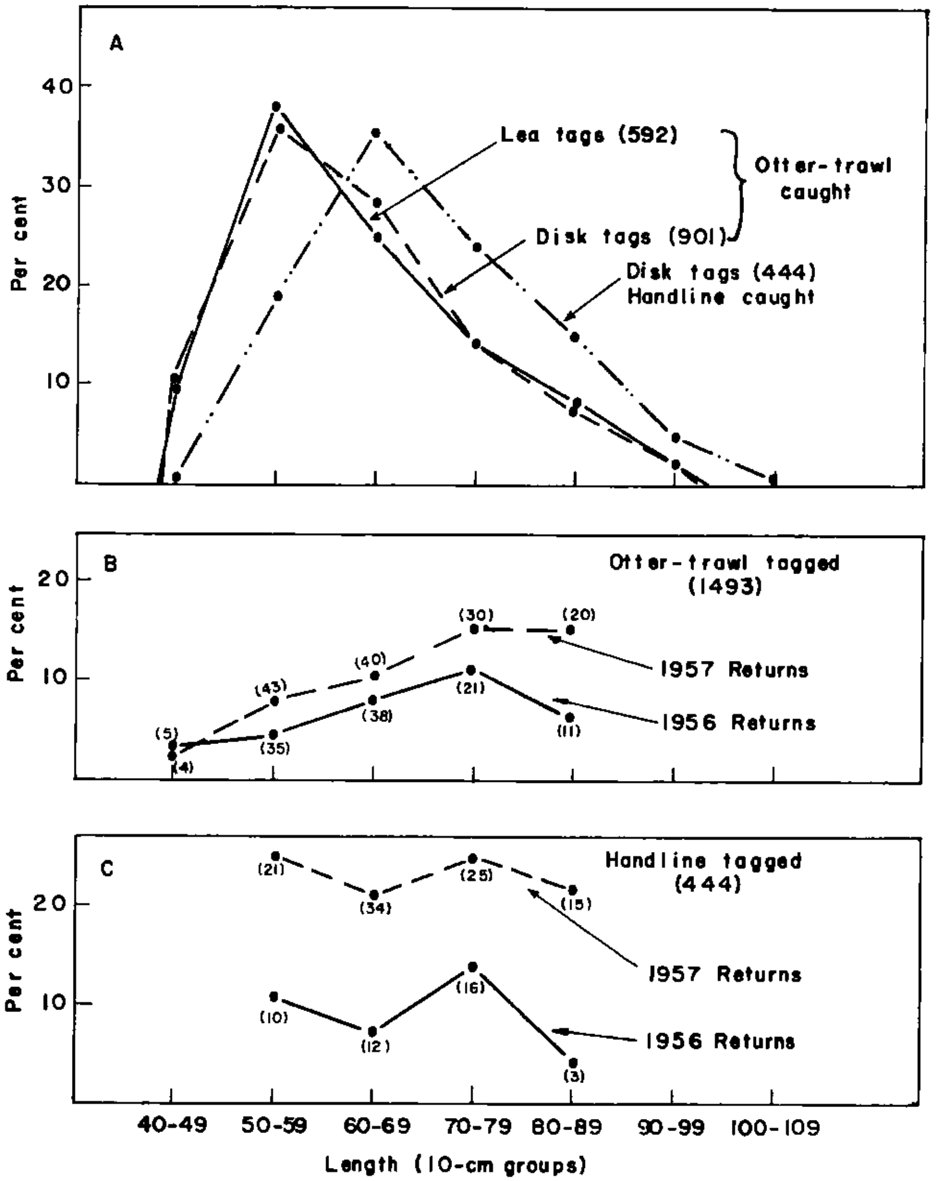


Figure 4.

A. Size composition of cod tagged and released in the western Gulf of St. Lawrence in 1956; number of fish in brackets

B. Percentage returns in relation to size at capture for cod caught by otter trawl and released in western Gulf of St. Lawrence in 1956; number of fish in brackets.

C. Percentage returns in relation to size at capture for cod caught by handline and released in the western Gulf of St. Lawrence during 1956; number of fish in brackets.

Percentage returns by sizes at tagging for otter-trawl and hook-caught cod for the 1955 tagging are shown in Fig. 5A. For small fish (40—69 cm) percentage returns in 1955—56 were higher by otter trawls (8 to 19) than by hooks (2 to 4). For fish larger than 69 cm, percentage returns were about the same (7 to 8) for both gears. Thus the proportion returns decreased with size of cod for otter trawls and increased for hooks. For this relatively large tagging (5,600 fish) the resulting curves of percentage returns are quite smooth.

Percentage returns by sizes for commercial hook- and otter-trawl-caught cod released from otter trawls and from hooks in 1956 are shown in Fig. 5B

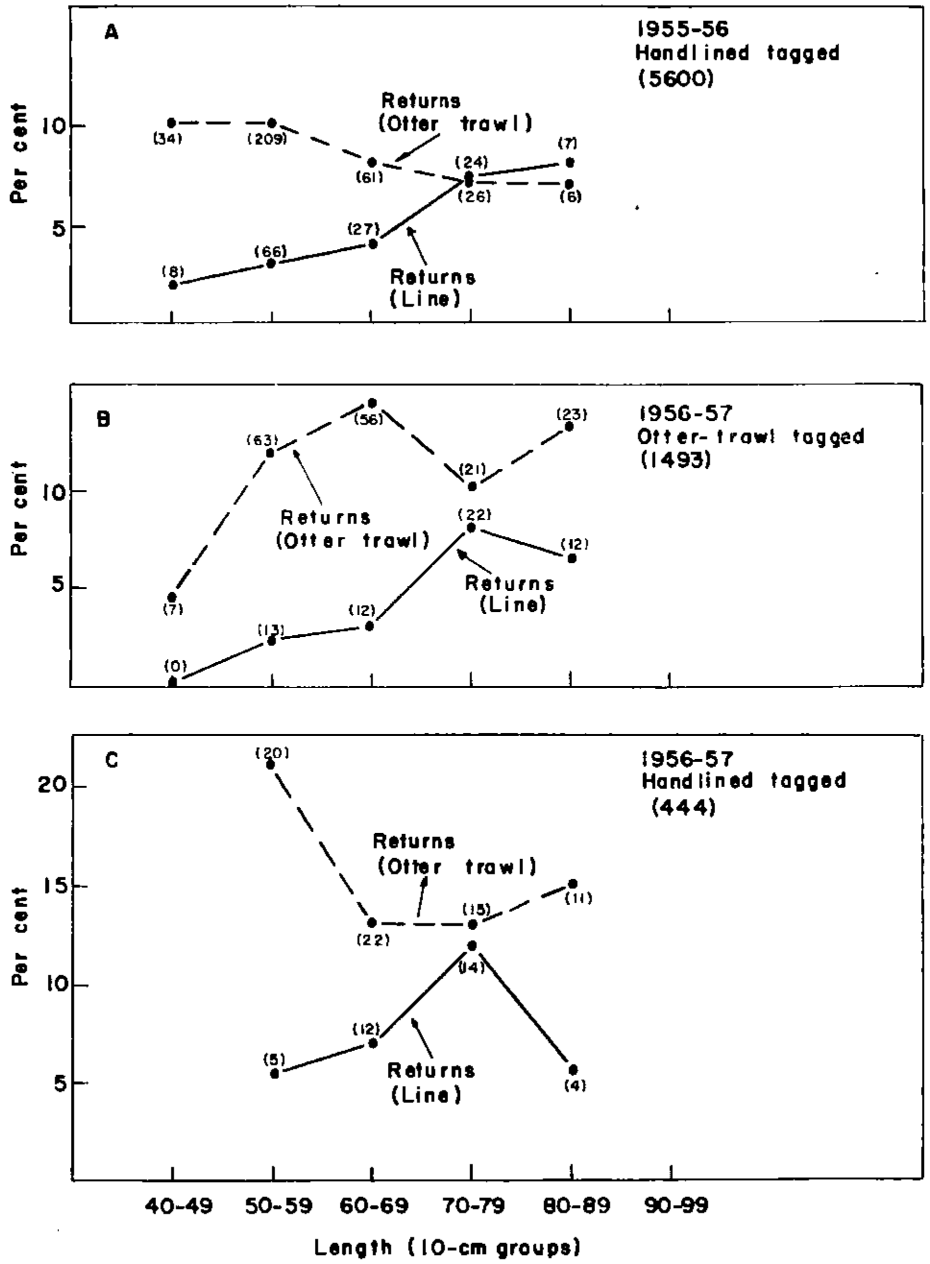


Figure 5. Percentage returns by length at tagging for cod released in the western Gulf of St. Lawrence; number of fish in brackets.

A. Returns by line and otter trawl for cod released from handlines in 1955.
B. Returns by line and otter trawl for cod released from handlines in 1956.
C. Returns by line and otter trawl for cod released from otter trawls in 1956.

and C, respectively. For both groups percentage returns from hooks increased with size of fish. For the otter-trawl releases this trend was marked with percentages increasing from about 1 to 7. The trend was more variable for the relatively smaller (500 fish) handline tagging compared to the larger (1,500 fish) otter-trawl tagging. Trends in proportions returned from otter trawls are not as definite as in the previous experiment. For hook releases percentage returns from otter trawls were highest for smaller fish (50—59 cm). For otter-trawl releases otter-trawl percentage returns were high (12—15), and about the same for sizes between 50 and 89 cm. Otter trawlers discarded a large proportion of cod below 50 cm in 1956 and 1957 (Martin and Jean 1958), and this probably explains the low percentage returns (5) for small fish (40—49 cm).

Returns related to depth of tagging

Release and total return data for Lockeport tagging and western Gulf of St. Lawrence tagging in relation to depth from which fish were taken for tagging are presented in Tables 3 and 4.

Table 3

Returns of cod tags according to depth of capture and release at tagging for Lockeport tagging, 1953 (all fish captured by handline)

Depth range (fathoms)	Number released Disk tags	Number released Lea tags	Percentage returns Disk	Percentage returns Lea
10—19	75	85	51	28
20—29	166	282	56	36
30—39	364	546	63	31
40—49	—	19	—	26

At Lockeport where cod were tagged between 10 and 39 fathoms in quantity, percentage returns were similar for all depths but were possibly slightly higher from deeper water for the disk tag.

In the western Gulf of St. Lawrence tagging of cod over the two years was carried out at depths between 10 and 69 fathoms. Cod tagging in 1955 was from relatively shallow water (10—29 fathoms) while in 1956 tagging was mainly from 20 to 59 fathoms.

Returns of Lea tags handlined in 1955 and otter trawled in 1956 were between about 25 and 30% at each of the 10-fathom depth intervals between 10 and 69 fathoms. Returns of disk tags were more variable. Returns for handlined fish were high, about 35%, between 10 and 29 fathoms, but although they appeared to increase to over 40% between 30 and 49 fathoms, this difference is probably insignificant, considering the smaller numbers involved. Returns for otter-trawled disk releases were lower than for the handline releases, ranging between 25 and 30% between 20 and 59 fathoms, with an exceptionally low value of 18% at 30 to 39 fathoms.

In general the results show that for the depth ranges considered, depth of capture was not a factor influencing the proportion returned.

Tag "conspicuousness"

Although there is no direct measure of "conspicuousness", the ratio of tagged fish returned by fishermen at sea versus the tagged fish missed by the fishermen and returned later gives an indication of how readily the different tags were seen. Results for the various tags are shown in Table 5.

Table 5

Percentage of various tag types seen by fishermen

Tag type	Place of tagging	No. of returns	Per cent returned by fishermen
Strap	Lockeport	74	38
Red and white disk	Lockeport	181	80
Yellow disk	Lockeport	179	89
Yellow disk	Gulf of St. Lawrence	1,306	84
Lea	Lockeport	301	89
Lea	Gulf of St. Lawrence	477	85

Table 4

Returns of tagged fish according to depth of capture and release for Gulf of St. Lawrence taggings, 1955 and 1956 (HL = handline; OT = otter trawl)

Depth range (fathoms)	Year tagged	No. released				Percentage returns				
		Yellow disk		Lea		Yellow disk			Lea	
						1955	1956		1955	1956
		HL	OT	HL	OT	HL	HL	OT	HL	OT
10—19	1955	1,445	—	1,014	—	38	—	—	26	—
	1956	—	—	—	—	—	—	—	—	—
20—29	1955	949	—	188	—	36	—	—	26	—
	1956	115	81	—	53	—	34	30	—	25
30—39	1955	—	—	—	—	—	—	—	—	—
	1956	94	308	—	68	—	48	18	—	29
40—49	1955	—	—	—	—	—	—	—	—	—
	1956	273	416	—	354	—	42	26	—	26
50—59	1955	—	—	—	—	—	—	—	—	—
	1956	1	67	—	48	—	—	29	—	31
60—69	1955	—	—	—	—	—	—	—	—	—
	1956	—	24	—	69	—	—	25	—	26

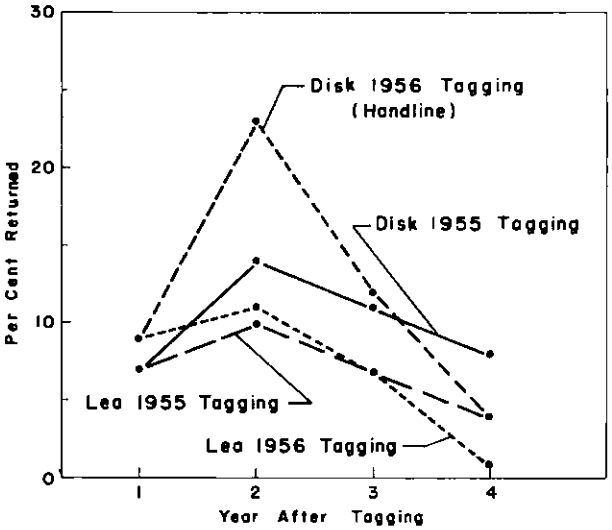


Figure 6. Comparison of return rates and retention of disk and Lea tags attached dorsally to codfish in the western Gulf of St. Lawrence.

For Lea, yellow disk and red and white disk tags the proportion noticed by fishermen was 80% or more. The proportion of yellow disk and Lea tags noticed by fishermen was slightly higher, although probably not significantly higher than red and white disks. The proportion of monel metal strap tags found by fishermen was much lower, about 38%, than any of the other types.

Examination of return data for possible differences in "conspicuousness" for different tag types in relation to type of fishing and in relation to nationality of fishermen did not yield regular or important differences.

Relative returns by countries

Returns by countries are difficult to compare since there are many variations in methods and area of fishing. Returns from the Lockeport tagging were almost entirely by Canadian inshore vessels and afford no opportunity for comparison. A large portion of the tag returns from the Gulf of St. Lawrence tagging were retaken by Canadian vessels (Table 6), hut an appreciable number were retaken by European vessels. Returns by Canadian vessels were mainly from the tagging region in Division 4T during "summer" (McCracken 1956) while European returns were mainly from Divisions 4T and 4V, off eastern Nova Scotia, in winter and early spring. The fisheries by different European countries are most comparable since for all countries otter trawling by large vessels is the most important fishing method. Even here, major differences in fisheries exist, e.g., Spanish pair trawling is important in the southern portion of Division 4V, and the results must he interpreted with caution. To make the Canadian results more useful for comparison the returns during 1956 from the 1956 tagging have heen omitted since they were being made in the immediate vicinity of the tagging.

Number of tags returned by Canada in relation to landings of cod from Division 4T and those for France, Portugal and Spain for landings from Divisions 4T and 4V in 1956, 1957 and 1958 are shown in Table 6. It is apparent that there are major differences between countries in the ratio of tags returned versus landings reported. Ratios for Canada and Portugal are similar (about 0.6) and from three to six times as great as for Spain and France, respectively.

It seems likely that the high ratio of returns from Canadian and Portuguese vessels reflects the organization and publicity devoted to tag returns and the resulting attention paid to tags by vessel crews.

Discussion

The high percentage returns of Petersen disk-type tags attached to the back compared to Lea tags

Table 6

Relation of tag returns to landings of cod by countries for Gulf of St. Lawrence taggings. (Landings and tag returns by calendar years; Canadian landings from Division 4 T; European landings from 4 T and 4 V combined)

Country	1956		1957		1958		Ratio Tag returns to Landings
	Landings '000 metric tons	No. tags returned	Landings '000 metric tons	No. tags returned	Landings '000 metric tons	No. tags returned	
Canada	62.8	390*	65.6	476	60.4	271	0.62
France	28.1	34	8.5	6	12.1	11	0.10
Portugal	5.8	29	2.8	23	3.1	15	0.57
Spain	8.3	15	10.7	28	13.0	12	0.17

* Returns from 1956 tagging not included in 1956 in order to make Canadian return conditions more comparable with European.

attached in the same region of the fish have been demonstrated in two tagging areas reported in this paper and also for a cod tagging off eastern Nova Scotia (McCracken 1957). In addition to higher total returns, the returns of disks remained at a high level for a longer period of time than those for Lea tags (Fig. 6), particularly in the Gulf of St. Lawrence tagging. The superiority of Petersen disk-type over Lea tags is contrary to many reported European results (for example, Trout 1958), and the difference needs evaluation.

When tagging was begun off Lockeport we were aware that European results showed Lea tags to be superior for cod tagging and ordered Lea tags to be used as a standard for comparison. However, tagging of flatfish off western Nova Scotia with disk-type tags attached through the nape had been quite successful and we decided to try a modification of this method for both cod and haddock. We believed that the disk-type tag attached to the back had obvious advantages in the Lockeport fishery. These included visibility from both sides of the fish when hauling on hook and line; minimum entanglement with hooks or rail rollers when fish were being brought into the boat; obstruction to filleting knives if the tag was missed prior to that stage of handling. The high percentage return at Lockeport prompted us to use this type of tag in other regions where the fishery was more mixed. The results justified the decision.

Although not demonstrated by direct experimentation, we believe that the positioning of the Petersen disk tags on the back is responsible for the difference between our results and European results with disk tags. Outside of the positioning, we have not been able to find any satisfactory reason or set of reasons for their marked superiority over Lea tags in our experiments.

Although there were no marked differences in returns for different colour disks, we suspect that the low returns for strap tags were related in part to coloration and positioning, as well as to probable loss of tags from their position on the tail region. Certainly it appears that the high proportion of strap tags missed by fishermen was a result of these conditions.

As can easily be seen, tag types and techniques have an important bearing on measurement of fishing mortality rate. For this reason, comparison of new tag types and techniques with previous "best" tag types should be continued, wherever feasible, in any tagging program.

Certain other variables of potential importance did not cause actual differences in results. The proportion of fish returned from different depths over a range from 10 to 55 fathoms was not appreciably different. It would appear that changes in pressure occurring in catching cod from these depths were not a limiting factor with the deck handling and culling procedures used. The results do not show marked differences in percentage returned from either handlining or longlining cod for tagging. While the data suggest that handlining cod for tagging may produce higher percentage returns than otter trawling, the results are not conclusive. This portion of the experiment, although tedious, needs repetition, particularly in those areas supporting mixed fisheries.

Differences in percentage returns by size appear to have been mainly a result of selection by different gears. Otter trawls were most effective for smaller fish and produced a higher proportion of returns for small fish than hooks. Hooks were most effective for larger fish and caught a higher proportion of large fish than otter trawls. Variations in sizes returned from different gears were particularly apparent when fish for tagging were captured by methods differing from those used for recapture.

These tagging experiments indicate a complexity of factors which can affect the usefulness of tag data in determining fishing rates. Most important of these appear to be the type of tag and attachment, but consideration must be given also to the relative effectiveness of various gears in catching fish of different sizes.

Summary and Conclusions

Cod tagged near Lockeport, N. S., between June and October 1953 were mainly retaken in the same region by Canadian hook-and-line fishermen. Cod tagged in the western Gulf of St. Lawrence near Miscou Island in the "summers" of 1955 and 1956 were retaken in the "summers" of succeeding years near the tagging area and in the "winters" off eastern Nova Scotia mainly by European vessels. Returns from the Gulf of St. Lawrence tagging came from both hooks and otter trawls.

Disk tags attached with stainless steel wire between the first and second dorsal fins of cod were much superior to hydrostatic tags attached in the same region, and much superior to strap tags attached ventrally to the caudal peduncle, both in total proportion returned and the length of time over which substantial returns were made. Total returns for disk tags reached 60% in the Lockeport tagging and about 40% in the Gulf of St. Lawrence tagging.

In fisheries with various types of gear the size composition of cod tagged is important in determining proportions of different sizes retained, since otter trawls and hooks selected fish of different size. Otter-trawl returns were proportionally higher for small fish and proportionally lower for large fish than returns from hooks.

Depth from which cod were caught for tagging did not influence the proportion returned, over a range from about 10 to 60 fathoms.

Metallic-coloured strap tags attached ventrally in the tail region were much less visible to fishermen than disk tags or hydrostatic tags attached dorsally. Differences between the visibility of disk tags, either yellow or red and white, and hydrostatic tags were insignificant.

Ratios of tag returns to landings for different countries varied markedly, probably as a result of differences in tagging publicity and handling procedures.

Acknowledgments

C. J. Bayers carried out the tagging at Lockeport and along with P. M. Powles that in the western Gulf of St. Lawrence. D. N. Fitzgerald collected most of the tags at Lockeport and in the Caraquet region. Staffs from the Marine Biological Station, Grand River, P. Q., the Fisheries Research Board's Biological Station, St. John's, Newfoundland, and the Fisheries Administration Branch of France, Portugal and Spain co-operated fully in returning tags and information. The assistance and advice of Dr. W. R. Martin in planning and carrying out these tagging experiments are appreciated greatly. Mrs. R. Garnett processed most of the tags received from all sources. It is a pleasure to acknowledge the co-operation and help of these various people and that of fishermen, fish processors and fisheries officers whose interest and help made these tagging experiments successful.

References

MARTIN, W. R. and Y. JEAN. 1958. First-year effects of mesh regulation on northern New Brunswick dragger fishery. *Fish. Res. Bd Can., Prog. Rep. Atl. Cst. Sta.*, No. 69: 33—40.

McCRACKEN, F. D. 1956. Cod and haddock tagging off Lockeport, N. S. *Fish. Res. Bd Can., Progr. Rep. Atl. Cst. Sta.*, No. 64: 10—15.

McCRACKEN, F. D. 1957. Results of cod tagging off eastern Nova Scotia. *Fish. Res. Bd Can., Progr. Rep. Atl. Cst. Sta.*, No. 67: 6—13.

McCRACKEN, F. D. 1959. Cod tagging off northern New Brunswick in 1955 and 1956. *Fish. Res. Bd Can., Progr. Rep. Atl. Cst. Sta.*, No. 72: 8—19.

McKENZIE, R. A. 1956. Atlantic cod tagging off the southern Canadian mainland. *Bull. Fish. Res. Bd Can.*, No. 105: 1—93.

TROUT, G. C. 1958. Results of English cod tagging in Barents Sea. J. *Cons. int. Explor. Mer*, **23**: 371—80.

17.

Factors Affecting Number and Quality of Returns from Tagging Cod with Different Tags and using Different Methods of Capture in ICNAF Divisions 4X and 5Y in 1957

By

JOHN P. WISE*

Introduction

During 1957, cod (*Gadus morhua* L.) captured in ICNAF Divisions 4X and 5Y by both research and commercial line trawlers and by research otter trawler were marked either with Petersen discs on stainless steel wire through the dorsal muscles or with an internally anchored Lea tag. During all except two operations, the types of tags were used alternately, primarily to compare the effectiveness of the two types of tag. Clearcut differences between the tags are apparent in the returns; other factors affecting the returns were also evaluated and are discussed below. Considerable information about movements and migrations was of course obtained from returns, and this will be reported elsewhere.

Table 1 gives a summary of the experiments.

Table 1

Summary of cod tagging experiments, Divisions 4X and 5Y, 1957

Place	Month	No. tagged	No. returned	Percent returned
Georges Bank	III—IV	434	66	15.2
Georges Bank	X	51	2	3.9
Browns Bank	III[1])	149	48	32.2
Browns Bank	X	76	11	14.5
Cashes Ledge	XI	50	5	10.0
Lurcher Shoal	X	7	1	14.3
Grand Manan Banks	X—XI	232	7	3.0
Fipennies Ledge ...	XI	7	0	0
Chatham, Mass. ...	II—III[2])	1020	253[3])	24.8
South Channel	X	177	13	7.3
Highland Ground ..	X	237	27	11.4
	TOTALS	2440	433	17.7

[1]) Petersen discs used exclusively.

[2]) Lea tags used exclusively.

[3]) Actually 248 fish; 4 caught after tagging, re-released and caught again, and one of these was released and caught yet again.

Methods and Materials

During line trawl operations, either from research or commercial vessels, fish which appeared not to have been seriously wounded by the hook or other parts of the trawl were gently released from the hook, immediately tagged and measured, and released.

The procedure used while otter trawling was quite different. The trawl net was towed on the bottom for periods varying from perhaps twenty minutes to an hour and a half — the time varied inversely with the abundance of fish. The objective was to secure for tagging a reasonable number of fish which had been in the trawl the shortest time possible.

At the end of the tow, the otter trawl was hauled back, the cod end hoisted aboard, and its contents dumped on deck. As quickly as possible, the fish which were alive and appeared to be in good condition were taken up from the deck by hand and placed in large wooden tanks of running sea water. Dead and distressed fish were culled from the tank, and sometimes when another tank was available the more promising specimens were transferred to a second tank. A measuring board was set up on the edge of the holding tank, and fish were dipnetted as needed for tagging. (While some workers feel it profitable when possible to hold tagged fish in tanks for further culling of weak or dying individuals, this procedure was not followed in any of these operations.)

Measurements were recorded usually to the nearest millimetre in the case of fish less than 900 millimetres in length, to the nearest centimetre when the fish were larger. Because of haste, carelessness or confusion, in some cases the fish were released before being measured. This happened perhaps one percent of the time.

The Lea tag is usually fastened to the dorsal musculature of the fish with a wire bridle, but in these experiments the tags were affixed to a short monel chain which was in turn fastened to a plastic tab inserted through a slit into the coelom.

The Petersen discs used were bright yellow, attached on stainless steel wire through the dorsal musculature. A large hypodermic needle was passed through the muscles just in front of the first dorsal fin and the first interspinous bone. The wire bearing the numbered disc was then pushed through the bore of the needle, the needle withdrawn, another disc placed over the free end of the wire, and the wire cut to length and knotted to hold the two discs firmly in place.

---

* Former Chief, Cod and Haddock Programs, Woods Hole Biological Laboratory, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service; now at Food and Agriculture Organization of the United Nations, Grupo Estadual de Pesquisas sôbre a Pesca Marítima, Santos, Estado de São Paulo, Brazil.

To eliminate as many variables as possible in comparison of the tags, alternate fish were tagged with one type, then with the other. Occasionally this design broke down somewhat under sea conditions; sometimes the tagger on deck ran out of one type of tag before the other, or he started with the wrong type after a period in which no fish were available. However, the principle of alternation was adhered to as far as possible and the records show that in the alternate experiments 632 fish were tagged with discs and 639 with Lea tags. Accurate measurements are available for 625 fish tagged with each sort of tag. The mean length at tagging of fish tagged with discs was 65.3 cm ($\sigma = 20.9$) and with Lea tags 64.1 cm ($\sigma = 20.4$).

The message enclosed in the Lea tags and stamped on one of the pair of Petersen discs states that there is a reward for the return of the tags and gives the laboratory address. While the tags are often returned directly by mail and the reward and information sent out by return mail, agents of the laboratory stationed in various ports have been empowered to pay the reward, a dollar, on the spot and to collect the pertinent information. In the same fashion, agents of the Fisheries Research Board of Canada working under a reciprocal agreement have collected tags and the Board has paid the reward. Since May 1958, agents of the Fish and Wildlife Service have paid an additional dollar when the fish was returned with the tag. These arrangements have undoubtedly fostered getting a good percentage of the recovered tags actually returned to the laboratory — more than if the initiative for sending them in were left entirely to the fishermen. In addition, having the tags and often the fish received by trained technicians has improved the quality of the information received, particularly about the length of the fish and its reaction to the tags.

Factors Affecting Number of Returns

The single factor that most markedly affected return percentages was the tags themselves. In the alternate experiments the discs yielded an overall percentage of 13.6 vs. 7.2 percent for the Lea tags. The cumulative number and percentage of returns by ten-week periods show that the discs give consistently better results regardless of the time the fish is at large between tagging and recovery, and that this difference becomes even more marked after the first year (Table 2). These results are in general agreement with those obtained by Canadian scientists in similar experiments (McCracken, contribution No. 16), but diametrically opposed to results obtained by English workers in the Barents Sea (Trout, 1958). An important difference in the English work was the methods of attachment of the two tag types — in the Barents Sea the Petersen discs were attached on the opercle and the Lea tags on the dorsum. This suggests that the place of attachment may be more important than the tag type itself.

Table 2

Alternate tagging experiment: time at large, with accumulated number and percentage of returns by ten-week periods for the two types of tags used

	Petersen discs		Lea tags	
Weeks out	Numbers returned	Accumulated Percentage	Numbers returned	Accumulated Percentage
0—10	17	2.7	8	1.3
11—20	13	4.7	8	2.5
21—30	8	6.0	10	4.1
31—40	7	7.1	6	5.0
41—50	16	9.6	9	6.4
51—60	4	10.3	1	6.6
61—70	3	10.8	1	6.7
71—80	1	10.9	2	7.0
81—90	2	11.2	—	7.0
91—100	7	12.3	—	7.0
101—110	3	12.8	—	7.0
111—120	2	13.1	—	7.0
121—130	2	13.4	1	7.2
131—140	—	13.4	—	7.2
141—145	1	13.6	—	7.2

There is a marked difference in recoveries obtained from tagging fish of different sizes, as evidenced by the mean size at tagging and the mean size (at tagging) of the recovered fish (Table 3). It would seem an expensive use of time and effort to tag otter-trawl-caught cod less than 40 centimetres in length (of the three recoveries, two were 39 centimetres long). Apparently with these tags and techniques, tagging and/or handling mortality is high enough in small fish to preclude any substantial returns.

Table 3

Alternate tagging experiment: percent return by sizes in 10 centimetre groups at tagging

Size group	Tagged			Returned			
(cm)	Disc	Lea	Total	Disc	Lea	Total	%
<40	68	78	146	3	0	3	2.0
41—50	125	111	236	12	4	16	6.8
51—60	89	107	196	16	7	23	11.7
61—70	77	83	160	14	10	24	15.0
71—80	109	92	201	14	8	22	10.9
81—90	80	89	169	14	10	24	14.2
91—100	45	41	86	6	4	10	11.6
>100	32	24	56	6	3	9	16.1

The Chatham tagging and the spring tagging on Georges Bank provide a reasonably good comparison of the two methods of capture used in these experiments. The Chatham tagging was done from a commercial line trawler in February and March, and the Georges Bank work was done from the *Albatross III* operating as an otter trawler in March and April. Size groups at tagging and recaptured fish (sizes at tagging) are shown in Table 4. Although the Petersen discs yielded superior percentages of returns in the alternate tagging, and the Georges Bank experiments show

Table 4

Comparison of returns by sizes at tagging from Georges Bank spring alternate tagging and Chatham tagging

Size group (cm)	Petersen discs Georges Bank Number tagged	Number returned	%	Lea tags Georges Bank Number tagged	Number returned	%	Lea tags Chatham Number tagged	Number returned	%
<41	0	—	—	0	—	—	71	10	14.1
41—50	1	1	—	0	—	—	228	56	24.6
51—60	5	1	20.0	7	1	14.3	255	68	26.7
61—70	28	10	35.7	25	4	16.0	211	50	23.7
71—80	54	9	16.7	56	5	8.9	136	38	27.9
81—90	61	11	18.0	62	6	9.7	62	11	17.7
91—100	38	6	15.8	35	3	8.6	24	4	16.7
>100	31	6	19.4	20	3	15.0	22	3	13.6

that this is true for all sizes of fish, line-trawl-caught fish marked with Lea tags yielded higher returns than otter-trawl-caught fish in many size categories, and also gave much better returns for fish of less than 50 centimetres, than did the otter trawl.

Thus line trawling appears a far superior method of capture for tagging cod regardless of tag type, either because of the inherent difference in the gear or because of the shallower depths fished. (In these experiments, the line trawl was fished at 6—25 fathoms while the otter trawl was fished at 40—65 fathoms.)

When the time of year that each of the tagging operations was performed is compared with the percentage of returns, it is obvious that, other things being equal, at least twice as many returns are obtained from tagging in the spring than at any other time. This is further borne out in other cod marking experiments performed from 1955 to 1959 but not reported here. The reason for this is probably because of the cold surface temperatures associated with the relatively isothermal conditions prevailing in spring in the area, so that the physiological insult of being caught and subjected to reduced pressures, increased light, and air exposure is not further aggravated by adverse temperature effects. It would seem that if the time of year for tagging in most areas is optional, spring would be best, but that if tagging must be done at another time, allowance for higher tagging mortality should be made in any subsequent calculations.

Analysis of returns from tagging haddock during some of the same operations (and during others) shows that there can be marked differences in percentage of returns from fish tagged at the same time and under identical conditions by different operators. Apparently some biologists and technicians are more skilful in eliminating fish that appear to be bad risks and/or in their handling of the fish which they tag. In these experiments there are insufficient data to demonstrate this phenomenon, since I did nearly 85% of the tagging myself, but this also is a factor to be considered in mortality calculations when more than one individual has done the marking.

Factors Affecting Quality of Returns

While sufficient numbers of returns are essential to any marking experiment, a factor sometimes neglected, particularly in the original planning of the experiment, is the *quality* of the return. There is a vast difference in value between a tag found in a fish chowder and a tag found by an alert co-operative fisherman who furnishes exact information about time, place, etc. Best is the return where the fisherman has been interviewed by a scientist or technician who has reminded him of various details he might have forgotten and who has had the opportunity to examine the fish for precise measurement, weight, condition, etc. Of course, various factors can affect the quality of the return, and some of these have been examined with relation to these experiments.

An important consideration in evaluating fish marks is the visibility to the captor. It is of little avail to mark fish if the mark is not usually found early enough to yield useful information about time and place of capture, etc. With this in mind, the way in which the tags were first discovered was analyzed (Table 5). The Lea tag has a higher visibility to the fisherman, as might be expected. Lea tags were discovered either when caught or shortly afterward on board the vessel about 55% of the time, while the Petersens were thus discovered only about 40% of the time. Although better and more reliable information is obtained from such early recoveries, the superiority of the Lea tag in this respect is not sufficient to outweigh the advantage of the discs in overall recoveries — in other words, in numbers, more Petersen discs were found early than Lea tags. An interesting point in this consideration is the much larger percentage of discs found while processing the fish — perhaps the reason for this is that it is virtually impossible to fillet a fish bearing such a tag without the knife striking the wire passing through the dorsal muscles.

Table 6 shows three important bits of information desired with tag return, and the varying degrees of precision with which they were obtained from the

Table 5
Alternate tagging experiment: analysis of when the tags were discovered on the fish

When discovered	Petersen discs Number	Petersen discs %	Lea tags Number	Lea tags %
1. When caught	13	15.1	10	21.7
2. On board	21	24.4	15	32.6
3. Unloading	5	5.8	2	4.3
4. Processing ashore	20	23.3	7	15.2
5. In market	11	12.8	6	13.0
6. By consumer	0	0	0	0
7. Unknown or other ...	16	18.6	6	13.0

recaptures made by various vessels and gear. It was always possible to make some reasonable estimate of the date of recapture, if only from the postmark on the envelope in which the tag came, but an inspection of the table shows that it was difficult to get from large and medium otter trawlers the exact date of recapture. This is undoubtedly due to the longer trips made by these vessels, but even this is not serious, for the date can usually be fixed with reasonable precision within a week or two.

Concerning location of recapture, the large and medium otter trawlers are the major offenders in respect of completely unknown locations. This is because of their propensity for ranging over wide areas in a single trip — a tagged individual not found until the fish are being or have been unloaded can often not be traced back to a particular fishing location. Line trawlers also show some serious discrepancies, because of the tendency of line trawl skippers either to neglect to mention location or to give it in terms of some local name not recorded on standard charts.

When it comes to useful measurement of the size of the recaptured fish, the otter trawlers as a group are far ahead of all other vessels and gear for producing good information; the majority of returns from otter trawlers produced a reliable measurement. This is probably not because of the nature of the vessels or their crews, but simply because they tend to land in the larger ports, where a technician is on hand to receive and measure the tagged fish.

Conclusions

1. Alternate tagging experiments, using Petersen discs on stainless wire through the dorsal muscles and Lea tags internally anchored, demonstrate the marked superiority of the former technique over the latter, at least for cod in the southern part of the ICNAF Convention Area. The advantage of the discs over the Lea tags is approximately 2:1 in return percentages, although there is a suggestion in comparison with other work that the place of attachment may be more important than the tag *per se*.

2. The use of either of these marking methods on otter-trawl-caught cod less than 40 centimetres in length yields very low returns (2%).

3. The line trawl was demonstrated as a superior method of capture for marking, particularly for smaller cod, although it is not entirely clear whether this is due to the gear itself or to the shallower depth fished.

4. Other things being equal, spring appears to be the best time of year for marking cod, probably due to hydrographic conditions.

5. Although these experiments do not demonstrate it, the skill of the operators, if there are more than one, is a factor to be considered in evaluating returns.

6. The Lea tag as used in this work is apparently more visible to the fisherman than the Petersen discs. When a tag is missed aboard the vessel it is more likely to be noticed soon afterwards if it is of a type which interferes with the work of processing the fish for market.

7. There is a marked difference in the quality of information received with tag returns from different sorts of fishing vessels. Generally the best information is received where it is possible for a trained person to interview the fishermen and to examine the fish.

Table 6
Number of returns with varying degrees of precision of information received with tag, from 1957 cod tagging experiments, classified by gear of recapture

Gear	Date Known	Date Estimated	Location Known	Location Estimated	Location Unknown	Size of fish at capture Known	Size of fish at capture Estimated	Size of fish at capture Unknown
Hand-line	23	3	24	2	0	12	0	14
Line trawl	90	3	82	11	0	20	3	70
Hand-line or Line trawl	10	2	10	2	0	0	0	12
Otter trawler, large	38	28	55	10	1	37	0	29
Otter trawler, medium	60	66	121	4	1	68	0	58
Otter trawler, small	51	2	50	3	0	26	0	27
Otter trawler, size unknown	0	1	0	1	0	1	0	0
Sink gill net	13	0	12	1	0	8	0	5
Unknown	28	15	23	4	16	3	1	39

Summary

During 1957, 2440 cod were tagged, 1291 of these alternately with Lea tags anchored internally and Petersen discs through the dorsal musculature. The alternate tagging experiments indicate clearly the superiority of the latter method. In a comparison of line-trawling vs. otter-trawling as a method of capture for tagging, the line appears to yield better results, particularly for smaller fish. The quality of the returns, that is the amount of accurate information received with the tag, is shown to be highly variable, although at least some of the reasons for the variability are subject to analysis.

References

McCRACKEN, F. 1963. Comparison of tags and techniques from recoveries of Subarea 4 cod tags. *This symposium*, contribution No. 16.

TROUT, G. C. 1958. Results of English cod tagging in the Barents Sea. *J. Cons. int. Explor. Mer*, 23 (3).

18.

The Effect on the Return Rate of Condition of Fish when Tagged

By

R. J. H. BEVERTON and B. C. BEDFORD*

Introduction

One cause of bias in tagging methods used for estimating population size or mortality rates arises if an appreciable proportion of tagged fish die within a short time after release. Rapid initial mortality of this kind is particularly difficult to detect or allow for, because it does not influence the pattern of subsequent recaptures; yet it introduces a corresponding bias in estimates of population size and fishing rate. One possible way of throwing further light on this question is to record the condition of tagged fish at release, and this procedure bas been adopted in recent tagging work on the herring, which is particularly liable to damage during capture and handling (see contribution No. 57). The technique is also described in connection with tagging experiments on sole, salmon and haddock in Nos. 20, 24 and 34.

Recording the condition of tagged fish at release has been introduced as a regular procedure in tagging experiments undertaken by the Lowestoft Laboratory in recent years on several demersal species. This paper reports on the results obtained with four species, namely two gadoids (cod, *Gadus morhua* and whiting, *Gadus merlangus*) and two flatfish (plaice, *Pleuronectes platessa* and sole, *Solea solea*), and suggests ways in which the resulting information can improve the interpretation of the tagging data.

Methods

Two main kinds of condition have been recorded for each fish liberated, (i) *superficial appearance* (good, moderate, poor) and (ii) *activity* (lively, sluggish, sinkers). The criteria for grading the condition of fish, which differ somewhat according to the species, are summarised in Table 1.

Fish included in the condition categories of Table 1 seldom, if ever, constituted the entire catch. Seriously scaled, damaged, or obviously moribund fish were never tagged, even if it meant that half or more of the catch had to be discarded. Fish of appearance categories G and M, and of all three activity categories A, B and S, would normally have been regarded as fit for tagging. What proportion of fish of appearance P (poor) would have been so regarded would have depended on the judgement of the observer and probably also on the general condition of the catches (i. e. if the general condition was good, more of the P fish might have been rejected, and vice-versa).

The tagging results reported here come from a number of experiments made in various areas and at various times within the last four years. Usually, for any one species, the observers were different on each cruise and had little opportunity to compare grading standards; as grading of condition is inevi-

Table 1
Criteria for grading the condition of whiting, cod, plaice and sole

SPECIES	SUPERFICIAL APPEARANCE GOOD (G)	MODERATE (M)	POOR (P)
WHITING	Not more than 2 cm² of scales missing; few small scratches; fins not broken or split; general appearance of uniform glistening golden colour and slimy.	From 2—6 cm² of scales missing, mostly in rubbed patches; slight fraying of fins; general appearance mainly glistening but with some dull patches.	More than 6 cm² scales missing; rather large rubbed patches; some damage to fin rays and membranes; general appearance dull and greyish.
COD	Very few scales missing; not more than one or two scratches; general appearance bright and shiny; no bruises.	Scales missing in small patches, showing dull and grey against natural colour; few small bruises.	More substantial areas with scales absent, especially along lateral line; general appearance blotchy; moderate bruising; slime absent over substantial part of body.
PLAICE SOLE	One or two slight scratches but no patches free of scales; no bruising; very slimy and bright in appearance.	One or two patches up to 2 cm² diam. rubbed free of scales and slime; slight bruising but *not* if near head.	Larger areas rubbed free of scales especially near head and tail; some bruising; general appearance dull greyishbrown; not much slime.

---

* Fisheries Laboratory, Lowestoft, England.

Table 1 (cont.)

	ACTIVITY LIVELY (A)	SLUGGISH (B)	SINKERS (S)
WHITING	Body distended with air; mostly floating on surface of tank, but making frequent and strong attempts to swim down; very active if touched.	Body distended with air; floating on surface of tank, but making strong attempts to swim down only when touched. Response to handling less marked than (A).	Body not distended; swimming freely at bottom of tank; active when handled.
COD	Swimming strongly in tank; struggles actively when handled for tagging.	Lies quiescent in tank or swims only slowly; reacts rather feebly to being handled.	—
PLAICE SOLE	Swims rapidly in tank for a number of second after being touched; struggles actively when handled.	Only a brief response to being touched when in tank; lies quietly on tagging board.	—

tably subjective to some degree, this may have introduced some lack of consistency in the results. In Tables 2—5 the results are given for each species in the same way; columns (x) show the total number of each category returned up to 1 February 1961 (first entry) and the total number of that category released (second entry); columns (y) show the percentage returned (underlined) with its confidence limits at the 0.95 significance level (brackets). The latter have been read graphically from Clopper and Pearson (1934) for $n < 1000$; where $n > 1000$, confidence limits have been calculated as plus and minus twice the standard deviation of the binomial, i. e. $\pm 2 \sqrt{n\,p\,q}$.

Cruises are shown separately and, in one species (plaice, Table 5), separate grounds worked during one cruise are distinguished. During analysis of the data, the possibility that the effect of condition might be a function of size of fish was examined; however, a clearly significant size effect was established in only one instance (cod, Table 3c), so with that exception sizes have been combined for presentation here.

Results

(a) Whiting

The data are from three cruises of R. V. "Platessa" in the north-western Irish Sea, two in November-December 1957 (Cruises XVIII and XIX) and one in December 1958 (Cruise XVIII). A preliminary account of the methods used and results obtained from the first two cruises combined has already been published (Beverton, Gulland and Margetts, 1959). Fish were caught by Danish seine and tagged with the Lowestoft plastic flag tag attached dorsally by a braided nylon loop (Williams, contribution No. 25). Most of the fish tagged were between 25 cm and 35 cm in length. The results for the three cruises separately are summarised in Tables 2a, b and c.

Tables 2

Whiting: effect of condition on the tag return rate

Columns (x) number returned (first entry), number released (second entry)

Columns (y) percentage returned (underlined) and its 95% confidence limits (brackets)

Table 2a. Cruise XVIII/1957

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	67/274	(31) 24.5 (19)	25/126	(28) 19.8 (13)	7/36	(38) 19.4 (8)	99/436	(28) 22.7 (18)
B	122/622	(22.8) 19.6 (16.4)	139/908	(17.7) 15.3 (12.9)	29/336	(13) 8.6 (6)	290/1,866	(17.2) 15.5 (13.9)
S	49/165	(38) 29.7 (22)	37/222	(22.5) 16.7 (12)	21/137	(23) 15.3 (9)	107/524	(25) 20.4 (16)
Total	238/1,061	(25.0) 22.4 (19.9)	201/1,256	(18.1) 16.0 (13.9)	57/509	(15) 11.2 (6)	496/2,826	(19.0) 17.6 (16.1)

Table 2b. Cruise XIX/1957

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	24/97	(35) 24.7 (17)	38/224	(23) 17.0 (12)	12/155	(13) 7.7 (8)	74/476	(19) 15.5 (12)
B	53/242	(28) 21.9 (17)	178/930	(21.7) 19.1 (16.6)	67/882	(9.4) 7.6 (5.8)	298/2,054	(16.1) 14.5 (13.0)
S	22/74	(42) 29.7 (19)	45/334	(18) 13.5 (10)	7/361	(5) 1.9 (1.5)	74/769	(11.7) 9.6 (7.5)
Total	99/413	(30) 24.0 (20)	261/1,488	(19.5) 17.5 (15.6)	86/1,398	(7.4) 6.2 (4.9)	446/3,299	(14.7) 13.5 (12.3)

Table 2c. Cruise XVIII/1958

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	14/63	(36) 22.2 (12)	17/121	(22.5) 14.0 (8)	6/54	(23) 11.1 (4)	37/238	(21) 15.5 (11)
B	58/242	(30) 24.0 (18.5)	139/740	(21.7) 18.8 (15.9)	34/417	(12) 8.2 (5)	231/1,399	(18.5) 16.5 (14.5)
S	11/53	(34) 20.8 (11)	10/114	(16.5) 8.8 (4)	7/83	(16) 8.4 (3.5)	28/250	(16) 11.2 (7)
Total	83/358	(28) 23.2 (18)	166/975	(19.4) 17.0 (14.6)	47/554	(11.5) 8.5 (6)	296/1,887	(17.4) 15.7 (14.0)

The following conclusions may be drawn from these tables:—

(i) *Effect of appearance* (*G*, *M*, *P*). There is a consistent and often marked decrease of percentage returned, over a two-to three-fold range, in the direction G-M-P. The trend appears in each cruise in each activity category and is highly significant ($p \ll 0.01$) where the numbers are large (e. g., category B on all cruises).

(ii) *Effect of activity* (*A*, *B*, *S*). A clear difference between lively (A) and sluggish (B) fish appears in Table 2a, but in the other two tables the return rate of these two categories is virtually the same. The effect of condition S ("sinkers", fish swimming at the bottom of the tagging tank without distended bodies) is rather variable. Thus, in both Tables 2a and 2b, GS fish gave the highest return rate of all categories (29.7%), but PS fish in Table 2b gave the lowest rate (1.9%). Some of this variability may have been due to the fact that "sinkers" were usually the last fish of each haul to be tagged (see Beverton and Bedford, contribution No. 59).

These effects of condition are shown graphically in Figs. 1a, b and c. Since the overall fishing rate was not necessarily the same during each cruise, the percentage returned of category MB on each cruise (in which there are the highest numbers of both liberations and recaptures) is taken as reference and given the index 100; the ratio of the percentage returned of the remaining eight categories to that of category MB (taken as 100) is then calculated. The resulting indices are shown plotted against appearance condition G, M, P in Figs. 1a, b and c. The relative effect of the two kinds of condition is at once apparent, with little difference between lively (A) and sluggish (B) fish except on Cruise VIII / 1957. In this connection it may be relevant

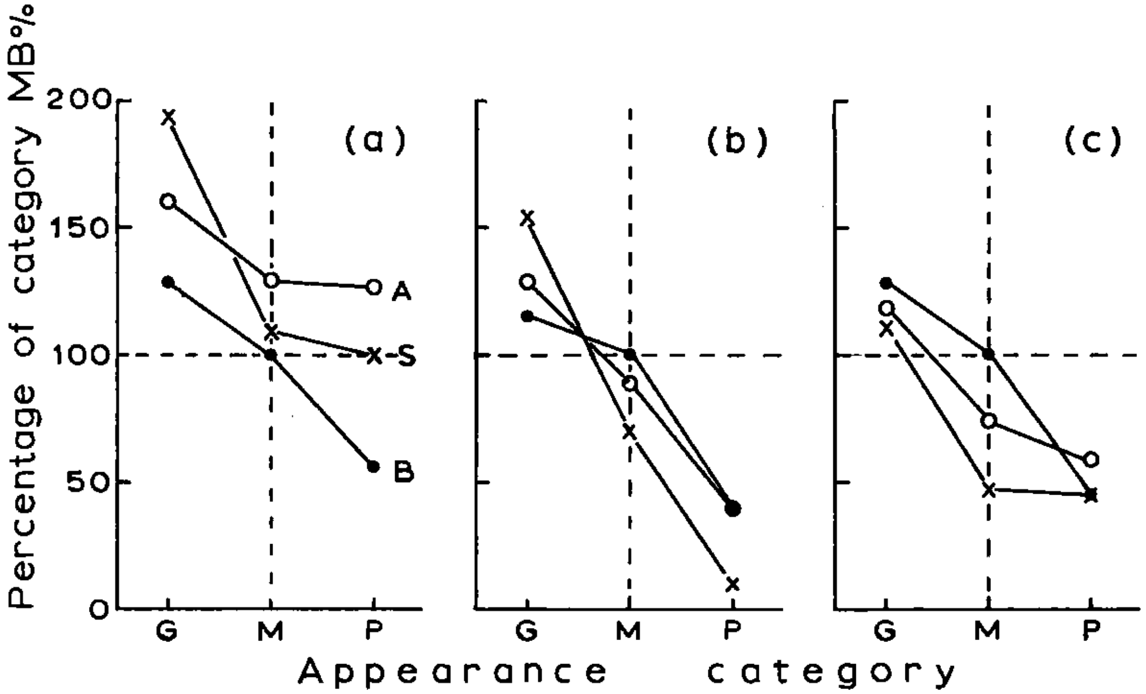


Figure 1. Effect of condition on return rate of tagged whiting for three cruises. The return rate of each category is expressed as a percentage of the return rate of category MB, to facilitate comparison between cruises. (a) Cruise XVIII, 1957; (b) Cruise XIX 1957; (c) Cruise XVIII, 1958.

that a higher percentage of fish tagged on this cruise were classified in category G than in either of the two subsequent cruises.

(b) Cod

The data are from three cruises of R. V. "Ernest Holt" in the north-east Arctic in 1959. The first two (Cruises V and VI) were made in July and August, off Spitzbergen; the fish tagged were almost entirely immature, ranging in size from 40 cm to 70 cm. The last cruise (Cruise VIII) was in November-December on Skolpen Bank in the south-western Barents Sea; the fish caught there were much larger, ranging from 60 cm to over 100 cm; roughly half were either mature or about to mature. All fish were caught by trawl, and the tag used throughout was the Lowestoft plastic flag tag, attached by a braided nylon loop (Williams, No. 25).

The results from each cruise are summarised in Tables 3a, b and c. No clear effect of size of fish on the difference between condition categories could be established for the first two cruises, perhaps because of the relatively restricted size range and small numbers of fish involved. There was, however, a clear size effect on Cruise VIII, and in Table 3c the data for this cruise are given by three size groups.

The main features of these tables may be summarised as follows:—

(i) *Effect of appearance* (*G*, *M*, *P*). There is usually (but not always) a decrease in the percentage returned, in the direction G-M-P. The trend is very steep and highly significant in some instances, e. g. for category B in Table 3a ($P \ll 0.01$) and for category A (60—69 cm) in Table 3c ($P \ll 0.01$; it is moderately significant for category A in Table 3a ($P = 0.05$) and for category A (70—79 cm) in Table 3c ($P = 0.02$). In other cases only the P fish are different (e. g. Table 3b, $P < 0.01$). In Table 3c no significant G-M-P differences can be established for category B fish, either for size groups separately or combined.

(ii) *Effect of activity* (*A*, *B*). The percentage returned of A fish is usually better than of B, and this difference is more consistent than in the whiting data although it is strongly significant only for M and P fish of Table 3a ($p < 0.01$). There are moderately significant differences between the combined A and B fish in Table 3c for the 60—69 cm group ($P \simeq 0.02$) and for the 70—79 cm group ($0.05 < P > 0.02$), but not elsewhere in any of the other data.

(iii) *Effect of size.* The decrease of return rate with appearance condition G-M-P becomes less marked

Tables 3

Cod: effect of condition on the tag return rate

Columns (x): number returned (first entry), number released (second entry)
Columns (y): percentage returned (underlined) and its 95 % confidence limits (brackets)

Table 3a. Cruise V/1959

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	135/578	(28) 23.4 (18)	30/185	(23) 16.2 (11)	7/59	(23) 11.9 (4)	172/822	(23.8) 20.9 (18.1)
B	39/180	(28) 21.7 (16)	3/72	(13) 4.2 (1)	0/27	(14) 0.0 (0)	42/279	(20) 15.1 (11)
Total	174/758	(27) 23.0 (18)	33/257	(18) 12.8 (8)	7/86	(17) 8.1 (3)	214/1,101	(21.8) 19.4 (17.1)

Table 3b. Cruise VI/1959

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	25/198	(18) 12.6 (8)	41/266	(21) 15.4 (11)	5/68	(17) 7.4 (2)	71/532	(18) 13.3 (11)
B	9/85	(19) 10.6 (4)	27/245	(16) 11.0 (7)	4/78	(13) 5.1 (2)	40/408	(14) 9.8 (7)
Total	34/283	(17) 12.0 (8)	68/511	(17) 13.3 (9)	9/146	(12) 6.2 (3)	111/940	(14) 11.8 (10)

Table 3c. Cruise VIII/1959

	60 to 69 cm							
	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	29/170	(24) 17.0 (12)	47/618	(11) 7.6 (5)	8/205	(8) 3.9 (2)	84/993	(10.3) 8.5 (6.7)
B	0/14	(24) 0.0 (0)	14/254	(9) 5.6 (3)	5/132	(9) 3.8 (2)	19/400	(8) 4.8 (3)
Total	29/184	(22) 15.8 (10)	61/872	(8.7) 7.0 (5.3)	13/337	(7.5) 3.9 (2)	103/1393	(8.8) 7.4 (6.0)

Tables 3

Cod: effect of condition on the tag return rate

Table 3 (cont.)

70 to 79 cm

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	20/124	(24) 16.1 (9)	45/356	(17) 12.6 (9)	6/129	(11) 4.6 (2)	71/609	(15) 11.7 (8)
B	0/10	(32) 0.0 (0)	6/110	(11) 5.4 (2)	4/50	(20) 8.0 (2)	10/170	(14) 5.9 (2)
Total	20/134	(23) 14.9 (9)	51/466	(14) 10.9 (8)	10/179	(10) 5.6 (2)	81/779	(12.6) 10.4 (8.2)

80+ cm

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	28/147	(28) 19.1 (13)	67/345	(24) 19.1 (15)	15/116	(21) 12.9 (7)	110/608	(23) 18.1 (15)
B	1/9	(50) 11.1 (0)	13/89	(24) 14.6 (7.5)	8/45	(32) 17.8 (8)	22/143	(23) 15.4 (9)
Total	29/156	(27) 18.6 (12)	80/434	(23) 18.4 (14)	23/161	(22) 14.3 (8)	132/751	(20.4) 17.6 (14.8)

Sizes Combined

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	77/441	(22) 17.5 (13)	159/1,319	(13.8) 12.1 (10.3)	29/450	(9) 6.4 (3)	265/2,210	(13.4) 12.0 (10.6)
B	1/33	(17) 3.0 (0)	33/435	(12) 7.3 (5)	17/227	(12) 7.5 (4)	51/713	(10) 7.2 (6)
Total	78/474	(21) 16.5 (12)	192/1,772	(12.3) 10.8 (9.4)	46/677	(9) 6.8 (4)	316/2,923	(12.0) 10.8 (9.7)

as size of fish increases. This is shown by the data of Table 3c for fish of category A, where the return rates relative to condition GA are:—

Size group	Relative return rate		
	GA	MA	PA
60—69 cm	1	: 0.45	: 0.23
70—79 cm	1	: 0.78	: 0.29
80+ cm	1	: 1	: 0.68

The G-M-P trends of A and B fish from the data of Cruises V and VI with sizes combined, and of A fish of Cruise VIII by size groups, are shown graphically in Figs. 2a and 2b.

Generally speaking, the results for cod conform to the same general pattern as those for whiting but are less consistent, being even more marked in some instances (e. g., both A and B fish on Cruise V; A (60—69 cm) fish on Cruise VIII) and virtually

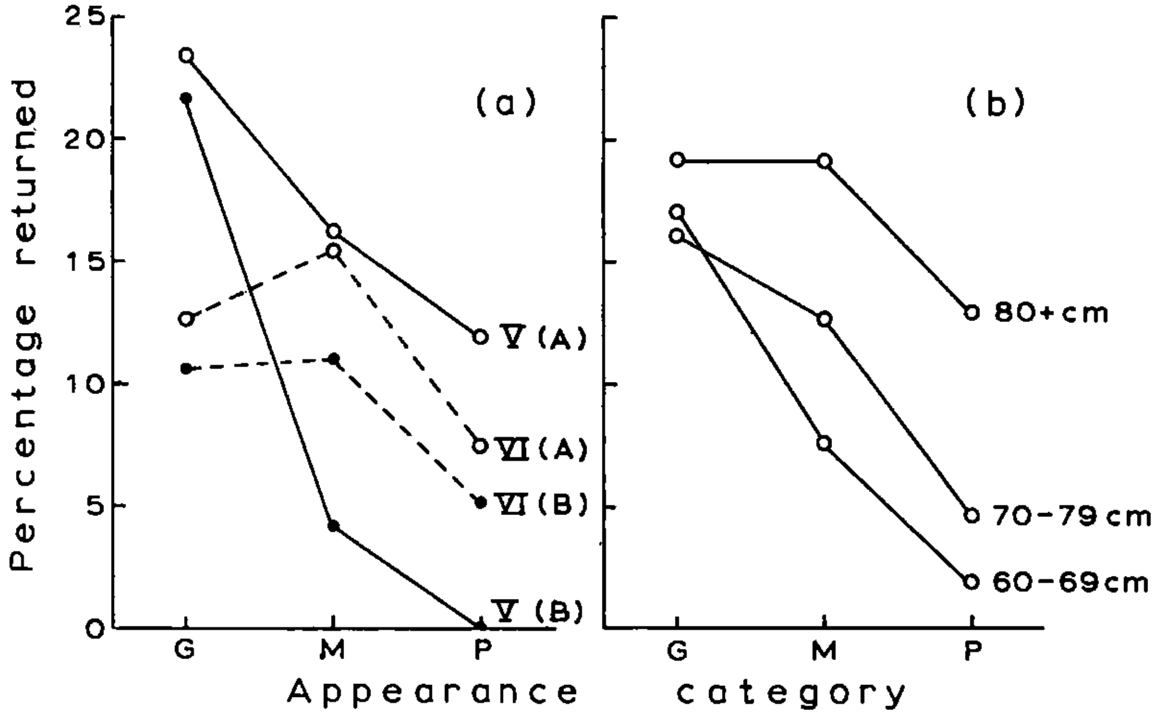


Figure 2. Effect of condition on return rate of tagged cod for three cruises. Figure 2a shows the contrasting results obtained for category A and B fish on Cruises V and VI, 1959; Figure 2b shows the effect of condition in relation to size of fish, for category A only, from Cruise VIII/1959.

absent in others (G—M on Cruise VI; G-M-P for B fish on Cruise VIII). The lack of a G-M difference on Cruise VI is perhaps the most anomalous feature, since this followed shortly after Cruise V in the same area, from which a marked G—M difference emerged. This may have been due in part to observer bias in the recording of condition, but the average condition of fish on Cruise V was unusually good and certainly better than on Cruise VI, so that a substantial proportion of the fish classified as G on Cruise V may have really been better than even the best caught on Cruise VI.

(c) **Sole**

The data are from a cruise in the White Bank area of the North Sea (55°00′N, 06°00′E) in March 1959. Fish ranged in size from about 23 cm to about 40 cm, but no size effect could be established. All the fish reported here (about 95% of the total liberations) were tagged with Petersen buttons (Williams, No. 25).

Fish were originally classified into five appearance categories, namely good, scratched, rubbed, bruised and lacerated. The majority of both the releases and returns were "good", which corresponds to the category G of Table 1; the numbers in the remaining categories were too few for separate analysis and they have been grouped together here as a single category which corresponds roughly to the combined categories M and P of Table 1.The results are summarised in Table 4.

Table 4

Sole; effect of condition on the tag return rate

Columns (x): number returned (first entry), number released (second entry)

Columns (y): percentage returned (underlined) and its 95 % confidence limits (brackets)

	G		M + P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)
A	203/1,206	(19.0) 16.8 (14.7)	39/414	(14) 9.4 (7)	242/1,620	(16.7) 14.9 (13.2)
B	6/143	(9) 4.2 (2)	7/167	(9) 4.2 (2)	13/310	(7.5) 4.2 (3)
Total	209/1,349	(17.5) 15.5 (13.5)	46/581	(12) 7.9 (5)	255/1,930	(14.8) 13.2 11.7)

Tables 5

Plaice: effect of condition on the tag return rate

Columns (x): number returned (first entry), number released (second entry)
Columns (y): percentage returned (underlined) and its 95 % confidence limits (brackets)

Table 5a. Plaice; Cleaver Bank

	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	39/70	(68) 55.7 (42)	51/84	(72) 60.7 (48)	44/63	(82) 69.9 (56)	134/217	(68) 61.8 (55)
B	11/23	(70) 47.8 (27)	25/54	(61) 46.3 (32)	36/70	(64) 51.5 (38)	72/147	(58) 49.0 (40)
Total	50/93	(64) 53.8 (43)	76/138	(64) 55.1 (46)	80/133	(69) 60.1 (50)	206/364	(62) 56.6 (50)

Table 5b. Plaice; Haddock Bank

	G		M + P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)
A	28/118	(33) 23.7 (16)	13/84	(26) 15.5 (8)	41/202	(27) 20.3 (15)
B	3/8	(78) 37.5 (7)	4/22	(42) 18.2 (5)	7/30	(43) 23.3 (10)
Total	31/126	(34) 24.6 (17)	17/106	(24) 16.0 (9)	48/232	(27) 20.7 (15)

Table 5c. Plaice; Black Bank

	G		M + P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)
A	7/13	(82) 53.8 (24)	17/36	(66) 47.3 (29)	24/49	(64) 49.0 (35)
B	2/2	(100) 100.0 (20)	13/24	(75) 54.2 (32)	15/26	(77) 57.7 (36)
Total	9/15	(84) 60.0 (32)	30/60	(64) 50.0 (36)	39/75	(64) 52.0 (39)

Certain definite conclusions emerge from this table, and can be summarised as follows: —

(i) *Effect of appearance* (*G*, *M* + *P*). There is a nearly two-fold difference in percentage returned between G and M + P of category A fish, which is highly significant ($P \ll 0.01$). There are too few fish of category B to determine whether or not such a difference exists among them too.

(ii) *Effect of activity* (*A*, *B*). There is a four-fold difference between A and B fish of category B, which is highly significant ($P \ll 0.01$). A moderately significant difference ($P \simeq 0.05$) in the same direction is shown between A and B fish of category M + P.

It seems that the average condition of fish tagged on this cruise was high, at least as classified, and although the effect of condition can be clearly established it may be that a further discrimination within the category G is possible. The noticeable feature of these results for sole is that the distinction between activity categories A and B seems to be much more marked than in either whiting or cod.

(d) Plaice

The data are from a cruise of R. V. "Sir Lancelot" in the North Sea in June 1958. Two kinds of tags were used, namely Petersen buttons and the Lowestoft plastic flag tag; these gave somewhat different percentage returns (Williams, No. 25), but as roughly equal numbers of each kind of tag were used and distributed representatively over the releases, the data have been combined for the present analysis. Fish were caught by trawl and the majority were between 27 cm and 37 cm in size; no size effect could be established. Liberations were made on three grounds (Cleaver Bank, 54°00′ N, 03°30′ E; Haddock Bank, 53°20′N, 01°40′E; and Black Bank, 53°20′N, 03°50′E); the results for each are shown separately in Tables 5a, b and c.

In contrast to the previous results, no significant effect of either appearance or activity condition can be established from these data, and such indications as appear are not consistent in all three tables. Thus, the trend of percentage returned *increases* (!) in the direction G-M-P in Table 5a but decreases in Table 5b, although neither trend is significant ($P \geq 0.2$). Similarly, the percentage returned of A fish is greater than of B fish in Table 5a but less in Table 5b; again, neither difference is significant ($P \geq 0.1$). In Table 5c (apart from the 100% return of GB fish, two out of two), the percentage returned is remarkably similar in all categories.

It is, of course, possible that small differences in condition effect may exist which cannot be established from the quantity of data available. Nevertheless, the results can be shown in certain instances to be incompatible with the order of differences found for the previous species. For example, the observed ratio of percentage returned of G fish compared with P fish of category A in Table 5a is 0.8:1; the probability is 0.01 or less that this could have arisen by chance from a true ratio of 1.3:1 or greater. Yet in whiting, cod and sole the ratio is for the most part between 2:1 and 4:1.

The fish to which Tables 5 relate were released as soon as possible after being tagged, but on the same cruise other fish were held on board for up to five days before release (Beverton and Bedford, Contribution No. 59). In these latter fish, moderately to highly significant effects of both appearance and activity condition were found. As all fish tagged on this particular cruise were graded by the same observers using the same criteria, this result strengthens the conclusion that the condition of plaice released within a short time of capture had little effect on their subsequent survival.

Time Pattern of Returns

Having established significant effects of condition in three of the four species by comparing the total percentage returned of each category, the question arises of whether the time pattern of returns also varies with condition. Ancellin and Nédèlec (1959) have examined this point for herring tagging data in which nearly all the returns were obtained within about three weeks after release. They showed that whereas each condition category gave much the same return rate over the first few days, the best condition fish gave significantly higher returns towards the end of the period. The present data cannot usefully be broken down into such short time intervals as this, but analysis can be made of the percentage of the total returns of each condition category which were returned at intervals of 25 or more days after release.

Table 6

Time pattern of tag returns in experiments where the total returns showed marked condition effects

1st entry — % of total returns
2nd entry (brackets) — number of returns

Whiting ("Platessa" XVIII& XIX/57& XVIII/58, A + B + S)

Period (Days)	Good	Moderate	Poor
0—50	56 (234)	63 (393)	61 (113)
51—100	24 (102)	20 (121)	26 (49)
101—150	12 (51)	10 (65)	7 (14)
151—200	3 (12)	2 (12)	2 (3)
201—250	1 (3)	1 (9)	0 (0)
251—300	1 (6)	2 (10)	1 (2)
301+	3 (12)	2 (10)	3 (6)
Total	100 (420)	100 (620)	100 (187)

Cod ("Ernest Holt" V/59, A's + B's)

Period (Days)	Good	Moderate	Poor
0—25	56 (92)	39 (11)	29 (2)
26—100	15 (24)	15 (4)	14 (1)
101+	29 (48)	46 (13)	57 (4)
Total	100 (164)	100 (28)	100 (7)

Cod ("Ernest Holt" VIII/59, 60—69 cm, A's + B's)

Period (Days)	Good	Moderate	Poor
0—25	33 (9)	33 (18)	40 (4)
26—100	30 (8)	15 (8)	30 (3)
101—200	18 (5)	28 (15)	20 (2)
201+	19 (5)	24 (14)	10 (1)
Total	100 (27)	100 (55)	100 (10)

Sole ("Platessa" V& VI/59)

Period (Days)	A's only		Good + Moderate + Poor	
	Good	Moderate + Poor	A's	B's
0—50	28 (57)	26 (10)	28 (67)	50 (6)
50—300	37 (76)	30 (12)	36 (88)	17 (2)
301+	35 (70)	44 (17)	36 (87)	33 (4)
Total	100 (203)	100 (39)	100 (242)	100 (12)

Note: The total returns shown in these tables are in some instances a little smaller than for the same experiment in earlier tables, because the exact time at liberty of a few returns was not known.

Some of the instances in which there are marked effects of condition on the total return rate are presented in this way in Table 6. Neither in these examples, nor elsewhere in the data considered in this paper, can any significant or consistent effects of condition on the time pattern of returns be established. In whiting, for example, although the total return rate of P fish was only about one-third that of G fish, the proportion of the total returns which came in during each time interval shown in Table 6 is very nearly the same for fish of both conditions.

It is therefore concluded that the effect of condition at release is associated, as might perhaps be expected, with a mortality which occurs within a relatively short time after release, and that when this mortality is over the subsequent survival is no longer influenced by condition at release.

Discussion

Grading takes very little extra time during the tagging operation, but where it is established that the condition at release has a significant effect on the return rate, as in whiting, cod and sole, this additional information can help to minimise the relative bias which might otherwise arise when comparing or combining different tagging experiments, either through differences in the average condition of released fish or, possibly, in their size composition. This may be especially important if the experiments in question have involved the use of different catching methods. Further, the information on the return rate of fish of various conditions can go some of the way towards reducing the absolute bias due to initial tagging mortality.

The whiting and cod data presented here provide examples of the use of condition information to minimise relative bias. Thus the difference between the gross return rate from Cruise XVIII/1957 (17.6%, Table 2a) and Cruise XIX/1957 (13.5%, Table 2b) is highly significant. Inspection of the data by condition categories shows, however, that this difference is due mainly to the lower average condition of the fish caught on the second cruise, in which category P comprised 42% compared with only 18% on the first. Comparison of the more reliable G and M categories shows very similar return rates from the two cruises, with the second cruise giving, if anything, slightly the higher value.

The cod data of Table 3c provide an example of the importance of condition information where the effect of condition is itself size specific. Thus, the gross return rate increases progressively with size of fish, viz: 7.4%, 10.4% and 17.6% for the size groups 60—69 cm, 70—79 cm and 80 + cm respectively. In the absence of conditioning, several possible explanations could be advanced; the two most plausible being that the smaller fish suffered a higher tagging mortality than did the larger, or that fishing rate increased with size of fish. Inspection of Table 3c shows, in fact, that the former explanation is probably the correct one, since the return rate of the best condition fish (GA) is nearly the same in all three size groups (17.0%, 16.1% and 19.1%, respectively).

On the other hand, the absolute bias due to initial tagging mortality cannot necessarily be eliminated by condition information, although it can be reducede. Thus it is clear that the best available estimate of the "true" return rate (i. e. if there were no initial tagging mortality) is obtained from fish of the best condition (GA, or possibly, in whiting, GS), with due allowance for the confidence limits attaching to it. Similarly, if this best return rate is denoted by x, then the proportion of fish of any other category, giving a return rate y, which must have died is at least $1-\frac{x}{y}$. In the whiting data, for example, the return rate of category P is roughly one-third that of category GA; this means that at least two-thirds of the P fish must have died shortly after liberation. In the sole and some of the cod experiments, the initial tagging mortality of the worst condition fish must have been higher still.

Even the highest of the observed return rates may, of course, be lower than the "true" rate — perhaps considerably so, since it does not follow that its members suffer no initial tagging mortality even if they appear to be in perfect condition. In the two gadoid species, where the G-M-P criteria are fairly quantitative (being determined primarily by the degree of scaling) and there is a fairly regular gradation of return rate in the sequence G-M-P, it might not be unreasonable to suppose that this same gradation exists also *within* the category GA (which itself includes up to a small degree of scaling.). On this basis, the ratio of the return rate of the best of the GA fish to the average GA fish could be taken, very roughly, as about half that between the whole categories GA: MA: PA. In the whiting data, the ratio of return rates in categories GA: MA and MA: PA is about 1.5 : 1 on average, so that the return rate of the best of the GA fish could be estimated on this basis as roughly 1.25 times higher than the average GA rate, i.e., about 30%. The fact that two out of the three GS return rates were in the region of 30% without this adjustment, suggests that even this figure probably includes some tagging mortality. On the other hand, where no marked differences in the return rate between even the best and worst conditions are found, as in plaice, it means that if there is any appreciable tagging mortality it must be due to causes which are not manifest in either the appearance or activity of the fish at the time of liberation. This does not seem very likely, and it would seem reasonable to suppose that the initial tagging mortality in such a case is, indeed, not high. Further evidence on the initial tagging mortality of both whiting and plaice is offered in Beverton and Bedford, contribution No. 59.

From these considerations it is suggested that releasing fish of several grades of condition as a routine procedure can provide valuable additional information to that obtained by releasing only fish of the "best" condition, or simply those which are judged by the observer to be fit for tagging.

Future Requirements

There would seem to be two main requirements for the future. One is to improve as far as possible the visual grading criteria, and in this connection it must be emphasized that the criteria set out in Table 1 are only what seemed, ***a priori***, to be the obvious differences in condition. Generally speaking, the results have shown that these criteria are evidently meaningful, although it is perhaps questionable whether whiting and cod of category "poor" as defined in Table 1 are worth tagging as a routine. There may also be other criteria which could provide better or additional discrimination. For example, in most species and especially in plaice, there are noticeable differences in the muscular tone of the fish, and it may be that this feature is a better indication of their chances of survival than "lively" and "sluggish" as defined in Table 1.

The other requirement is the search for the "perfect" tagged fish, which suffers no initial mortality, so that some idea can be obtained of the mortality to be expected among even the best fish under normal tagging conditions. There are several possibilities here, such as capture by hook and line to avoid all bruising and scale damage (especially in gadoids); capture in shallow water to avoid rupture of the air-bladder (which probably occurred in most or all of the whiting and cod reported here); and holding fish on board until the phase of initial mortality is over (see Beverton and Bedford, No. 59). Each of these possible techniques would, of course, need to be tested against normal tagging procedure by controlled experimentation.

Summary

(a) The condition at release has been recorded in tagging experiments on whiting, cod, sole and plaice. Two kinds of condition have been distinguished; ***appearance***, good (G), moderate (M) and poor (P); and ***activity***, lively (A), sluggish (B) and (in the case of whiting) sinkers (S).

(b) Appearance condition (G, M, P) is found to have a marked influence on the return rate of whiting, cod and sole. The influence of activity condition (A, B, S) is less consistent, but is significant in some experiments (e.g., cod and sole). The effect of condition, of either kind, was least marked in plaice.

(c) Condition is found to be size-specific in cod, the effect of condition being more pronounced among small fish than large.

(d) It is shown that the differential mortality responsible for the effect of condition on the return rate occurs within a short time after release.

(e) It is concluded that releasing tagged fish of a reasonable range of condition, recorded as objectively as possible, can provide valuable additional information compared with the more usual procedure of releasing only the "best" fish. Examples are given of the use of such information to improve the comparability of tagging experiments in which the tagged fish were of varying average condition and size.

(f) It is suggested that information on the return rate of fish of various conditions can also give some indication of whether any substantial initial tagging mortality is to be expected among even the fish in best condition.

References

BEVERTON, R. J. H., GULLAND, J. A. & MARGETTS, A. R. 1959. Whiting tagging: how the tag return rate is affected by the condition of fish when tagged. *J. Cons. int. Explor. Mer.*, **25**: 53—57.

CLOPPER, C. J. & PEARSON, E. S. 1934. The use of confidence or fiducial limits illustrated in the case of the binomial. *Biometrika*, **24**: 404.

ANCELLIN, J. & NÉDÈLEC, C. 1959. Marquage de harengs en Mer du Nord et en Manche Orientale. *Rev. Trav. Off. Pêches marit.*, **23**: 177—201.

19.

Some Aspects of Fish-Marking Mortality*)

By

ROBERT R. PARKER**, EDGAR C. BLACK*** and PETER A. LARKIN****

Introduction

Tagging or marking fish has long been a valuable procedure in tracing movements of fish or in studying their growth and mortality rates. Fisheries biologists are generally aware that this technique is subject to some limitations. Aside from the obvious errors due to structural failure of the tag, mortality due directly to wounds, etc., the assumption is often made that a tagged fish is similar in all respects to other members of the population to which it is returned. This assumption may apply both to short and long term effects of marking and to the mechanics of operation of various facets of the biology such as movements, migration, feeding, predator and competitor relationships, and the interaction of the marked fish with others of their own kind. The validity of this assumption is the main subject of this communication. Most of the following discussion and examples are concerned with salmonid fishes and reflect the limitations of the authors' experience. It is left to the reader to interpret the results and suggestions in the light of his own experiences with other species.

Short-term Mortality

Injury

In addition to obvious critical injury and operative shock, the act of capturing, handling and marking may provide an entrance for infection either through the marking wound or breaks in the epidermis brought about by handling. Such slight wounds may also lead to the over-taxation of osmoregulation facilities. Of possible significance here are the observations of Robertson and Wexler (1960) describing the active growth and thickening of the skin of chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) with approaching sexual maturity. In the mature salmon this process appears to minimize the possibility of abrasion and puncture leading to entrances for infection. In juvenile stages, salmonids may be particularly susceptible to osmoregulatory distress following loss of scales.

Such sources of mortality may easily be determined by holding marked individuals. It does not appear that this type of loss is commonly excessive in salmonids, for Armstrong (1949) reported no excess mortality (over control lots) in fin-clipped lake char (*Salvelinus namaycush*) fingerlings held for ten months. Barnaby (1944) held fin-clipped sockeye smolts for a few days and observed no excess mortality. Davidson (1934) held marked pink salmon (*O. gorbuscha*) fry for 24 hours without mortality attributable to marking. Foerster (1936), Rich and Holmes (1928), Shetter (1951) and Ricker (1949) have reported essentially similar results for a variety of fishes. Recently, the present authors held 350 pink salmon fry marked by the removal of the adipose and right ventral fins, together with a control group of 350 unmarked fry, with no significant differences in mortality rate over a 40-day period. In these cases it appears that death from the operation itself does not constitute an important source of short-term mortality. Moreover, it is usual for tagging crews to reject fish which appear to be seriously injured in the tagging procedure, and this technique has led to increased tag recovery percentages in several instances (Fry and Hughes, 1951; Van Hyning, 1951).

Fatigue

Marking of fish in field conditions usually involves a pursuit, a struggle and a handling procedure, all of which activities may impose a "stress" on the fish and lead to some degree of fatigue. That fish may die in captivity following hyperactivity has been demonstrated by several investigators. First among these was von Buddenbrock (1938), working with cod (*Gadus morhua*) and dab (*Platessa limanda*) at the Heligoland Biological Station in 1936 and the Biological Station at Naples in 1937. Huntsman (1938) related the amount of struggling of herring in nets and haddock on hand lines and in trawls to the incidence of death while yet in water. He was able to keep herring and haddock alive at the Atlantic Biological Station, New Brunswick, only when struggling was reduced to a minimum. Milne and Ball (1956) observed death of coho salmon (*O. kisutch*) and later (1958) of chinook salmon following capture by troll gear. Black (1957c) observed mortality of

---

* Contribution from the Biological Station, Fisheries Research Board of Canada, Nanaimo, B. C., the Department of Physiology and the Institute of Fisheries, University of British Columbia, Vancouver, Canada.

** Senior Scientist, Biological Station, Nanaimo, B. C.

*** Professor, Department of Physiology, University of British Columbia, Vancouver, Canada.

**** Professor of Zoology and Director of the Institute of Fisheries, University of British Columbia, Vancouver, Canada.

juvenile sockeye salmon following 15 minutes of forced activity. Bates and Vinsonhaler (1957) reported death following exhaustion of smolt chinook, striped bass (*Roccus saxatilis*) fry and shad (*Alosa sapidissima*) fry at the Tracy, California pumping plant (see also Anon. 1957). Parker and Black (1959) and Parker, Black and Larkin (1959) reported serious delayed mortality following struggling of coho and chinook salmon on troll gear. In each case, severe muscular activity was followed by significant mortality. With the exception of the observations of Bates and Vinsonhaler, all fish were in sea water.

Other observers, working with these and other species, have reported apparently contradictory results. Black (1957a and b) working with rainbow trout (*Salmo gairdnerii*) and lake char in fresh water subjected his fish to strenuous activity without ensuing mortality. Paulik and De Lacy (1958) and Paulik, De Lacy and Stacy (1957) subjected adult coho and sockeye salmon to repeated exhaustive performance tests in fresh water without significant mortality. Parker, Black and Larkin (1959) subjected adult coho to simulated troll-caught conditions in fresh water with no ensuing mortality. It is worth noting, however, that Paulik, De Lacy and Stacy (1957) reported that the fish's capacity for further work was but 67% recovered after a three-hour rest period (minimum estimate).

Von Buddenbrock (1938) observed that the red blood cells appeared to be collapsed and misshapen when blood lactate levels were high following strenous activity. Secondat and Diaz (1942) reported that blood lactate concentrations of tench (*Tinca tinca*) increased following forced activity but usually subsided by the end of six hours. These investigators also observed that some fish died and the blood lactate levels of these had failed to decrease. Black (1955, 1957a, b, c) demonstrated a similar lactate response for several species of fishes, and Parker and Black (1959) and Parker, Black and Larkin (1959) followed the rise and fall of blood lactate concentrations during post-exercise rest both in independent and in sequential samples of troll-caught chinook and coho salmon in sea water. A positive association was demonstrated between blood lactate level and death. While high blood lactate levels have not been shown to be a direct cause of death, they are a significant correlate of death following hyperactivity.

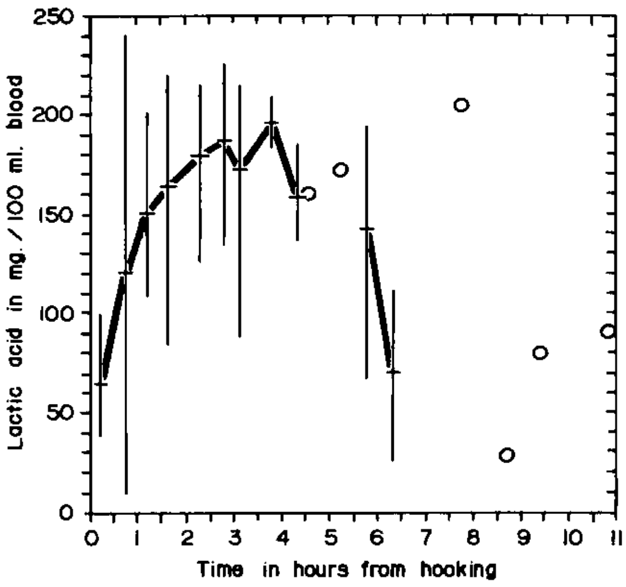


Figure 1. Blood lactate levels of chinook salmon following capture by trolling. Horizontal lines through means represent the time range of the group; vertical lines through means represent the range in lactate level. Single observations are indicated by circles.

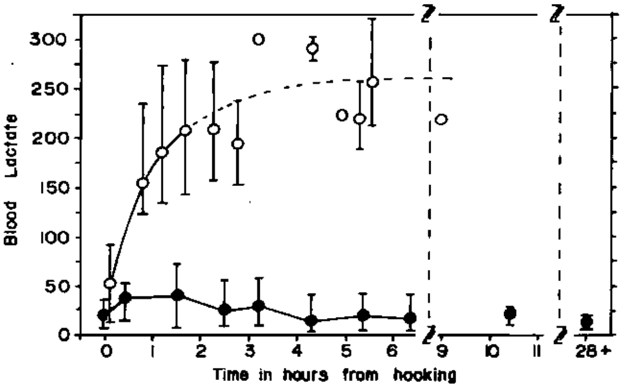


Figure 2. Coho blood lactate (expressed as mg % lactic acid) response in time from hooking. Open circles represent mean value for fish which died in the salt water experiment. Dashed line drawn freehand to indicate probable average. Solid circles represent mean value for fish in fresh water. Vertical lines through means indicate range of values.

These responses to forced activity are shown graphically in Figure 1 for chinook and Figure 2 for coho. In Figure 1, the rise and subsequent decline of blood lactate is shown following approximately 10 minutes of struggle by the fish on troll gear. In Figure 2 the upper line traces the blood lactate level of coho which died following capture by troll gear. These were sub-mature feeding fish in salt water. The lower line of Figure 2 depicts the average blood lactate concentration of non-feeding mature coho in fresh water following simulated troll-caught conditions. Initial values for both sets of observations indicate blood lactate levels for fish immediately after capture.

The fact that maturing fish were notably less susceptible to hyperactivity than sub-mature or immature feeding fish is of possible general significance. Many marine fishes cease or reduce feeding activity during spawning, e. g., haddock (Homans and Vladykov, 1954), and to some degree it may be surmised that physiological changes may parallel those found in Pacific salmon. It is possible then that if tagging or marking is restricted to the spawning season, death due to fatigue may be much reduced and the survival of marked fish enhanced. Conversely, it seems possible that smolts, because of the physiological state associated with migration, are particularly susceptible to the effects of lactate accumulation, which effects would be enhanced by osmoregulatory stress associated with their proneness to scaling. Considering the variety of findings it seems appropriate to suggest that fish may be more or less susceptible to the effects of fatigue at particular life-history stages. Knowledge of the various stages is of practical value to the fisheries biologist engaged in a marking program.

Mortality indirectly caused by fatigue or injury

It is worth re-emphasizing that, even though death may not result from violent exercise, the fish at best is less prepared for several hours to meet demands for vigorous sustained swimming. In addition there are behavioural changes: (1) a sharp drop in swimming rate, (2) a breakup in normal schooling behaviour, (3) a change from active to passive evasion (Black, 1957a). Moreover, any injury, though it may not cause death directly, may cause the release of "alarm substances" (von Frisch, 1941) with a variety of effects. Schools of the same species may concentrate and take flight; predators may be attracted; in short the injured and fatigued fish may not only invite predation but may be incapable of escape and may also lose the statistical protection of being one of a school.

It is tempting to suggest that part of a successful marking program might be: the satiation of the predators in the local area; the holding of marked fish until effects of fatigue are over and injuries are healed; or the release of marked fish in an area removed from the site of capture and injury.

Long-term Mortality

Amputation of a fin or fins or affixing a tag may place the individual at a disadvantage, compared with unmarked fish, in meeting its natural environment over a longer period of time. Several studies (i. e. Armstrong, 1949; Pritchard, 1939; Ricker, 1949; and Shetter, 1951) have shown that the rate of growth is generally unaffected or but slightly. Studies of Harris (1936, 1937, 1938) and Radcliffe (1950) indicate that amputation of a dorsal, pectoral or ventral fin affects the fishes' ability to manoeuvre, and hence an adverse effect upon the ability to elude a predator except by a straight line race is to be expected. Barnaby (1944) remarked that removal of a pectoral fin on sockeye resulted in a slight "list" of the individual.

Ricker (1949) experimented with survival of marked and unmarked spiny-rayed fishes under simulated natural conditions and reported a persistently lower survival rate for the marked populations. His treatment of data from sockeye salmon of Foerster (1936) demonstrates that a small increase of day to day mortality (of but 1.3 times that of the unmarked population) leads to an observed survival of 0.88% as opposed to 2.49% of the unmarked group at the end of a two-year period of time. That size affected the degree of differential mortality was also demonstrated. On the other hand Shetter (1952), experimenting with lake char, found statistically significant predator preference for marked over unmarked fingerlings.

Using data of Pritchard (1939, 1941, 1948) and of Hunter (1959) similar calculations for the effect of fin removal on the survival of pink salmon fry are presented in Table 1. In these experiments, fins were amputated during the descent of fry from the stream into the sea. Recoveries were made at the marking site when the fish returned 17 months later as adults. A weir provided the opportunity for both fry and adult enumeration. The first four experiments were conducted at McClinton Creek (Queen Charlotte Islands) and the fifth at Hooknose Creek (central British Columbia coast). It is not suspected that the fishery was selective in respect to marked fish, and hence the ratios Z[*]$_m/Z_u$ are too low, depending upon the extent of fishing mortality. It is more likely, after consideration of the effect of a non-selective fishery on the ratio Z_m/Z_u, that the true ratio for McClinton Creek returns was of the magnitude 1.5 and that for Hooknose Creek 2.0. The remarkable fact apparent in these data is the relative consistency of the marking factor, despite differences in location, brood years, fins used, and persons employed in marking. While a lower limit of the ratio may be set as 1.0 (no effect) there is no *a priori* reason for excluding values much higher than 2.

A laboratory examination of differential mortality is being conducted at the Biological Station at Nanaimo. While much remains for elucidation, the current results are of interest to this discussion. A population of 708 pink fry was divided equally into two lots, one being marked by amputation of the adipose and right ventral fin, the other similarly treated with anaesthetic, handled, etc., but not marked. These were placed in an aquarium and maintained as a control.

---

[*] Z is the instantaneous total mortality coefficient, in the notation of Holt *et al.* (1959) (i in the notation of Ricker, 1958).

Table 1

Differential mortality resulting from fin amputation of pink salmon. (s — denotes survival rate, z — denotes instantaneous mortality rate)

	Unmarked	Marked	z_m/z_u	s_u/s_m
1931—32 adipose mark				
Fry	5,200,000	185,557		
Adults	15,504	96		
s	0.0030	0.0005		6.0
z	5.8	7.6	1.31	
1933—34 both ventrals				
Fry	2,150,000	107,949		
Adults	152,255	2,941		
s	0.0708	0.0272		2.6
z	2.65	3.6	1.36	
1935—36 adipose-right ventral				
Fry	12,500,000	87,634		
Adults	52,277	35		
s	0.0042	0.0004		10.5
z	5.5	7.8	1.42	
1939—40 both ventrals				
Fry	1,821,371	178,629		
Adults	34,744	781		
s	0.0191	0.0044		4.3
z	3.96	5.40	1.36	
1948—49 both ventrals				
Fry	20,516	10,787		
Adults	1,070	103		
s	0.0522	0.0096		5.4
z	2.95	4.65	1.57	

A second population containing 100 marked and 400 unmarked fry was placed in a second aquarium, and after an hour's recovery period an eight-inch rainbow trout introduced as a predator. The trout attacked and killed fry but did not eat them, perhaps because it had had no previous experience with salmon fry. After 17 hours the trout occupied a corner of the tank close to the bottom and the remaining fry formed a school in the upper strata of water. During this period, 21 unmarked and 4 marked fish were killed. These were removed from the aquarium, leaving 96 marked and 379 unmarked fish for the experiment. This is taken as the start of observations. At the end of 7 days, 57 marked and 259 unmarked fish remained alive; the difference had been consumed. The Z_m/Z_u ratio is 1.37. Differences are not, however, significant. Adjusted $\chi^2 = 2.375$, d. f. $= 1$,P ≈ 0.13. For the control lot, one unmarked fish had died; thus no correction is necessary for mortality other than from predation. A second test was conducted which used marked fish from the control group and additional unmarked fry from the same source, of equivalent length, age, treatment, etc. The experimental group contained 100 marked and 399 unmarked individuals and the control, 208 marked and 208 unmarked. At the end of 7 days, 53 marked and 244 unmarked fish remained alive, the ratio $Z_m/Z_u = 1.29$. Again these differences are non-significant, $\chi^2 = 1.672$, d.f. $= 1$,P≈ 0.20. In the control group, 1 unmarked and 2 marked fish had died; thus no correction is necessary. The experiment was repeated a third and fourth time. A summary of results is presented in Table 2. In no case was mortality within the control lots significant. In no single experiment was the predator's preference statistically significant; however, the pooled data indicate a preference by the predator for marked fish which is consistent and significant beyond the 0.001 probability level.

These experiments demonstrate a definite selectivity for marked pink fry by a predator. The degree of selectivity is of the same order of magnitude as obtained from field observations. It is noteworthy that an instrument of destruction is necessary to bring about this difference; without the predator no differences in mortality rate can be discerned.

Table 2

Laboratory test for selectivity of predator on marked and unmarked pink salmon fry

Exp. no.	Survived		Killed		Total fish	χ^2	P	Z_m/Z_u
	marked	unmarked	marked	unmarked				
1	39	120	57	259	475	2.375	0.13	1.37
2	47	155	53	244	499	1.672	0.20	1.29
3	53	175	47	225	500	2.399	0.12	1.31
4	43	143	48	257	491	3.694	0.08	1.42
Pooled	182	593	205	985	1965	11.226	<0.001	1.35

These results might be explained by the following hypothesis: Aggregations or schools of like individuals provide protection to the individual in that the chances of becoming prey are shared equally by other members. If removing a fin or fins, or placement of a tag, causes the fish to swim differently or alters the appearance of the fish so that it appears different from its fellows, it may stand out as an individual in a school or aggregation. The attention of a predator may then become focussed upon that individual to the exclusion of several normal-appearing individuals, and the marked fish, to some degree, loses the statistical protection provided by the school.

Discussion

From a practical standpoint there are two ways of solving these problems: by either avoiding the losses or correcting for them.

Losses caused by fatigue are probably most serious in "active types" of fishes and appraisal of fatigue mortality should be a standard adjunct of a marking study. Even for less active fishes evaluation of fatigue losses would be desirable. To avoid mortality or reduction in capacity for subsequent exercise there are several profitable avenues for both practice and further research:

1. Violent exercise should be minimized in the catching and landing procedure. The sustained exertion of fish caught by gill-netting, for instance, should be avoided.

2. Exercise after capture should be minimized, and in this respect exposure to air seems particularly to be avoided.

3. The time taken to mark the fish should be minimized. Even the time taken to obtain a measurement may cause higher losses.

4. Narcosis can reduce losses. The use of cold chill and/or drugs is recommended, although some tranquilizing drugs have the limitation that they may exhaust glycogen stores, apparently by induction of adrenalin excretion. Miller, Sinclair and Hochachka (1959) have reported low survival in trout with low liver glycogen stores. Horton (1956) has reported success using cold narcosis.

5. Choice of a particular life-history stage may reduce losses from fatigue.

Recent studies reviewed by Black, Robertson and Parker (1961) suggest that further physiological research on fish may provide the basic understanding of fatigue mortality from which something better than trial and error remedies might be developed. It has only recently been demonstrated that glycolytic enzymes in fish are similar to those in other vertebrates; and that both adrenocorticoid and pituitary hormones are involved in osmoregulatory functions. The measurement of respiration efficiency in fish has still not been adequately explored. Further developments in these fields may have important practical applications to the problem of reducing marking mortality associated with fatigue and injury.

Short-term losses caused by the combined effects of injury and fatigue which cause attraction of and susceptibility to predators are not so easily appraised or avoided. Holding of fish until injuries are healed and fatigue effects are eliminated may involve formidable expense, and the alternative of satiating local predators seems forlorn. But together with long-term losses resulting from selectivity of marked individuals by predators these types of losses may provide explanation for much of the differential mortality to marked fish. The use of internal tags might be recommended as a way of avoiding drawing attention of predators to marked individuals; however, problems of marking and recovery become formidable. Perhaps the wisest course is to plan, with each marking program, experimental studies designed to assess the order of magnitude of these kinds of losses.

Summary

It is observed and to be expected that marked fish suffer a mortality rate higher than that of the unmarked population. This additional mortality may be due, in the short term, to the combined effects of wounding and fatigue. More insidious but equally important may be long-term effects, which appear to accrue through bias on the part of predators toward marked individuals of prey. It is not known whether this bias is due to the disability of the prey, thus making them easier to capture, or to the recognition on the part of the predator of an individual item of prey, thus partially destroying the statistical protection afforded by a school. Most or all of these effects may be reduced, but not entirely eliminated and it is recommended that an assessment of differential mortality be included in the design of experiments which involve capture and handling and marking of fishes.

Acknowledgements

Dr. K. S. Ketchen and Mr. F. C. Withler, Biological Station, Nanaimo have kindly played the role of critics of the manuscript. Mr. R. A. Bams assisted in the marking experiments conducted at the Biological Station, Nanaimo. Facilities and the opportunity to prepare the manuscript, as well as encouragement to do so, were provided by Dr. A. W. H. Needler, Director of the Biological Station at Nanaimo.

References

ANON. 1957. Fish protection at the Tracy Pumping Plant Central Valley Project, California. Development of a fish salvage facility. *U. S. Dept. Int., Bur. Reclaim. and Fish and Wildl. Serv.*

ARMSTRONG, GEORGE C. 1949. Mortality, rate of growth and fin regeneration of marked and unmarked lake trout fingerlings at the Provincial Fish Hatchery, Port Arthur, Ontario. *Trans. Amer. Fish. Soc.* **77**: 129—31.

BARNABY, JOSEPH T. 1944. Fluctuations in abundance of red salmon, *Oncorhynchus nerka* (Walbaum), of the Karluk River, Alaska. *Fish. Bull. ,U. S.*, **50** (39): 237—295.

BATES, DANIEL W. and RUSSEL VINSONHALER. 1957. Use of louvers for guiding fish. *Trans. Amer. Fish. Soc.*, **86**, 38—57.

BLACK, EDGAR C. 1955. Blood levels of hemoglobin and lactic acid in some freshwater fishes following exercise. *J. Fish. Res. Bd Can.*, **12**: 917—29.

BLACK, EDGAR C., 1957a. Alterations in the blood level of lactic acid in certain salmonid fishes following muscular activity. I. Kamloops trout, *Salmo gairdnerii. Ibid.*, **14**: 117—34.

BLACK, EDGAR C., 1957b. *Ibid.* II. Lake trout, *Salvelinus namaycush. Ibid.*, **14**: 645—49.

BLACK, EDGAR C., 1957c. *Ibid.* III. Sockeye salmon, *Oncorhynchus nerka. Ibid.*, **14**: 807—14.

BLACK, EDGAR C., ANNE C. ROBERTSON and ROBERT R. PARKER. 1961. Some aspects of carbohydrate metabolism in fish. In *Comparative Physiology of Carbohydrate Metabolism in Heterothermic Animals*. Ed. Arthur W. Martin, 89—124. Univ. Wash. Press, Seattle.

BUDDENBROCK, W. VON. 1938. Beobachtungen über das Sterben gefangener Seefische und über den Milchsäuregehalt des Fischblutes. *Rapp. Cons. Explor. Mer*, **101** (IV/2): 3—7.

DAVIDSON, FREDERICK A. 1934. The homing instinct and age at maturity of pink salmon (*Oncorhynchus gorbuscha*). *Fish. Bull.*, U. S., **48**, (15): 27—39.

FOERSTER, R. E. 1936. The return from the sea of sockeye salmon (*Oncorhynchus nerka*) with special reference to percentage survival, sex proportions and progress of migration. *J. Fish. Res. Bd Can.* **3**: 26—42.

FRISCH, K. VON. 1941. Die Bedeutung des Geruchsinnes im Leben der Fische. *Naturwissenschafter*, **29**: 321—33.

FRY, DONALD H. and ELDON P. HUGHES. 1951. The California salmon troll fishery. *Bull. Pacif. Mar. Fish. Comm.*, No. **2**: 7—42.

HARRIS, J. E. 1936. The role of fins in the equilibrium of the swimming fish. I. Windtunnel tests on a model of *Mustelus canis* (Mitchell). *J. exp. Biol.*, **13**: 476—93.

HARRIS, J. E. 1937. The mechanical significance of the position and movements of the paired fins in the Teleostei. *Pap. Tortugas Lab.*, **31** (7): 173—189.

HARRIS, J. E. 1938. The role of fins in the equilibrium of the swimming fish. II. The role of the pelvic fins. *J. exp. Biol.*, **15**: 32—47.

HASLER, ARTHUR D. 1954. Odour perception and orientation in fishes. *J. Fish. Res. Bd Can.* **11**: 107—129.

HASLER, ARTHUR D. 1957. Olfactory and gustatory senses of fishes. In *The Physiology of Fishes* Vol. 2, Ed. Margaret E. Brown. 187—209. Academic Press, N. Y.

HOLT, S. J., J. A. GULLAND, C. TAYLOR and S. KURITA. 1959. A standard terminology and notation for fishery dynamics. *J. Cons. int. Explor. Mer*, **24**: 239—42.

HOMANS, R. E. S. and V. D. VLADYKOV. 1954. Relation between feeding and the sexual cycle of the haddock. *J. Fish. Res. Bd Can.*, **11**: 535—42.

HORTON, HOWARD F. 1956. An evaluation of some physical and mechanical factors important in reducing delayed mortality of hatchery-reared rainbow trout. *Progr. Fish Cult.*, **18**: 3—14.

HUNTER, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. *J. Fish. Res. Bd Can.*, **16**: 835—86.

HUNTSMAN, A. G. 1938. Overexertion as a cause of death of captured fish. *Science*, **87**: 577—78.

MILLER, R. B., A. C. SINCLAIR and P. W. HOCHACHKA. 1959. Diet, glycogen reserves and resistance to fatigue in hatchery rainbow trout. *J. Fish. Res. Bd Can.*, **16**: 321—28.

MILNE, D. J. and E. A. R. BALL. 1956. The mortality of small salmon when caught by trolling and tagged or released untagged. *Fish. Res. Bd Can., Progr. Rep. Pacif. Cst. Stas. Nanaimo & Vancouver*, No. 106: 10—13.

MILNE, D. J. and E. A. R. BALL. (1958). The tagging of. spring and coho salmon in the Strait of Georgia in 1956 *Ibid.*, No. 111: 14—18.

PARKER, ROBERT R. and EDGAR C. BLACK. 1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). *J. Fish. Res. Bd Can.*, **16**: 95—106.

PARKER, R. R., E. C. BLACK and P. A. LARKIN. 1959. Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). *Ibid.*, **16**: 429—48.

PAULIK, GERALD J., ALLAN C. DeLACY and EDWIN F. STACY. 1957. The effect of rest on the swimming performance of fatigued adult silver salmon. *Univ. Wash., School Fish., Tech. Rep.* No. 31.

PAULIK, GERALD J. and ALLAN C. De LACY. 1958. Changes in the swimming ability of Columbia River sockeye salmon during upstream migration. *Univ. Wash., Coll. Fish., Tech. Rep.* No. 46.

PRITCHARD, A. L. 1939. Homing tendency and age of maturity of pink salmon (*Oncorhynchus gorbuscha*) in British Columbia. *J. Fish. Res. Bd Can.*, **4**: 233—51.

PRITCHARD, A. L. 1941. The recovery of marked Masset Inlet pink salmon during the season of 1940. *Fish. Res. Bd Can., Progr. Rep. Pacif. Cst Sta. Nanaimo & Vancouver*, **48**: 13—17.

PRITCHARD, A. L. 1948. A discussion of the mortality in pink salmon (*Oncorhynchus gorbuscha*) during their period of marine life. *Trans. roy. Soc. Can.*, Ser. 3, **42** (Sect. 5): 125—33.

RADCLIFFE, ROLAND W. 1950. The effect of fin-clipping on the cruising speed of goldfish and coho salmon fry. *J. Fish. Res. Bd Can.*, **8**: 67—73.

RICH, W. H. and H. B. HOLMES. 1928. Experiments in marking young chinook salmon on the Columbia River, 1916—1927. *Fish. Bull.*, U. S., **44**: 215—64.

RICKER, W. E. 1949. Effect of removal of fins upon the growth and survival of spiny-rayed fishes. *J. Wildlife Mgmt.*, **13**: 29—40.

RICKER, W. E., 1958. Handbook of computations for biological statistics of fish populations. *Bull Fish. Res. Bd Can.* (119): 300 p.

ROBERTSON, O. H. and B. C. WEXLER. 1960. Histological changes in the organs and tissues of migrating and spawning Pacific salmon (genus *Oncorhynchus*). *Endocrinology*, **66**: 222—39.

SECONDAT, MARCEL and DIEGO DIAZ. 1942. Récherches sur la lactacidémie chez le poisson d'eau douce. *C. R Acad. Sci.*, Paris, **215**: 71—73.

SHETTER, D. S. 1951. The effect of fin removal on fingerling lake trout (*Cristivomer namaycush*). *Trans. Amer. Fish. Soc.*, **80**: 260—77.

SHETTER D. S. 1952. The mortality and growth of marked and unmarked lake trout fingerlings in the presence of predators. *Trans. Amer. Fish. Soc.* **81**: 17—34.

VAN HYNING, Jack M. 1951. The ocean salmon troll fishery of Oregon. *Bull. Pacif. Mar. Fish. Comm.*, No. **2**: 41—76.

20.

Tagging Experiments with the North Sea Sole *(Solea solea)* in 1959 and 1960

By

ADOLF KOTTHAUS*

Introduction

The German sole tagging was done as part of an international experiment in which the following countries are engaged: Belgium, Denmark, England, France, Holland, and Germany. Since the recovery data of the various countries have not yet been combined for evaluation, no definite conclusions may be drawn concerning natural and fishing mortality of the sole stock. This report includes all recoveries until February 1961.

Liberation Techniques

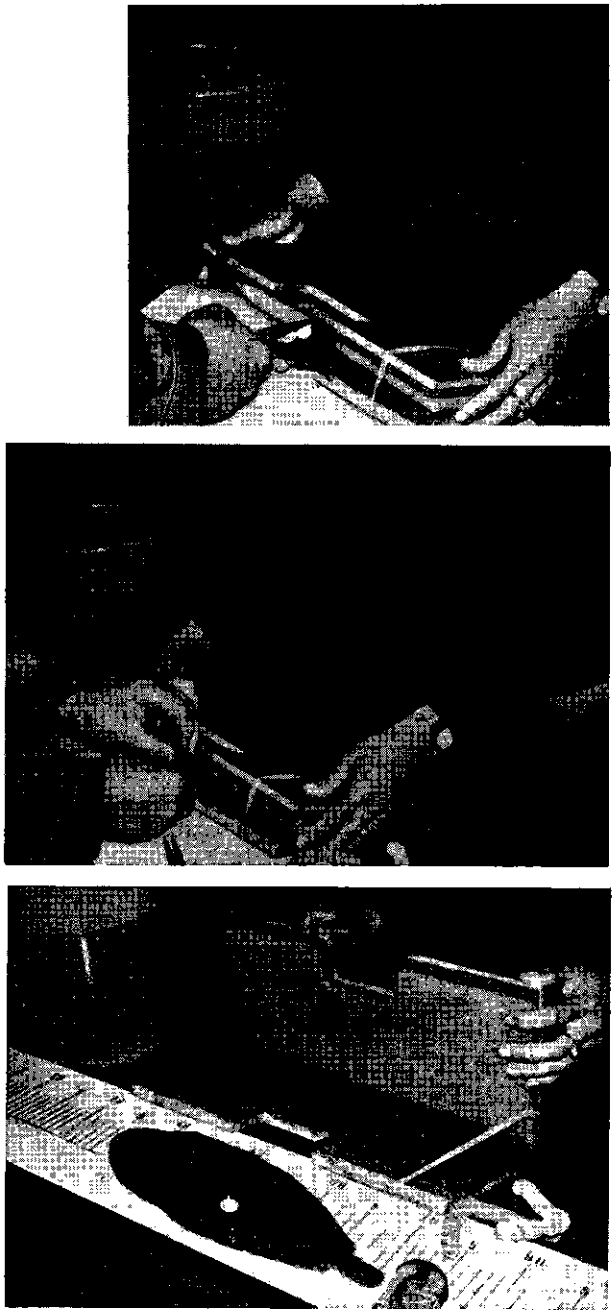
a) *Method of catching.* Sole tagging was done on board the research vessels "Anton Dohrn" and "Uthörn". The soles used for tagging were caught by an ordinary cutter trawl in standard hauls of half-an-hour's duration, as part of investigations on the plaice (*Pleuronectes platessa*) stock of the southern North Sea. There was no special fishing for soles.

b) *Handling the fish before tagging.* Immediately after the catch was liberated from the cod-end, the soles were picked up and transferred to aquarium tanks or low troughs, the bottoms of which were supplied with fine sand so that the fish could dig into the sand and were protected from being bumped against the sides of the reservoirs in rough sea. The water in these tanks was running and aerated. The fish remained there until the other fish of the haul had been processed (about 1 to 2 hours). Moribund soles were not used for tagging.

c) *Tags.* For tagging we used exclusively the well-known Petersen discs, which were connected by silver wire (1959) or titanium wire (1960). Titanium wire has the advantage of being very light, but its high pliability makes it difficult to pierce through the musculature of the fish. This difficulty, however, may be overcome by cutting the wire very slantwise so that its ends become tapering. The colour of the discs was red for the blind side and yellow for the eye side.

d) *Method of attaching the tags.* The tags were attached dorsally and somewhat ventrally to the interneurals, about halfway along the fish.

e) *Tagging procedure* Since the sole is a very active fish, a simple "sole holder" was constructed. Two boards of 40 × 25 cm each were fastened with



Figures 1, 2 and 3. Three stages of the tagging procedure.

---

* Biologische Anstalt Helgoland, Germany

glue on thick plates of foam rubber and then folded together. For handling the marks and pliers a rectangle of about 4 × 8 cm was cut out from the outer edge of the boards, as may be seen from Figs. 1—3. By the use of this holder it is possible to keep the fish quiet during the tagging operation and to prevent them from damaging themselves. For tagging, the fish were taken out of the tanks and gently pressed in the holder, whose rubber was fully drenched in order to keep the fish wet. Then the tags were attached. After measuring (total length in mm), the soles were liberated immediately.

In the 1960 experiments 281 of the tagged fish were conditioned according to vitality and scale conditions in the following manner (see Table 1):

Index "A" — active
Index "B" — sluggish
Index "1" — no scales missing or only occasional ones
Index "2" — a few small patches with scales missing
Index "3" — larger patches with scales missing

Table 1
Release and return of different conditioned fish (for description of condition see text)

Condition	Number of tagged fish		Returns No.		Returns %	
A1	44	133	8	21	18.2	15.8
A2	79		13		16.4	
A3	10		0		—	
B1	21	148	1	6	4.8	4.0
B2	99		4		4.0	
B3	28		1		3.6	

Liberation and Recovery Data

From June to October 1959, 441 soles were tagged in the southern North Sea (318 of them — 72.3 per cent — near Helgoland, 91 — 20.7 per cent — off the North-Frisian and Danish coasts, and the rest at different places in the southern North Sea). From this experiment 92 fish were returned up to February 1961; this is about 21 per cent within $1^1/_2$ years. In 1960, 327 fish were liberated from May to September, mostly within a ten-mile radius of the island of Helgoland and off the island of Amrum. Up to February 1961, 35 of these fish, 11 per cent, were returned. The length distributions of the tagged and returned fish are shown in Fig. 4.

As shown in Table 2 most of the fish were returned by Dutch fishing vessels (48 per cent in the 1959 experiments, in the 1960 experiments 57 per cent). The corresponding figures for German vessels are 15.2 per cent and 25.7 per cent. The rest is divided among Belgian, Danish, French, and English vessels. These figures show clearly that the most effective fishery on the sole stock is carried out by Dutch fishermen. The positions of the recaptures are plotted in the charts, Fig. 5 (for the 1959 experiments) and Fig. 6 (for 1960).

Table 2
Recoveries by countries

	1959 experiment No.	1959 experiment %	1960 experiment No.	1960 experiment %
Belgium	13	14.2	3	8.6
Denmark	5	5.4	—	—
England	9	9.8	2	5.7
France	7	7.6	1	2.9
Germany	14	15.2	9	25.7
Holland	44	47.8	20	57.1

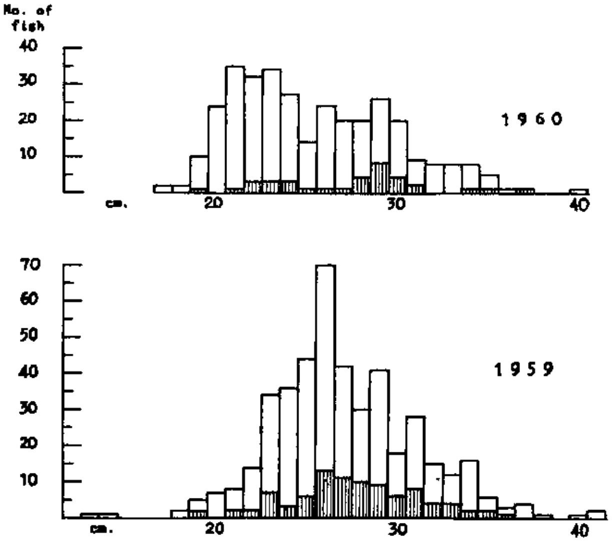


Figure 4. Length distributions of the tagged and returned (hatched) sole.

Discussion of the Results

a) *Migration.* The variations in place of recapture in the course of time show clearly a periodic migration of the sole. The sole tagged during the summer in the eastern North Sea at first make short-distance and undirected migrations, typical migrations for seeking food. From October there is a sudden long-distance migration towards the west (or southwest for the fish from the Danish coast). On their way westwards the fish reach their hibernation quarters (Shell Bank, Brown Bank, Cleaver Bank, etc.), about the end of the year, after having migrated about 150 to 200 miles. This migration, no doubt, is induced by the cooling of the water in the southeastern North Sea in autumn. In March/

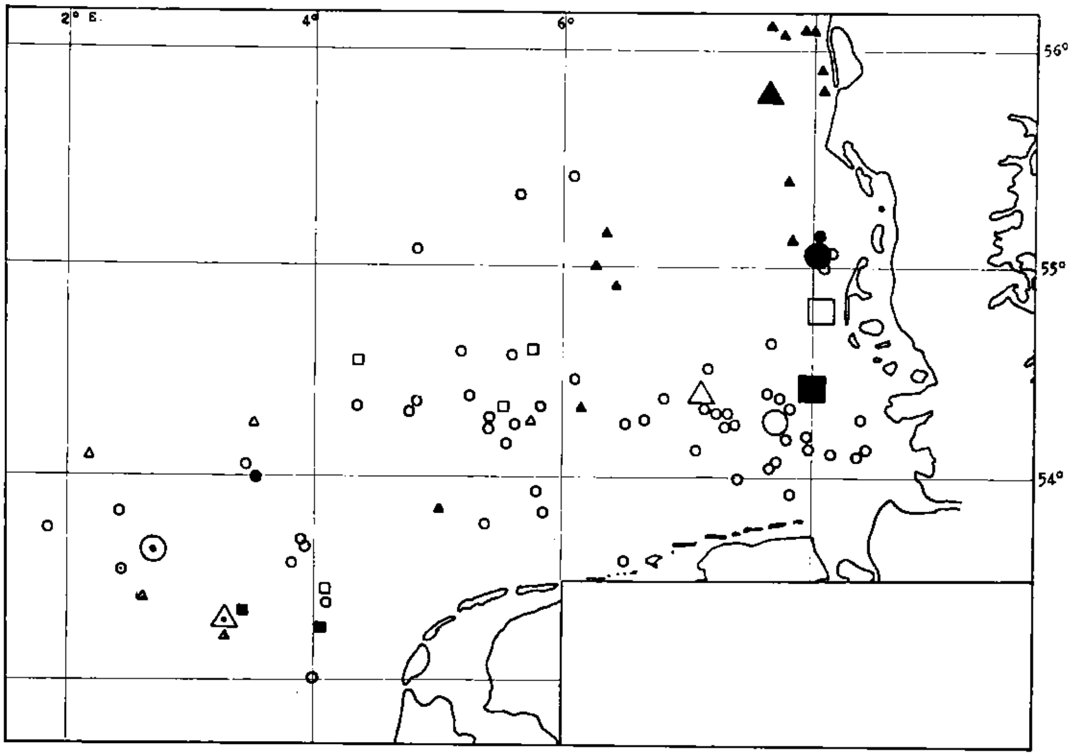


Figure 5. German sole tagging, 1959. Big signs — position of tagging, Small signs — position of recapture.

April the soles return very quickly to the east and northeast, and are found in May/June within the shallow coastal waters, mostly to the east of their tagging position. In these areas the fish spawn, and afterwards they retire to the deeper waters, where they remain until the migration westwards begins again in early autumn. The mode of seasonal migration is clearly shown in Figs. 7 and 8 (1959 and

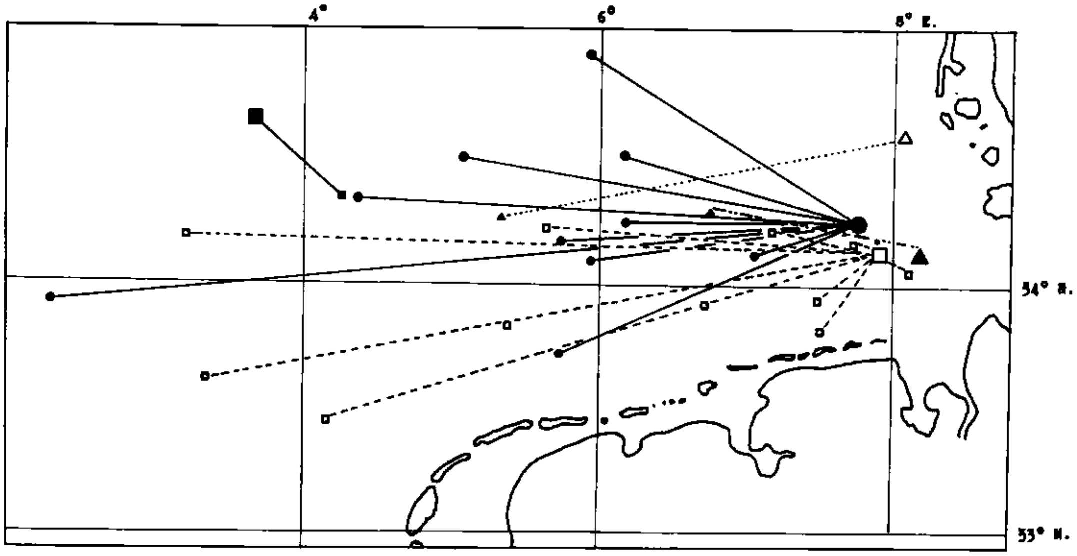


Figure 6. German sole tagging, 1960. Big signs — position of tagging, Small signs — position of recapture.

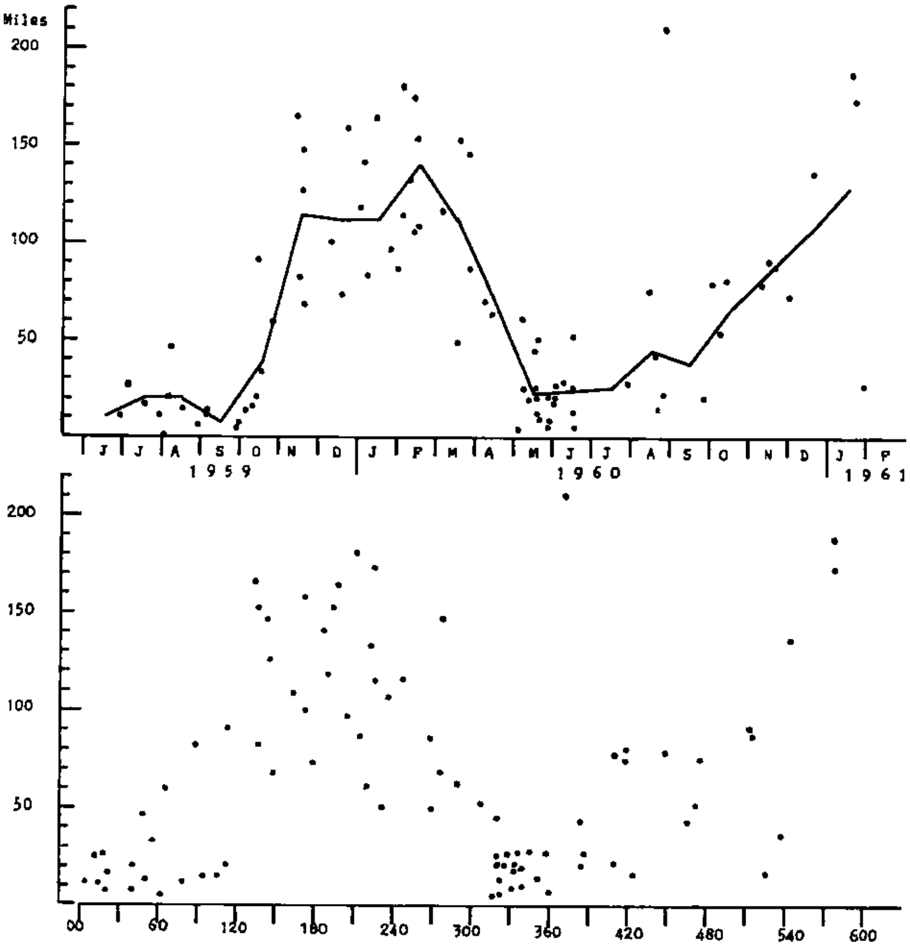


Figure 7. 1959 tagging, mode of seasonal migration (see text). Ordinate — miles; abscisse — month of recapture and days after tagging; full line — average displacement

1960), in which are plotted the displacements in relation to date of recapture (above) or days after tagging (below). It seems that the sole has what may be called a "home sense", for all fish recaptured in May/June were found not far from their tagging position.

It must be mentioned that we could not find any differences in migration behaviour between the smaller and the bigger fish.

Only three of the fish which were tagged in the summer of 1959 in the southwestern part of the North Sea were recaptured, and they had not moved far from their tagging position. Therefore nothing can be said about the question of whether the sole of the southwestern North Sea are also carrying out long-distance migrations, or whether they form a separate and more stationary stock.

Mention must be made of sole No. 11, which was recaptured in August 1960, 210 miles westwards of the tagging place, after having been at liberty for 370 days. Evidently this fish had not returned to the eastern North Sea in the spring, but had separated from the other fish.

The recovery data show that a sole may move up to 4 miles within 24 hours (not including the undetectable roundabout routes!). This is extraordinarily high for a fish which must be regarded as a very sluggish one, and which generally is active only during the night.

b) *Growth.* In Figs. 9 and 10 we have plotted the differences between fish length at recapture and at tagging in relation to days after tagging, for the 1959 and 1960 releases respectively. In both the early and later recaptures there were fish whose length was less than at tagging (fish No. 160 was at liberty for 202 days; its length had decreased by 7 mm!). This shrinkage of the fish may be due partly to errors when measuring, and partly to the fact that most of the fish were not measured imme-

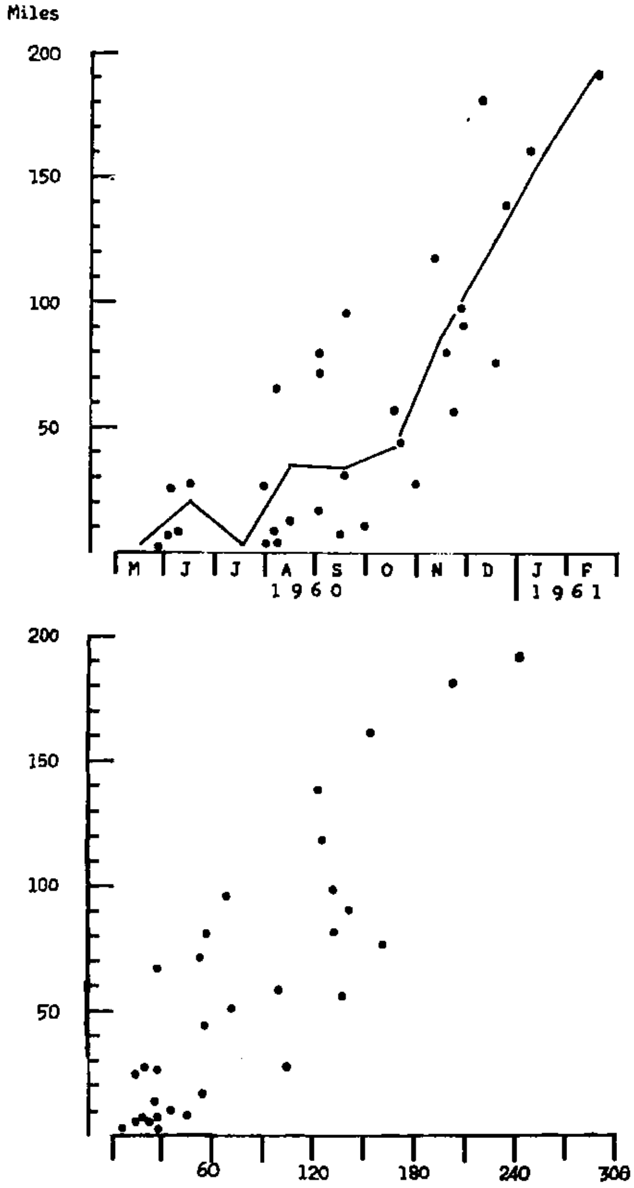


Figure 8. 1960 tagging, mode of seasonal migration (see text). Ordinate — miles; abscisse — month of recapture and days after tagging.

diately after they were caught, but were gutted, put on ice, and measured after return to harbour. A shrinkage of the fish after this procedure seems to be possible. However, our tank experiments have also shown that the fish decrease in length after tagging, even though they are supplied with sufficient food, as may be seen from the following experimental data: —

Tag No.	Date of tagging	Length at tagging	Length at 7. 8. 60	Length at 1. 8. 60
231	30. 4. 60	307 mm	301 mm	303 mm
225	30. 4. 60	264 mm	258 mm	261 mm
35	30. 4. 60	204 mm	202 mm	205 mm
30	30. 4. 60	192 mm	188 mm	191 mm

It must be mentioned that no untagged fish were used as controls at the same time, so that the question remains of whether the shrinkage may also be observed in untagged fish. (This question will be resolved by new experiments now in progress.)

From the recovery data we have calculated the average length increment for the three length groups: 20—25 cm, 25—30 cm and 30—35 cm (Fig. 11a, b and c, respectively). The negative figures are included for calculation, but not the value of 100 mm for fish No. 359, which seems to be incorrect. The data are taken from only the 1959 experiments. The growth calculated in this manner is no doubt very much less than the actual growth of untagged fish, for we must take into consideration the "shrinkage" within the first weeks after tagging. Moreover we must expect that tagged fish are hindered in their activity and so in their feeding.

c) *Fish of different conditions.* As mentioned above, in the 1960 experiments, 281 soles were categorized according to activity and scale condition before liberation. Of these fish, 27 (about 10 per cent) were returned. Comparing the rate of recapture in the different categories, Table 1 shows that the "A" fish by far exceed the "B" fish both in number and in percentages: 15.8 per cent of the category "A" were returned, compared with only 4.0 per cent of the "B" category. Returns of fish with good scales (category 1) are slightly higher than those with poor scales (categories 2 and 3), but the numbers of fish are small, and it appears that degree of scaling is less critical than the activity. From this evidence we may conclude that the survival rate depends directly on the condition (activity) of the fish at tagging, i. e. that "active" fish have a higher rate of survival than "sluggish" fish. These results agree well with the English observations (Beverton and Bedford, this symposium, contribution No. 18).

When calculating the fishing mortality from the recapture data it is necessary to consider these facts, for the fishing mortality must be far higher than the total percentage of recaptured fish indicates. It would be wrong to conclude from the 10 per cent of recaptured fish that the fishing mortality within the half-year of observations amounts to the same percentage. It must be at least as high as the rate of recaptured "A1" fish, i. e. 18.2 per cent, as far as

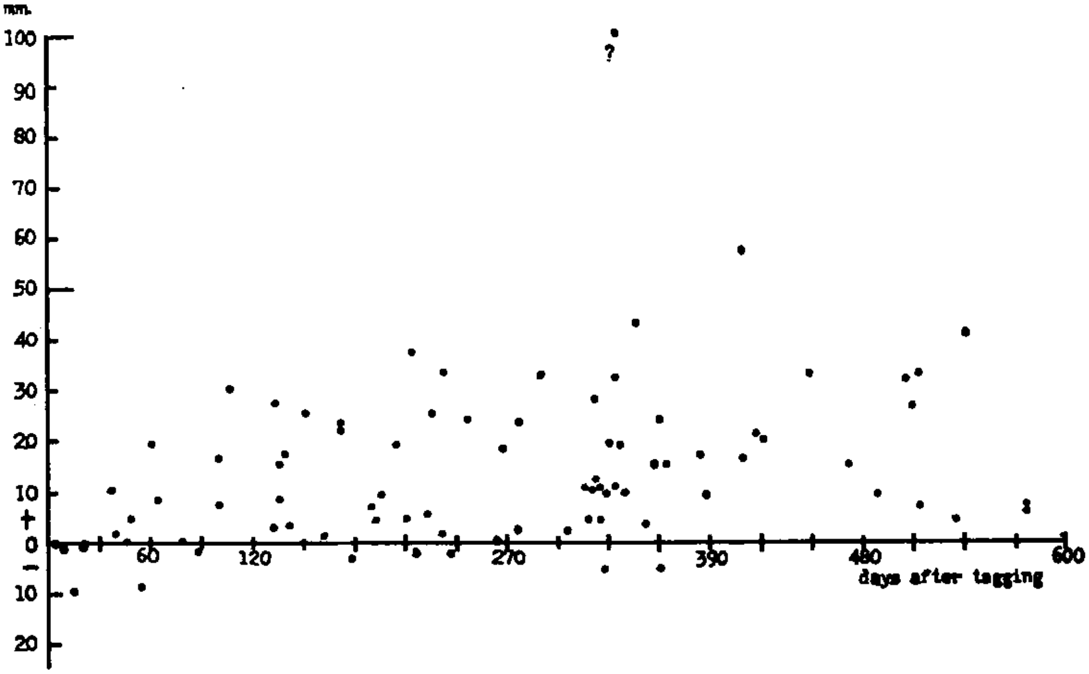


Figure 9. Difference between length of fish at recovery and length at release, in relation to number of days after tagging (1959 tagging).

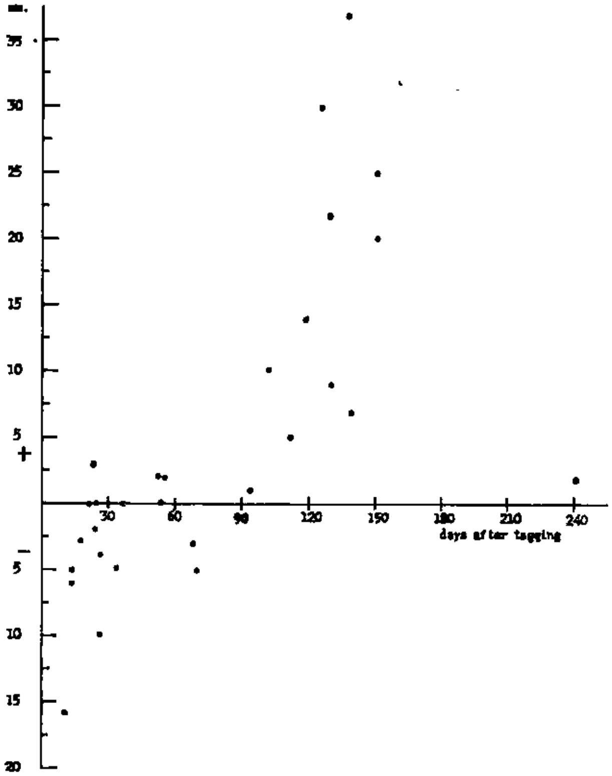


Figure 10. Difference between length at recovery and length at release, in relation to number of days after tagging (1960 tagging).

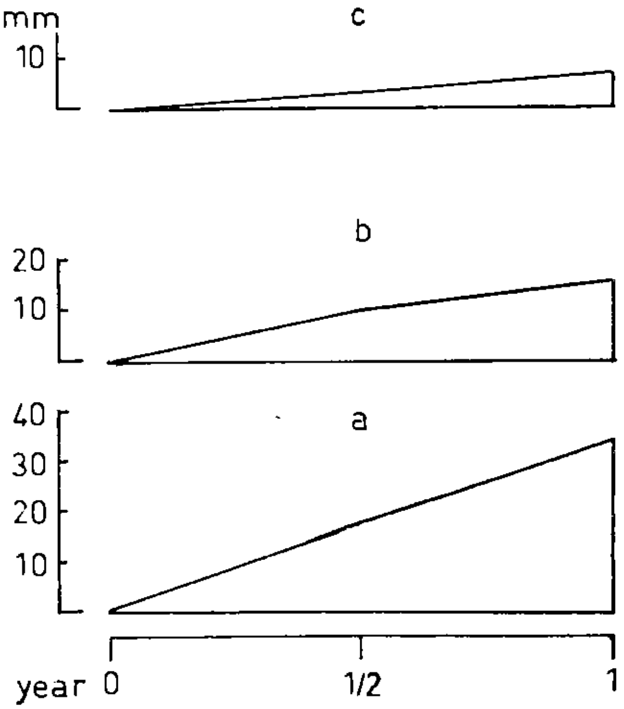


Figure 11. Average growth of the length groups: (a) 20—25 cm, (b) 25—30 cm, (c) 30—35 cm.

the German experiments are concerned. Final conclusions in this respect, however, must wait until the recovery data of the other nations are available.

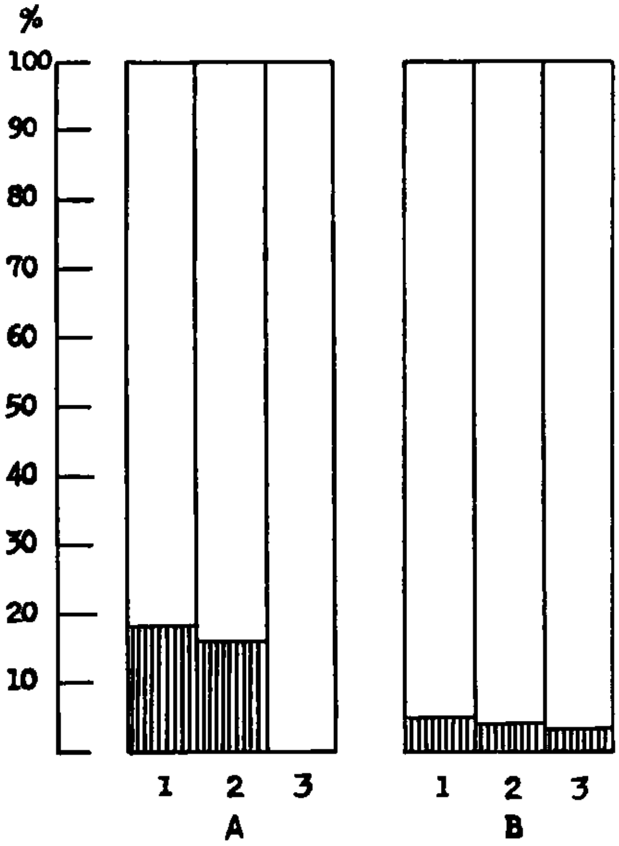


Figure 12. Returns of differently conditioned fish.

Summary

Preliminary results are discussed of German sole tagging in 1959 and 1960, as part of the international project in which Belgium, Denmark, England, France and Holland also took part.

Liberation techniques, including type of tag and method of handling the fish for tagging, are described.

From the 1959 taggings 92 fish out of 441 had been returned up to February 1961. Positions of recapture show that the fish have a strong tendency to "home" in the summer months to the feeding ground, and in that season many are recaptured only a short distance from where they were tagged the year before.

The growth rate of recaptured fish is thought to be substantially less than the actual growth of untagged fish and there were many instances of fish shrinking in length, even after being at liberty for some time. The same phenomenon was also observed in fish kept in aquaria.

The activity of fish at liberation ("lively" or "sluggish") was found to have a marked effect on their subsequent recapture rate, but the degree of scaling did not seem to be so critical, as judged from the rather small number of recaptures which are available so far from the 1960 liberation.

Reference

BEVERTON R. J. H. and BEDFORD B. C. 1963. The influence on the recapture rate of condition of fish when tagged. *This symposium*, No. 18.

21.

Some Marking Experiments on Spawning Populations of Char

By

E. D. LE CREN and C. KIPLING*

Introduction

During the course of investigations by Dr. W. E. Frost into the biology and life history of the char (*Salvelinus willughbii* Gunther) in Windermere (briefly described in Frost, 1951) the need for information on the behaviour, numbers, sex ratios and mortality rates, etc., of the various spawning populations became apparent; therefore in co-operation with Dr. Frost a series of marking experiments was carried out. The object of these experiments has been partly to try out different methods of marking and analysis of results, and partly to derive information about the char populations. Two quite different problems concerning the char have been under consideration. Firstly the pattern of movement within the spawning season has been studied and secondly population parameters have been estimated from catches in different years.

The char in Windermere form two distinct taxa, a slower growing "race" that spawns in November in water of about 1 m depth on the lake shore or in rivers, and a faster growing "race" that spawns in February on the lake bottom at a depth of about 20 m. For both taxa the spawning places are distinct and limited in area and have gravelly bottoms; the individuals that spawn in a particular place return to that place in successive spawning seasons with a very high consistency and each place therefore appears to have a discrete spawning population. At spawning times the char congregate in these particular places and can be captured quite easily; at other times of the year they are pelagic and the capture of a large number is much more difficult. In the present series of experiments the populations of four spawning places were studied; details are given in Table 1. All the fish used in these experiments were taken during their spawning seasons; a few were subsequently recaught by anglers. At Low Wray Bay there was no 'within season' investigation.

Table 1
Particulars of sampling places

Place		Depth	Time of year	Net
Brathay	river	shallow	autumn	seine
Holbeck	lake	deep	spring	seine
Red Nab	lake	shallow	autumn	seine
Low Wray Bay ..	lake	shallow	autumn	gill net

Methods of Sampling

Throughout the spawning season at each place (except Low Wray Bay) visits were made every few days and seine hauls made until a reasonable number of fish had been caught. The fish were then sexed and measured, previous tags and marks were noted, untagged fish were tagged, and in the within-season experiments all fish were marked with the day's mark, and all were then released again. Seining at each place had some features peculiar to the place: in the River Brathay success depended upon the water level (netting was impossible in flood), at Red Nab it was only fully successful at dusk or after dark, and at Holbeck the net had to be drawn up a steep bank from deep water, and was liable to encounter obstructions.

The seine used was 50 yd (45.7 m) long, and 4 to 5 yd (3.7 to 4.6 m) deep, the mesh being graded from 1 in. (2.54 cm) bar on the wings to $^3/_8$ in. (0.95 cm) bar at the bag. It was always worked from the shore.

At Low Wray Bay one gill net 30 yd (27.4 m) long with mesh size $1^1/_4$ in. (3.17 cm) bar was set for two consecutive nights each week during the spawning season. It was examined after each night's fishing, and the tagging procedure described above was carried out.

Char anglers were very interested in the tagging experiment and were most co-operative in returning marked fish. A reward, based on the market price, was given for the return of the whole fish, which proved satisfactory to all concerned.

Methods of Marking

The maximum number of visits in any one spawning season was seventeen, at Holbeck. A system of marking was needed which would identify on which occasions any individual was captured, so that the full history

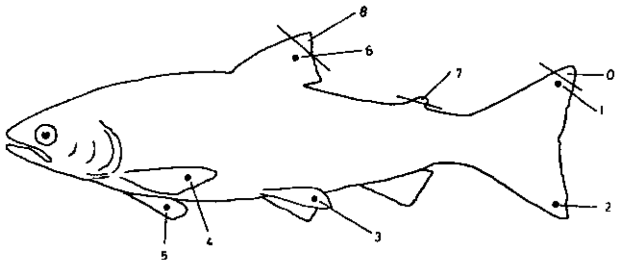


Figure 1. Marks used at Brathay in 1952. 0 Top tail clip; 1 Top tail punch; 2 Bottom tail punch; 3 Pelvic punch; 4 Left pectoral punch; 5 Right pectoral punch; 6 Dorsal punch; 7 Adipose clip; 8 Dorsal clip.

---

* Freshwater Biological Association, Ambleside, Westmorland, England.

of its previous captures could be easily recorded. This was achieved by assigning one mark for each occasion, using a combination of fin clips and holes punched in fins, the latter being done with a leather punch (see Fig. 1). The removal of a small piece of a fin proved a satisfactory short-term mark. Sometimes regeneration was rapid and the presence of a clip after a few weeks could only be recognised by a faint scar showing as an interruption in the fin rays, much as described by Stuart (1958) for trout; occasionally the cut healed but no regeneration took place, such marks were easily recognised. The punched holes appear to be a new method of marking; they proved very satisfactory for the short term of the within-season experiments. A leather punch was used for making the holes, which were about 4 mm in diameter. The punch needed to be sharp, and a firm squeeze together with a slight twist were required to cut a clean hole. Usually a clean, complete hole was formed, but occasionally the fin rays and the part of the fin distal to the hole were accidentally torn out. Regeneration consisted of the gradual closing in of the hole, but usually with distorted growth that formed a small lump in the fin, easier to feel than to see. Some holes had been completely filled in after about six weeks, so the fin punch could not be used reliably for experiments lasting longer than this.

In general, the recording of previous marks could be done accurately and quickly, and could be checked; as, for example, a fish with marks made on occasions $0 + 3 + 4 + 6 + 8$ ought already to have been recorded as $0, 0 + 3$, $0 + 3 + 4$, and $0 + 3 + 4 + 6$ before its final recapture. By checking thus, almost all the recapture records were found to be accurate, but some errors were detected in the records of a few fish; the effect on the results was negligible. In any future experiment a system of double checking at the time of recapture would be desirable.

No adverse effects on the fish were observed to have been caused by this method of marking, and a marked fish was apparently neither more nor less liable to be captured than an unmarked fish. It is considered that the marked fish quickly became distributed among the rest of the fish on the spawning site, and that seining provided a random sample of the fish present. All recapturing and recording of returned marks was done by the Association's staff, so there was no loss of information due to recaptured marked fish not being reported.

An example of tabulated results is shown in Table 2.

For the year-to-year population study subcutaneous tags and fin cuts were used, the whole of the fin being removed. These methods have been described by Le Cren (1954) who concluded that subcutaneous tags had no deleterious effects on the fish. The remarks made above about liability to capture, random sampling and recording all apply also to the year-to-year experiments at Brathay, Holbeck and Red Nab. They do not apply to the experiment in Low Wray Bay, where the fish were caught by gill net, which is selective for size, and where some mortality was observed at the time of tagging.

Table 2
Example of tabulation of within-season results

Brathay 1952 Females

Date	Number of fish caught	Mark	Recaught with mark								Fresh fish newly marked
			0	1	0+1	2	1+2	3	2+3	6	
31 Oct.	22	0	—	—	—	—	—	—	—	—	22
3 Nov.	22	1	7	—	—	—	—	—	—	—	15
4 Nov.	14	2	—	5	4	—	—	—	—	—	5
10 Nov.	31	3	1	3	—	2	1	—	—	—	24
11 Nov.	16	4	—	—	—	—	—	9	2	—	5
13 Nov.	2	5	—	—	—	—	—	—	—	—	2
20 Nov.	11	6	—	1	—	—	—	1	—	—	9
21 Nov.	8	7	—	—	—	—	—	—	—	3	5
25 Nov.	0	8	—	—	—	—	—	—	—	—	0

Methods of Analysis

(a) Within-season

In the within-season experiments it was assumed that there was no recruitment or mortality, and that changes in the size of the population on the spawning site were due to immigration to the site from elsewhere in the lake and emigration away from the site. Therefore in the within-season analysis estimates were made of immigration and emigration rates, whereas the year-to-year analysis provided estimates of recruitment and mortality.

As a first analysis of the data, tables of the number of fish marked and recaptured were made in a modified form of the traditional trellis diagram. Two main variants of these tables were possible, (a) those using only the first mark on any one fish and (b) those using all marks. Simple population estimates were attempted using the Petersen and Schnabel methods (Petersen, 1889; Dahl, 1917; Schnabel, 1938), but it soon became apparent that, although sampling could justifiably be considered random, the population was far from constant and that the males and females were behaving differently as regards migration. The changing population size and changing immigration and emigration rates precluded any application of more sophisticated trellis analyses such as that of Fisher and Ford (1947) and Jackson (1940).

An attempt was made, however, to apply Bailey's 'triple catch' method (Bailey, 1951) to successive triple sets of data analogous to a moving average, to obtain a continuous series of values of immigration and emigration rates covering the whole season. Such rates could yield valuable information on the pattern of migration into and out of the spawning places. Various groupings of data were tried, including catches per visit, per week and per half week, but in general the numbers proved inadequate for an effective analysis; the parameters obtained fluctuated wildly and the standard errors were very large. Some worth-while comparative results for emigration rates in the early part of the season were obtained, however. Untenable assumptions and small numbers also prevented the use of the more recent method of analysis given by Darroch (1959).

Although the formally derived precise methods of Bailey and Darroch could not be employed, much useful information was obtained by a few simple calculations. The data were sorted to give distributions of the number of tags per fish on final recapture, and the observed duration of stay on the spawning site (i. e. days elapsed between first and last capture). Means were calculated, and from these and other facts a general idea of the migration pattern during the spawning season was obtained. Detailed scrutiny of the recapture records of individual fish provided information on the efficiency of netting.

(b) Year-to-year

From the numbers of recaptures of tagged fish and fish which had lost their tags but which were identified by cut fins, estimates of population size and their standard errors were calculated for all four spawning sites, by direct proportion using Bailey's modified formulae. Wherever possible these were calculated for recaptures after one and more years, and for double recaptures, i. e. fish which were recaught both one and two years after tagging. Allowance was made for recruitment of young fish to the spawning populations by using the length-frequency distributions of the total catches in the years after tagging to identify and omit all fish which would have been too small to have formed part of the original population tagged. In doing so the known increments in length put on by tagged fish have been used to estimate growth during this period. Circumstantial evidence suggests that recruitment in char is erratic, and that there is an abundance of small adult fish only every few years; this is confirmed by the data shown in Table 3. In calculations using double recaptures allowance has been made for fish which had lost their tags, which could not therefore be identified as double recaptures, by assuming that 20% of all tags were lost. (Le Cren, 1954).

Only at Brathay and Red Nab was tagging done on a sufficient scale in two successive years to enable Bailey's triple-catch method to be applied. Population estimates, recruitment rates and survival rates and their standard errors were calculated.

Table 3
Recruitment found from length-frequency distributions

Place	Date	Males		Females	
		total catch	percentage recruits	total catch	percentage recruits
Brathay	1950—51	57	7	60	8
	1950—52	34	32	88	11
	1951—52	34	15	88	11
Holbeck	1952—53	230	28	408	17
	1952—54	200	55	297	39
Red Nab ...	1950—51	238	6	—	—
	1950—52	194	24	—	—
	1951—52	194	12	165	45
	1951—53	169	72	36	44
Low Wray Bay	1950—51	80	11	157	9
	1950—52	49	24	—	—

Estimates of instantaneous mortality rates were calculated from the natural logarithms of the ratios of recaptures in successive years whenever tagged fish were recaptured in two subsequent years. Standard errors were found by the Holt-Spicer method (Holt, 1958). For Holbeck, where recaptures were made over a longer period, the combined method of Holt-Spicer was also used to find both mortality rates and standard errors.

Further estimates of population size were made by extrapolation (see Fig. 3) of the lines fitted to the logarithms of the numbers of recaptured fish. The ratio of the intercept of this line with the vertical at the time of tagging to the number of fish tagged gives an estimate of the proportion of the population caught at the time of tagging; hence multiplication gives an estimate of the total population at that time. The proportion caught also gives another estimate of netting efficiency.

Sex ratios have been calculated whenever satisfactory population estimates for both males and females, calculated by the same method, are available.

The individually numbered tags provide valuable information on growth increments, but this subject is not being dealt with in this paper.

(c) Fishing effort

No precise determination of fishing effort has been possible. During the spawning season catches rise from zero to a maximum at the peak period and then sink to zero again (see Fig. 2); therefore the number of fish caught on a particular day will largely depend on whether the day is at the beginning, middle or end of the season. The catch will not be proportionate to the number of visits or the number

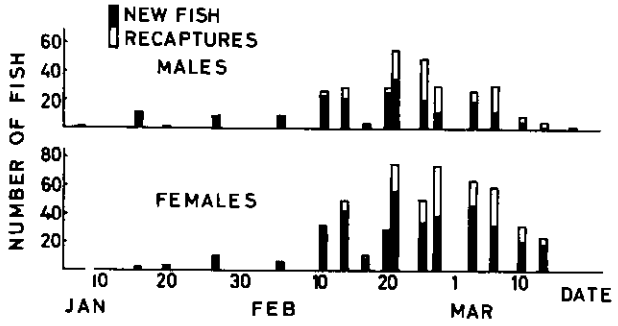


Figure 2. Catches at Holbeck throughout the 1953 spawning season.

of hauls, and neither visits nor hauls can be used as units of fishing effort. Apart from this basic objection, number of hauls could not provide a satisfactory unit because, although as far as possible the same procedure was carried out at each place for each haul, the catches in separate hauls on any one day could be most erratic (see methods of sampling). On each visit several hauls were made until sufficient fish had been taken, so that if the first or second haul provided plenty of fish no further hauls would be done, whereas if only a few fish were caught more hauls would be made.

In general, as many visits as possible were made to each of the spawning sites in each of the years of these experiments and, with some exceptions, it seems justifiable to assume that the annual fishing effort remained approximately constant in each place from year to year. The main exceptions are Brathay 1951 females and Brathay 1953 males and females, and Holbeck 1953 and 1955—7.

In 1951 the river Brathay was in flood for a period of twelve days in the middle of the season and no nettings were possible at this time. The catch of males, who stay longer than the females on the site, was not greatly affected, but the catch of females was very much reduced, as presumably most of them came and went during the time netting was impossible. This explanation is supported by the fact that, of females tagged in 1950, more were recaptured in 1952 than in 1951. In 1953 the river was in flood for almost the whole of the spawning season, and only one effective netting could be done. Because of this the catches of both males and females were very small and have not been used in the calculations.

At Holbeck in 1953 visits were made over a much longer period than in other years. Therefore, in order to have data on a comparable basis when calculating mortality rates, only those fish caught between the same dates as the 1954 visits have been used. From 1955 to 1957 fewer visits were made to Holbeck, so, again to put this data on the same basis as the 1954 data, the number of recaptures has been adjusted in proportion to the number of visits made in 1954 and the successive years. The adjusted values are: 1953, 57 males, 140 females; 1955, 3 males, 24 females; 1956, 14 females; 1957, 8 females. This procedure is open to objections, but it seemed more satisfactory than just omitting these recaptures.

Results and Discussion

(a) Within the spawning season

Brathay. In 1952 nine seinings were done between 31 October and 25 November and on each occasion all fish were given a fin clip or punch to identify that occasion. Certain conditions peculiar to this spawning site should be noted. The fish come up the river and mostly congregate in a deep pool about 1.3 km from the lake until they have finished spawning, when they return to the lake. The pool can usually be almost completely encircled by the net, except in flood conditions when netting is impossible. No variation in catches according to the time of day has been observed (cf. Red Nab). Analysis of the punch marks and fin clips shows plainly that the males and females have different migration habits. The males come up early and stay up: of nine males caught on 21 and 25 November six had been up since at least 3 November and all had been recaught intermediately. The total number of males taken was 36, and of these 10 were recaught on three or more occasions. After 10 November only one new male was caught. In contrast individual females had a much shorter stay and new arrivals were recorded throughout the season. Of the 87 females taken none was recaught more than twice. The mean duration of stay of fish caught at least twice was 12.6 days for the males and 3.8 days for the females. (No allowance has been made for arrival or departure between nettings or non-capture before or after, so these are minimum figures.) The intervals between netting were irregular, and included one of six days and one of seven days. As the mean duration of stay of the females was less than six days some of the females must have been missed altogether. In this experiment 69% of the males and 37% of the females were recaptured at least once (see Table 4).

Holbeck. In 1953 seventeen seinings were done between 7 January and 17 March and on each occasion a punch or fin clip was given to all fish to identify that occasion. This spawning site is in the lake at a depth of about 20 m on a narrow spit of gravel about 200 m from the shore. The general pattern of results is very similar to that found in the Brathay, though the difference between the sexes is less clearly defined. The mean duration of stay for fish caught at least twice was 11.4 days for the males and 9.1 for the females. Of 207 males 39% were

Table 4
Within-season results

	Brathay ♂	Brathay ♀	Holbeck ♂	Holbeck ♀	Red Nab ♂	Red Nab ♀
Total number of fish marked	36	87	207	378	140	160
Not recaught	11	55	126	267	124	159
Recaught once	6	25	58	89	16	1
Recaught twice	9	7	18	19		
Recaught 3 times	5		1	3		
Recaught 4 times	4		3			
Recaught 5 times	1		1			
Mean number of marks per fish on final recapture	1.7	0.4	0.6	0.4	—	—
Percentage of fish recaptured at least once	69%	37%	39%	29%	11%	<1%
Percentage of fish recaptured in next netting after marking	50%	30%	15%	14%	2%	<1%
Mean duration of stay at spawning site (in days)						
(a) fish recaught at least once	12.6	3.8	11.4	9.1	8	1
(b) all fish	8.8	1.4	4.7	2.7	—	—
Emigration rate per day in early part of season	5%	44%	9%	18%		

recaptured at least once, and of 378 females 29% (see Table 4).

Red Nab. In 1952 between 13 November and 8 December ten seinings were done at Red Nab, and all fish caught on each occasion given a punch or fin clip to identify that occasion. Out of 140 males 16 (11%) were subsequently recaptured once and out of 160 females only one (0.6%) was taken again. No fish was recaptured twice. The very poor recapture rate compared with Brathay and Holbeck can be explained by conditions on the spawning site. The spawning area extends along the shore from a depth of about 1 m and is much larger and less closely defined than the other sites; further, owing to obstructions in the lake only a small part of this area can be netted. The fish move into the spawning area each evening at dusk, the males earlier than the females. During daytime no fish are present. In these conditions the chances of recapturing a marked fish are much less than at the other two spawning places (see Table 4).

Differences between sites

The same general pattern of movement to and from the spawning site is found at Brathay, Holbeck and Red Nab, and in addition at Red Nab there is a diurnal movement. It appears that the males come to the spawning site early in the season and remain there for most of it. The females come in, a few at a time throughout the season, spend a short time on the site, and then depart. This difference in behaviour is not quite so distinct at Holbeck as at Brathay; possible a partial explanation may be that the females have less urge to move away from the deep water at Holbeck than from the alien shallow river, but other explanations are also possible (see Sex Ratio). The mean duration of stay of females at Holbeck (9.1 days) was more than twice that at Brathay (3.8 days), but the mean number of punches (i. e. recaptures) was the same, owing to the greater efficiency of netting at Brathay. The males stayed much the same length of time at Holbeck (11.4 days) and at Brathay (12.6 days), but the mean number of punches at Brathay was about three times that at Holbeck, again due to the difference in netting efficiency. The returns at Red Nab, though few, suggest the same general seasonal behaviour as at Brathay. In the diurnal movement with the fish moving in at night there is also a difference between the sexes, as the males come in earlier than the females.

These behaviour differences are of great importance when considering a scheme for satisfactory sampling. Nettings at approximately weekly intervals should give reasonably adequate samples of males at Brathay and Holbeck, and of females at Holbeck, but not of females at Brathay, for which more frequent visits would be necessary. At Red Nab approximately weekly nettings in the late afternoon should be sufficient to sample the males, but more frequent nettings during the hours of darkness would be needed for the females.

Efficiency of netting

A rough estimate of the efficiency of a single seining has been obtained by finding the percentage of males recaught in the next seining after they had first been marked. This will give an under-estimate of the true efficiency, as some fish will have emigrated in the interval between the nettings; it provides, however, a reasonable basis for comparison of the different places. Males only have been used because of their longer duration of stay. The estimates of the efficiency of one seining thus calculated are 50% for Brathay, 15% for Holbeck and 2% for Red Nab.

Another estimate, which could be calculated only for Brathay males, has been made by assuming that fish recaught twice or more were in fact present on the site continuously. For example, a fish caught on occasions 0, 3 and 4 is assumed to have been present but missed by the net on occasions 1 and 2. The percentage of actual to possible recaptures on this basis is 72%. This will be an over-estimate as the fish may have been present but missed by the net on occasions either before the first capture or after the last capture, and these particular fish may have been more liable to be captured than the rest of the population.

A further estimate is provided by the percentages of males recaught at least once. These are 69% for Brathay, 39% for Holbeck and 11% for Red Nab.

(b) Year-to-year

Char were tagged subcutaneously and given a distinctive fin cut at Brathay and Red Nab in 1950 and 1951, at Holbeck in 1951 and 1952 and at Low Wray in 1950. The number of fish tagged, recaptures in subsequent years and total catches are given in Table 5. The question of homing is not being dealt with in this paper; it is necessary however for our present purpose to mention that all these recaptures were made at the same spawning site at which the fish had originally been tagged. From these data, with the adjustments already described, Fig. 3 has been drawn and estimates of population numbers and mortality and survival and the sex ratio have been calculated and are shown in Tables 6—8. It must be stressed that all these results refer to adult mature fish, which would be aged at least four years (Frost, 1951) when first captured and tagged, and many would be five or more years old.

Table 5
Numbers of char tagged and recaptured, and total catches

Place	Year	Males		Females	
		Tagged and recaptured	Total catch	Tagged and recaptured	Total catch
Brathay	1950	(103)		(225)	
	1951	32 (25)	57	17 (41)	60
	1952	16(1) 11	34	25(2) 8	88
	1953	1 0	44	3 0	16
Holbeck	1951	(7)		(28)	
	1952	1 (322)	334	1 (589)	596
	1953	77	230	158	408
	1954	19(3)	200	66(4)	297
	1955	2	ca 200	18	ca 200
	1956		97	7	139
	1957		73	2	113
Red Nab	1950	(90)		(47)	
	1951	19 (213)	238	0 (262)	264
	1952	11(2) 43	194	0 5	165
	1953	2 16	169	1 1	36
Low Wray Bay	1950	(56)		(58)	
	1951	3	80	1	157
	1952	2	49		123

Double recaptures (1) 8 of these had been recaught in 1951 also.
(2) 2 of these had been recaught in 1951 also.
(3) 8 of these had been recaught in 1953 also.
(4) 16 of these had been recaught in 1953 also.
The number of fish tagged is shown in brackets.

Table 6
Population estimates

Place	Sex	Year	Total catch	Population estimate	Standard error of population estimate	Source of estimate
Brathay	male	1950	122			
	male	1950		169	18	Direct proportion. Recaptures after 1 year.
	male	1950		145	19	Direct proportion. Recaptures after 2 years.
	male	1950		197	—	Extrapolation method.
	female	1950	239			
	female	1950		700	132	Direct proportion. Recaptures after 1 year.
	female	1950		684	108	Direct proportion. Recaptures after 2 years.
	male	1951	57			
	male	1951		59	23	Triple-catch estimate on '50, '51, '52.
	male	1951		63	13	Direct proportion. Recaptures after 1 year.
	male	1951		87	20	Direct proportion. Double recaptures.
	female	1951	60			
	female	1951		434	254	Triple-catch estimate on '50, '51, '52.
	female	1951		360	107	Direct proportion. Recaptures after 1 year.
	female	1951		336	146	Direct proportion. Double recaptures.
Holbeck	male	1952	334			
	male	1952		685	56	Direct proportion. Recaptures after 1 year.
	male	1952		1481	286	Direct proportion. Recaptures after 2 years.
	male	1952		619	—	Extrapolation method.
	female	1952	596			
	female	1952		1263	73	Direct proportion. Recaptures after 1 year.
	female	1952		1600	154	Direct proportion. Recaptures after 2 years.
	female	1952		1169	—	Extrapolation method.
	male	1953	230			
	male	1953		644	55	Direct proportion. Double recaptures.
	female	1953	408			
	female	1953		1369	274	Direct proportion. Double recaptures.

Table 6 (cont.)

Place	Sex	Year	Total catch	Population estimate	Standard error of population estimate	Souree of Estimate
Red Nab	male	1950	94			
	male	1950		1013	211	Direct proportion. Recaptures after 1 year.
	male	1950		1110	293	Direct proportion. Recaptures after 2 years.
	male	1950		254	—	Extrapolation method.
	male	1951	238			
	male	1951		636	245	Triple-catch estimate on '50, '51, '52.
	male	1951		828	106	Direct proportion. Recaptures after 1 year.
	male	1951		614	117	Direct proportion. Recaptures after 2 years.
	male	1951		812	359	Direct proportion. Double recaptures.
	male	1951		441	—	Extrapolation method.
	female	1951	264			
	female	1951		4017	1468	Direct proportion. Recaptures after 1 year.
Low Wray Bay ...	male	1950	116			
	male	1950		1008	438	Direct proportion. Recaptures after 1 year.
	male	1950		709	340	Direct proportion. Recaptures after 2 years.
	female	1950	92			
	female	1950		4321	2478	Direct proportion. Recaptures after 1 year.

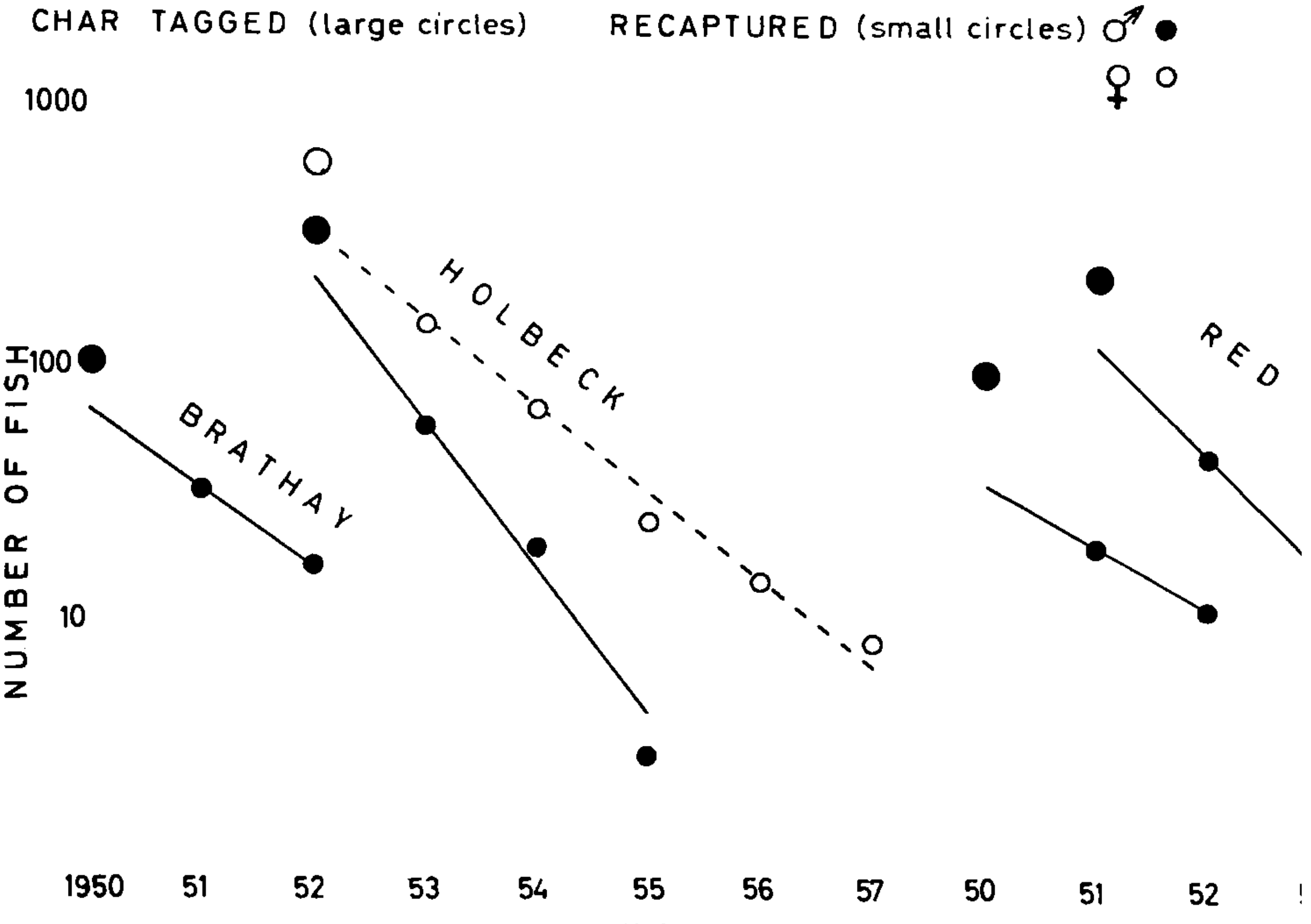


Figure 3. Number of char tagged, related to the numbers recaptured in subsequent seasons.

Table 7
Mortality and survival

Place	Sex	Date	Instantaneous mortality rate z	Annual survival e^{-z}	Standard error of z
Brathay	male	1951—52	0.69	0.50	0.31
Holbeck	male	1953—54	1.10	0.33	0.27
	female	1953—54	0.75	0.47	0.15
Holbeck	male	1953—55	1.30	0.27	0.19
	female	1953—57	0.78	0.46	0.06
Red Nab	male	1951—52	0.55	0.58	0.38
	male	1952—53	0.99	0.37	0.29

Table 8
Sex ratios

Place	Date	Ratio females/ males	Sources of population estimates
Brathay	1950	4.1	Direct proportion, recaptures after 1 year
	1950	4.7	Direct proportion, recaptures after 2 years
	1951	5.7	Direct proportion, recaptures after 1 year
	1951	3.9	Direct proportion, double recaptures
	1951	7.4	Triple catch method
Holbeck	1952	1.8	Direct proportion, recaptures after 1 year
	1952	1.1	Direct proportion, recaptures after 2 years
	1952	1.9	Extrapolation method
	1953	2.1	Direct proportion, double recaptures
Red Nab	1951	4.9	Direct proportion, recaptures after 1 year
Low Wray Bay	1950	4.3	Direct proportion, recaptures after 1 year

At Holbeck the large number of fish tagged and the good recapture rate in subsequent years have given very satisfactory results. The mortality rates for males and females, calculated by the Holt-Spicer method, have been compared and were found to differ significantly, the male mortality ($z = 1.30$) being higher than the female ($z = 0.78$). Unfortunately similar comparisons were not possible for Brathay and Red Nab owing to the poor recapture rate of females in both places. Estimates relating to the same periods of time only can usefully be compared; there is no significant difference between the mortality rates for males at Brathay and Red Nab for the period 1951—1952. Standard errors of the mortality rates are large, owing to the small numbers of recaptures made in two successive years only. Despite this, it may however be of interest to note that the two lowest rates related to the period 1951 to 1952, and the highest to the period after 1953, possibly on account of mortality increasing with age.

The results suggest that the male annual survival rate can vary at least between 25% and 60%, and that the female survival rate is higher than the male.

Estimates of survival rates calculated by the triple-catch method were not inconsistent with those found by the other method (see Table 9).

The population estimates in Table 6 arrived at by various methods are remarkably consistent, with a few exceptions. It is clear that the spawning population at Brathay is much smaller than the other populations studied, and that numbers declined between 1950 and 1951. This decline was also found at Red Nab, the only other place for which figures for these years are available. This fall in population numbers is almost certainly connected with the recruitment rates, which, as found from length frequency distributions, were very low for the period 1950 to 1951.

The estimates made for Holbeck based on recaptures after two years' absence and on double recaptures are definitely too high, the males more so than the females. All these estimates ultimately depend on the estimated number of recruits present in the population in the second year after tagging. Now the spring spawners (Holbeck) grow faster than the autumn spawners, and the males grow faster than the females. It is probable that the faster growing of the recruits had after two years grown larger than the smaller of the tagged fish, and that therefore the method used to separate recruits from the rest of the population was not in this case satisfactory, insufficient allowance being made for recruitment. The males would be the more affected, as they grow faster than the females.

The estimates for males and females at Red Nab made by the extrapolation method are both too low; with small numbers of recaptures this method is very unreliable, and catches at Red Nab are always rather erratic.

The very large standard errors of some of the population estimates emphasize the unreliability of estimates based on few recaptures.

In round figures, assuming that the Red Nab and Low Wray Bay populations are equal, the total

Table 9
Survival and recruitment by triple-catch method

Place	Sex	Years of tagging	Annual survival e^{-z}	Standard error of e^{-z}	Annual recruitment $e^{\beta}-1$	Standard error of e^{β}
Brathay	male	1950, 1951	0.35	0.13	0.16	0.24
Brathay	female	1950, 1951	0.51	0.20	—0.03	0.25
Red Nab	male	1950, 1951	0.59	0.19	0.30	0.26

population of the three autumn spawning sites studied was in the winter 1951—1952 approximately 2,000 male and 9,000 female char, and of the one spring spawning site 650 male and 1,300 female char. The population had been larger in the previous year.

No attempt has been made to estimate the total population of char in Windermere. The figures given relate only to mature fish from some spawning sites in the north basin of the lake. There are probably other spawning sites in the north basin, and certainly some in the south basin, which have not been studied in these experiments.

(c) Sex ratio

It is obvious on account of the seasonal movements described in a previous section that the relative numbers of males and females caught depends on various factors largely independent of actual relative numbers present, and that very misleading results could be obtained by calculating the sex ratio from the catch on any one occasion or from the total catch in a season.

The sex ratio for any one year-class will change as the fish grow older if the mortality rates of the two sexes differ, and if in addition the year-classes vary in abundance the sex ratio will not remain constant from year to year. Both these provisos appear to apply to char in Windermere.

Ratios calculated from strictly comparable population estimates of males and females (Table 8) (i.e. relating to the same year and based on equivalent data) show that there are many more females than males in these spawning populations. The dominance of females appears to be relatively less at Holbeck than at the other spawning places, and there thus seems to be a real difference in this respect between spring and autumn spawners. At Holbeck there were about two females for every male, and at the other places about four females for every male. It is possible that the longer stay of individual females at Holbeck during the spawning season might be correlated with this.

(d) Anglers' returns

Altogether twenty marked fish were returned by anglers, of which five had lost their tags; their place and year of tagging was identified by the fin cut. Two other marked fish are known to have been caught, but information about them is incomplete. These reports give a recovery rate of 1.1% from a total of 1952 fish tagged (see Table 10). No figures are available for the total number of char caught by anglers, so no population estimates can be made from these results, but the returns by anglers in this experiment suggest that the mortality due to fishing is very small. It does not seem likely that the very low rate of return was caused by marked fish not being noticed or reported, as the few persons concerned in angling and selling char were all eager to report marked fish. Most fish passed through the hands of the angler and the fishmonger before being cooked and eaten, when discovery of a tag would be almost certain.

The proportions of tagged returned fish from the three places are approximately constant, so it appears that fish from each of these three spawning places are equally liable to capture by anglers. No sure method is known of identifying fish from the various spawning places except during the spawning season, so this experiment made it possible for the first time to sort the fish caught by anglers according to their place of spawning.

(e) Discussion of techniques and conclusions

The simple method of fin clipping and punching to record the recapture histories of individual fish proved adequate to give information on the behaviour of the migratory spawning populations during the spawning season. The fin clips and punch holes were easily made and easy to identify, though a few errors were made in the records of some fish which had been recaptured many times. The numbers thus marked were too small to allow the use of precise methods of estimating population numbers and migration rates. To enable the effective use of the moving triple-catch method or the more sophisticated of the trellis methods in order to make precise estimates of the rapidly changing migration rates would require much larger catches and more frequent visits. Much useful information has been found in this experiment without the use of elaborate methods of analyses, and this has proved to be completely adequate to give a general picture

Table 10
Anglers' returns

Place where tagged	Males		Females		Total number tagged	Total number of anglers' returns	Percentage returned by anglers
	Number tagged	Number of anglers' returns	Number tagged	Number of anglers' returns			
Brathay	128	1	266	2	394	3	0.8
Holbeck	329	6	617	5	946	11	1.2
Red Nab	303	3	309	3	612	6	1.0
Unidentified	—	—	—	—	—	2	—
Total	760	10	1192	10	1952	22	1.1

of the migration patterns at the various places. To give precision to this general picture would require much additional effort, which the improvement in results would certainly not justify.

The use of subcutaneous tags and fin cuts was satisfactory for the year-to-year experiments. The longest interval between tagging and recapture was five years. The fin cuts were essential for identifying the tagged fish, and also they provided some information for fish which had lost their tags. However fin cuts alone would not have been sufficient, as double recaptures could not have been identified.

Considerably more information could have been obtained if fish had been tagged at Holbeck in 1953 (or if sufficient had been tagged in 1951), to provide data from two successive years. The inability to recapture enough females at Brathay in 1951, and at Red Nab generally, could not be foreseen when planning the experiment, but these failures caused the loss of valuable comparative information.

Small numbers of fish have been mentioned several times as precluding precise analysis. This factor was not within our control, as during the experiments, with few exceptions, all fish caught were released with a mark; the few which were not were either dead or removed from the lake for other experiments. At Holbeck the numbers tagged in 1952 (322 males, 589 females) proved adequate for estimating mortality rates, but in the within-season experiment in 1953 the 207 males and 378 females marked, when divided among the seventeen occasions of netting, and taking into account the efficiency of the netting, were not sufficient to allow the precise determination of immigration, emigration and population size. The total numbers of males and females marked within the season at Holbeck represent respectively 22% and 25% of the estimated total population available for marking, while at Brathay in 1951 49% of the males and 21% of the females were marked, so no very great improvement in the numbers marked (e.g. of the order of tenfold) would have been possible; statistical errors are bound to be large when dealing with relatively small populations.

In general it is concluded that the two series of marking experiments have provided satisfactory population parameters for these spawning populations, most of which would have been difficult or impossible to obtain by other methods.

Acknowledgements

These experiments were carried out in conjunction with investigations on char being made by our colleague Dr Winifred Frost, whose co-operation is gratefully acknowledged. The netting operations were done by Mr G. J. Thompson and his assistants, and Mrs E. Booth did much of the recording. We are grateful to all of these for their help.

Summary

In one series of marking experiments carried out within the few weeks of the spawning season the char of three distinct spawning populations were netted on a number of occasions, and on each occasion all were given a fin clip or a hole punched in a fin, peculiar to the occasion. Simple analyses of the previous capture history of all fish recaptured provided data on the migration onto and off the restricted spawning areas. Males came early and stayed on average about twelve days on the spawning ground, females arrived throughout the season and stayed less time.

In a second series of experiments the char were marked during one season with subcutaneous tags combined with fin amputations and recaptured in subsequent spawning seasons one or more years later. Three autumn spawning populations together totalled about 2,000 males and 9,000 females (about four females to one male) and one spring spawning population consisted of about 650 males and 1,300 females (two females to one male). Annual mortality rates (z) varied, but for the spring spawning population were about 1.3 for males and 0.8 for females. Only one per cent of the tagged fish were recaptured by anglers.

Although the small numbers involved and difficulties in netting limited the accuracy and completeness of the data, altogether the experiments provided satisfactory information on population parameters that would have been difficult to obtain without marking.

References

BAILEY, N. T. J. 1951. On estimating the size of mobile populations from recapture data. *Biometrika*, **38**: 293—306.

DAHL, K. 1917. Studier og Forsøk over ørret og Ørretvand. Kristiana. 107 pp. English version: 1918—19. Studies of trout and trout waters in Norway. *Salm. Trout Mag.*, **17**: 58—79 and **18**: 16—33.

DARROCH, J. N. 1959. The multiple-recapture census. II. Estimation when there is immigration or death. *Biometrika*, **46**: 336—51.

FISHER, R. A. & FORD, E. B. 1947. The spread of a gene in natural conditions in a colony of the moth *Panaxia dominula* L. *Heredity*, **1**: 143—74.

FROST, W. E. 1951. Some observations on the biology of the char, *Salvelinus willughbii* Gunther, of Windermere. *Verh. int. Ver. Limnol.*, **11**: 105—10.

HOLT, S. J. 1958. Estimating the parameters of an exponentially declining population. F.A.O., Fish Div., Mimeo.

JACKSON, C. H. N. 1940. The analysis of a tsetse fly population. *Ann. Eugen., Lond.*, **10**: 332—69.

LE CREN, E. D. 1954. A subcutaneous tag for fish. *J. Cons. int. Explor. Mer*, **20**: 72—82.

PETERSEN, C. G. J. 1889. *Fisk. Beretn. Kbh.*, 1888—9.

SCHNABEL, Z. E. 1938. The estimation of the total fish population of a lake. *Amer. math. Mon.*, **45**: 348.

STUART, T. A. 1958. Marking and regeneration of fins. *Sci. Invest. Freshwat. Fish. Scot.*, 22.

22.

A Review of Tagging Experiments in New Zealand

By

K. RADWAY ALLEN*

The object of this paper is to describe briefly the tagging work which has already been done in New Zealand waters, the scope of the experiments, the techniques used, and some of the conclusions which have been reached with regard to the utility of various methods.

It is convenient in this paper to consider freshwater and marine fisheries separately. In the freshwater field tagging has been carried on almost continuously since 1939 and a total of about 20,000 fish have been tagged. The great majority of these have been trout (brown and rainbow trout in roughly equal numbers) but about 1400 eels have also been marked. Essentially the same tag has been used on all trout work; this is a thin silver disc 5 mm in diameter attached immediately in front of the dorsal fin with a loop of wire. Originally silver wire was used and the ends were twisted together; more recently equally satisfactory results and much greater speed of tagging have been obtained by using preformed loops of stainless steel suture wire with a sharpened end which can be pushed directly through all but very large fish, the ends then being hooked together and crimped up. The thickness of wire for this technique is critical and 0.018 inches (0.45 mm) diameter has been found best. Experiments are now being planned using titanium wire which can be obtained in a variety of hardnesses and is extremely light; it cannot however yet be procured with the high polish available with stainless steel. No precise measurements of retention have been made, although these are now in progress using fin clipping as a cross-check. Recoveries of up to three years have, however, been made. The method has been used successfully for fish down to about 12 cm in length and the wire loop allows adequately for growth even in fast-growing stocks which may reach 50 cm or more before recapture. In some work, where recovery has been chiefly with gill nets, difficulty has sometimes been experienced due to the ends of the wire catching in the net and pulling the tag out. Attempts to overcome this by welding the ends of the wire together have not yet been successful. In most work recovery has been essentially by research staff and the problem of overlooking the relatively inconspicuous tag does not arise. Where recovery may also be by anglers much seems to depend on whether the anglers, through their organizations, have been closely identified with the scheme. In work involving the tagging of several thousand fingerlings prior to liberation, experiments are being made using coloured plastic tags with a colour code to indicate length at time of tagging. This will eliminate the time taken in recording the length of each individual fish, without losing any information. It will also yield data on the effect of tag colour on survival. It is also proposed to use a tag-shape code to distinguish the different years' liberations.

The tagging of eels presents special problems due to their habits which would quickly cause an external tag to be wiped off. Work in New Zealand has been concentrated on the long-finned eel (*Anguilla dieffenbachii*) and a sub-cutaneous tag has been used on these with considerable success. This tag is a narrow metal strip about 10 mm long which is inserted under the skin with a special instrument. A miniature "mine-detector" has been developed for the purpose of detecting these tags in recaptured fish. This method has been used in experiments in which particular eel-populations have been sampled at regular intervals using electric-fishing techniques, and an average recovery rate of 18% has been obtained, although many fish have undoubtedly moved out of the areas observed; recoveries after three years have been recorded.

Tagging of marine fish was not started in New Zealand until about 1954 and has been largely confined to about five of the principal commercial species; tarakihi (*Cheilodactylus macropterus*) 8500; snapper (*Chrysophrys auratus*) 5300; and several species of flat fish (*Rhombosoleinae*) 10,800. A few of the early experiments with the first two species employed opercular tags, but these were soon abandoned in favour of Petersen type tags. Those used have been 13 mm in diameter and made of plastic, and are bright yellow in colour to facilitate recognition. In all experiments, except one with flatfish, the discs have been paired, one on each side of the fish. The recovery rate when only one disc was used was, however, not significantly different from that obtained with paired discs. Three different methods of attachment have been used:

(a) Monofilament nylon threaded through the discs and knotted at each end (all species)

(b) Stainless steel wire toggles joined by an elastic thread (tarakihi and snapper)

---

* Director of Research, Fisheries Laboratory, Wellington, New Zealand.

(c) Stainless steel wire staples threaded through the discs and with the ends turned over (flatfish only).

The second method appears to be unsatisfactory with the materials now in use and has given a very low recovery rate. Although fully comparable tests of the other two methods on the same species in the same area at the same time have not been made, the recovery rates obtained with them are generally of the same order and do not indicate significantly different rates of retention. As will be discussed in a later paper, however, there is evidence for a fairly high rate of loss for both types. Recoveries have been almost entirely from commercial fishermen for tarakihi and flatfish, but about equally from professionals and amateurs for snapper. It is not known how complete these returns are, but efforts have been made to stimulate them by press and radio publicity. Rewards, however, have not been offered. In all this work care has been taken to ensure that only fish in good condition were tagged and released, and for snapper it has proved necessary to restrict operations to hand lining, since virtually no trawl-caught fish are in suitable condition for tagging when landed.

The percentage return depends of course to a large extent on the intensity of the fishing and so varies in different areas and seasons for the same species. The following table summarises the results for the five principal species; the operations with elastic-toggle tags and opercular tags are ignored as the efficiency of these tags is so doubtful.

	No. tagged	No. recovered	% recovered
Snapper	2174	32	1.47
Tarakihi	3363	76	2.26
Dab .... (*Rhombosolea plebeia*)	5503	272	4.94
Lemon Sole .... (*Pelotretis flavilatus*)	2032	88	4.33
Yellow belly flounder . (*R. leporina*)	1964	160	8.14

Summary

Tagging in New Zealand has been carried out about equally with freshwater and marine species. Principal freshwater species are trout, tagged with small silver discs, and eels, tagged subcutaneously. Principal marine species are snapper, tarakihi, and various species of flatfish, all tagged with Petersen tags.

23.

The Use of Stains in Shrimp Mark-Recapture Experiments

By

T. J. COSTELLO*

Petersen tags have been used with some success to mark the white shrimp, *Penaeus setiferus*, (Lindner and Anderson, 1956) and the pink shrimp, *P. duorarum*, (Iversen and Idyll, 1960). However, small shrimp, because of their general frailty, suffer excessive mortality during or shortly after the tagging process. Thus, an undesirable restriction of the tagging method in shrimp population studies is that tagged populations consist only of large and robust individuals, in which the recurrence of molting is minimal. In addition, shrimp agility and mobility are believed impaired by tags, limiting still further the method's utility as a research tool.

On the basis of small-scale laboratory trials with the white shrimp, *P. setiferus*, Menzel (1955) reported that injection of a biological stain, which concentrated and remained fast in the shrimp's gill filaments, promised a more feasible means of marking penaeid shrimp. Under contract with the U. S. Bureau of Commercial Fisheries, Dawson (1957) expanded on the staining technique and reported four vital dyes that seemed useful for this purpose. During 3 years of experiments in which 146,500 shrimp were stained and released in the South Atlantic Ocean and Gulf of Mexico, Costello (1959) and Costello and Allen (1960) demonstrated the utility of this method for studying shrimp movements and growth. Refinements in staining techniques and increasingly efficient field procedures evolved from these experiments.

Methods

Successful shrimp marking requires that experimental animals be held at temperatures and salinities most conducive to their survival. It is also important to time the staining process so it will not be undertaken while high proportions of shrimp are in a "soft-shelled" condition. A high rate of mortality will prevail if shrimp are handled and stained too soon after ecdysis.

Preferably, the sites of shrimp capture, staining, and release should be contiguous, so as to maintain uniform conditions throughout the marking operation and to eliminate the need for transporting marked shrimp any great distance.

When obtaining animals for marking it is suggested that, where possible, an experienced commercial fisherman, especially one familiar with techniques in handling live shrimp, be contracted to obtain suitable quantities of shrimp in good condition.

When a study of growth rates is planned, shrimp of uniform size must be released. A simple and efficient device for separating shrimp into size groups is described by Allen and Costello (1961).

For holding shrimp prior to marking, small floating "live cars" consisting of wood frames covered with hardware cloth are useful. Twenty-four-gallon plastic garbage cans perforated with $^1/_4$-inch holes and supported in the water by automobile tire inner tubes serve equally well. A table with inset trays to hold shrimp just prior to marking facilitates the staining operation. The table should also be fitted with a trough in which freshly stained shrimp are carried by means of running sea water to a suitable holding tank. Other equipment such as water pumps, hose systems, etc., must be arranged to suit the particular field situation.

Trypan blue (C. I. No. 477), Trypan red (C. I. No. 438), fast green (FCF, C. I. No. 42053), and Niagara sky blue 6B (C. I. No. 518) have proved to be the best dyes for marking shrimp. More than any other factor, the care with which stain solutions are prepared controls the success of shrimp staining experiments. The following important points should be considered when making solutions:

1. Sterile distilled water is the preferred solvent.
2. Solutions should be filtered through Whatman No. 1 filter paper or equivalent.
3. Stains differ according to manufacturer. Fast green manufactured by the National Aniline Co., and Trypan blue, Trypan red, and Niagara sky blue 6B manufactured by Harleco are recommended.
4. Stain solutions must be freshly prepared, since in solution they become toxic with ageing.

Shrimp are injected at the articulation of the fourth and fifth abdominal segments. Care should be taken to avoid puncturing the hindgut. One-half-cc tuberculin syringes fitted with $^1/_4$-inch hypodermic needles (27 or 30 gauge) are recommended for injecting shrimp of all sizes.

The quantity and strength of stain solution required vary according to the type of stain and size of shrimp. For a pink shrimp 130 mm long, 0.07 ml of a 0.25 percent solution of Trypan blue, 0.18 ml of a 0.5 percent solution of fast green (FCF), or 0.09 ml of a 0.5 percent

---

* Fishery Research Biologist, U. S. Bureau of Commercial Fisheries, Galveston, Texas.

solution of Trypan red are optimum. Only freshly prepared solutions should be used. Shrimp can be injected at the rate of 300 to 350 per hour per man.

Field tests with Trypan blue and fast green indicate that these stains remain fast over a period of at least 6 months. Trypan red is subject to some fading. No field tests have been conducted with Niagara sky blue 6B.

To eliminate from any experiment specimens that do not immediately recover from handling shock, marked shrimp should not be released for at least 4 hours following injection of the staining solution. Releases should be made in areas where undue predation by fishes at the time of release can be avoided.

Because stained shrimp are not as easily detected as tagged shrimp, greater stress must be placed on the recovery phases of mark-recapture experiments using stains as marking agents. Stained shrimp are readily recognized by trained personnel but not by commercial fishermen, upon whose coöperation in recognizing and returning marked specimens the success of each experiment depends. Shrimp staining experiments have proved most successful when they have been widely publicized, when sizeable rewards have been offered for recaptures, and when carefully planned and complete coverage has been given to landing ports.

Summary

The usefulness of biological stains for marking penaeid shrimps has been demonstrated. The staining method is simple, rapid, and suitable over a wide range of shrimp sizes. Successful application of the staining method in mark-recapture experiments requires: (1) careful handling of shrimp; (2) correct timing of each experiment so as to avoid too high a proportion of soft-shelled (molting) animals; and (3) injection of recommended amounts of properly prepared stain solutions. The method's disadvantages are: (1) animals recaptured by commercial fishermen are not as easily recognized as tagged shrimp and (2) for purposes of growth estimation, experimental shrimp must be of uniform size when released.

References

ALLEN, D. M. and T. J. COSTELLO. 1962. Grading large numbers of live shrimp for marking experiments. *Progr. Fish. Cult.*, **24** (1): p. 46—48.

COSTELLO, T. J. 1959. Marking shrimp with biological stains. *Proc. Gulf Caribb. Fish. Inst.*, 11th Ann. Sess., 1958, p. 1—6.

COSTELLO, T. J. and D. M. ALLEN. 1960. Notes on the migration and growth of pink shrimp (*Penaeus duorarum*). *Proc. Gulf Caribb. Fish. Inst.*, 12th Ann. Sess., 1959, p. 5—9.

DAWSON, C. E. 1957. Studies on the marking of commercial shrimp with biological stains. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.* No. 231, 23 p.

IVERSEN, E. S. and C. P. IDYLL. 1960. Aspects of the biology of the Tortugas pink shrimp, *Penaeus duorarum*. *Trans. Amer. Fish. Soc.*, **89** (1): p. 1—8.

LINDNER, M. J. and W. W. ANDERSON. 1956. Growth, migrations, spawning and size distribution of shrimp, *Penaeus setiferus*. *Fish. Bull.*, U. S., **56** (106): p. 553—645.

MENZEL, R. W. 1955. Marking of shrimp. *Science*, **121** (3143): p. 446.

24.

Problems in Tagging Salmon at Sea

By

ALLAN C. HARTT*

Tagging has become a standard and useful tool in the research and management of salmon in coastal areas as a result of many years' development of methods and techniques. In extending salmon tagging to the high seas, however, we have encountered new problems that require considerable modification of methods used in coastal areas. It is the purpose of this paper to describe some of the problems met in oceanic salmon tagging, and to report progress in overcoming them.

Although the experiments discussed were entirely with Pacific salmon (genus *Oncorhynchus*) and steelhead trout (genus *Salmo*), findings should be applicable in some measure to Atlantic salmon (genus *Salmo*) and perhaps to other pelagic species.

Data discussed are from United States high seas tagging experiments conducted from 1955 through 1960 under auspices of the International North Pacific Fisheries Commission (Canada, Japan, and United States).** Tagging is one of several major investigations by the three countries to determine oceanic distribution and movements of salmon with reference to continent of origin. This information is needed for determining a line or lines at sea which best separate Asian and American salmon in accordance with terms of the North Pacific Fisheries Convention (INPFC Annual Report for year 1959). Summaries of progress in the various research programs are available in INPFC Annual Reports (INPFC 1956—1960). In addition, a detailed report on fishing gear used, methods and tagging results of United States experiments for the years 1956—1958 has been published (Hartt, 1962). The present paper draws together our findings regarding gear and methods for the full six years of operations, 1955—1960.

Fishing Gear

The selection of gear for catching salmon for tagging purposes is a much more important consideration in high seas than in coastal experiments. This is due mainly to the prevalence of rough water, and to the more delicate condition of salmon during their ocean feeding period. Salmon at sea have a relatively thin mucous layer and skin, and are easily scaled. As a result, the success of tag return varies greatly according to the degree of injury caused by the gear.

The four types of gear commonly used for taking salmon at sea are gill nets, long lines, purse seines, and trolls. Trolling will not be discussed, since this gear has not been used in the mid-Pacific experiments. (The mortality of troll-caught chinook salmon (*O. tshawytscha*) is discussed by Parker and Black (1959).) Sufficient numbers of tagged salmon have been released from the other types of gear that the problems of injury may be discussed, and the relative success of tag return compared.

Gill nets

Since gill nets are effective and convenient for taking salmon at sea, it would be very desirable if they could be used for taking salmon for tagging. However, tag returns have been consistently poor in all high seas experiments where this gear has been employed.

In 1955, tagging experiments in the Gulf of Alaska using gill nets for capturing specimens yielded only three returns from 333 salmon released, or less than 1.0%. These were experiments only incidental to the main task of exploratory fishing by the "John N. Cobb" that year (Powell and Peterson, 1957), but the very low rate of return indicates the difficulty in releasing fish in good condition when caught by gill nets. Japanese biologists released many salmon from gill nets annually between 1952 and 1956 in the North Pacific and Bering Sea. Returns were less than 1% each year. Their results were better in 1957, when 13 returns (2.1%) were received from 621 tagged red salmon (*O. nerka*) released (Japan, Fisheries Agency, 1958). For comparison, red salmon released from purse seines in the same vicinity in 1957 yielded 57 returns from 729 tagged, or 7.8%.

In coastal areas, salmon have been successfully tagged from gill nets by constantly tending a short section of net and removing the fish to a holding net as soon as possible after gilling. In experiments in Bristol Bay in 1950, for example, 41% of those tagged from gill nets in the above manner were returned (1754 released, 722 returned; unpublished data,

---

* Fisheries Research Institute, College of Fisheries, University of Washington, Seattle.

** Contribution No. 126, College of Fisheries, University of Washington.

Tagging by the United States section of the INPFC has been done by the F.R.I. (College of Fisheries, University of Washington) under contract from the United States Fish and Wildlife Service, Bureau of Commercial Fisheries.

Fisheries Research Institute Bristol Bay project, 1950). In these experiments, fish injured or obviously weakened by their struggles in the gill net were not tagged. Moreover, their recapture was only a few hours or days after release, whereas maturing salmon tagged at sea are usually at liberty three weeks or longer. In high seas tagging from gill nets, it is not practical to use the methods described for coastal areas. Since fish are usually scattered, a very long gill net must be used to take reasonable numbers, and the time in the net correspondingly increases. Moreover, the prevalent chop and swell do considerable additional damage. In most high seas tagging from gill nets it has not been practical to patrol the net with a smaller boat, so the net is simply set for the desired period of time, and then retrieved in the usual manner; fish in apparently good condition are removed carefully and either tagged and released directly or placed in a holding tank and tagged later. Even those in relatively "good" condition must suffer a high mortality, as evidenced by the low rates of return cited. Thus, gill nets, although an effective means of capturing salmon, are not a practical gear for tagging on the high seas.

Long lines

The Japanese, who for many years have fished salmon commercially with long lines, have since 1958 been very successful in tagging salmon caught by this means in the central North Pacific and Bering Sea. The gear consists of a light cotton or synthetic main line suspended near the surface by small floats. Monofilament nylon "branch lines" or gangions about one meter long are spaced every 3 meters. Hooks are baited with whole small fish. The gear differs from Danish long lines as described by Larsen (1950) in having shorter gangions and thereby closer spacing of hooks, and also in the elimination of sinkers. Several miles of the gear are set during the hours of darkness or early morning. Fish are tagged immediately as they are brought aboard.By tagging only lively fish with superficial hook injuries, tag returns have been much greater than in experiments where gill nets were used. In 1958 for example, 105 reds were returned from 1137 mixed mature and immature reds released, or 9.2% (INPFC Annual Report for 1958). Of 250 maturing red salmon similarly tagged and released in the eastern Bering Sea, 25 — 29 June 1960, 50 were returned, or 20.0%. By way of comparison, 213 purse-seine-caught reds released in the same general vicinity on 20 and 21 June 1960, yielded 90 returns, or 41.8%. Tag return percentages were higher from both types of gear in 1960, partly because of general improvement of techniques, and partly because of a $ 25.00 reward offered by the United States for the return of high seas tags captured by our fishermen (irrespective of country releasing fish).

Purse seines

Following trials with gill nets in early 1956, purse seines have been used by the Fisheries Research Institute in all high seas salmon tagging experiments. Salmon caught for tagging by purse-seines have consistently yielded a higher tag return rate than those caught by either gill nets or long lines, where comparable data were available. Each year the gear has been improved or methods of fishing adapted in order to make fishing more effective or to reduce injury by the gear.

The small-sized salmon encountered at sea were found to gill in the web of standard commercial purse seines ($4^1/_4$″ mesh), so that very small mesh size (2″) was required to avoid gilling of the smallest fish. The heavier knotted netting in the bunt end of the seine was found to chafe and scale fish severely during brailing, and small-meshed knotless webbing was therefore used to reduce this problem. Also, an outrigger pole with a bridle attached to the bunt was used to hold the bunt from collapsing against the side of the vessel as the seine set was completed. This insured swimming room for the fish during the critical last few minutes of retrieving the web, when collapsing of the net due to wind and seas previously caused considerable injury. Figures 1 and 2 illustrate the outrigger and bridle just before, and just after, completion of web retrieve. Figure 3 shows fish in the bunt, and the ample swimming room afforded by the outrigger and bridle.

In the instance illustrated in Figures 1—3, seas are calm. When chop and swell are large, fish must be removed quickly to the holding tank, or chafing injury would result even using the knotless bunt material.

From the foregoing, it is evident that purse seines can provide fish in excellent condition for tagging at sea. However, on the debit side, seine gear cannot be used in as rough weather as can gill nets or long lines. The large size (400 fathoms long, 35 fathoms deep) and weight of the seines place an extreme strain on the ship's tackle in heavy chop and swell. The exact conditions under which fishing can be done would be hard to define, since it depends on the direction the seine is to be set in respect to wind direction, and also upon the type of swell, whether short and steep or long and rounded. The weather limitations to seining at sea are probably not a serious handicap in our operations however, since only a small percentage of salmon caught by any type of gear in rough seas would be in suitable condition for tagging.

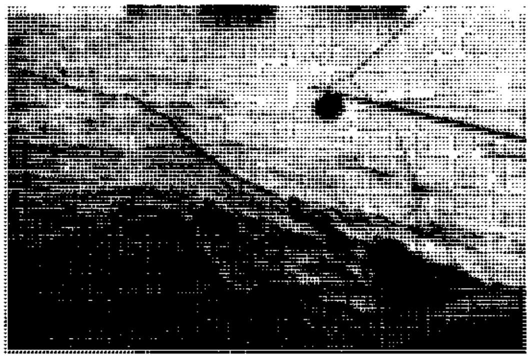


Figure 1

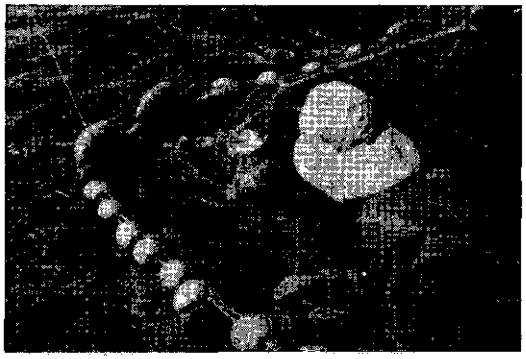


Figure 2

Figure 3

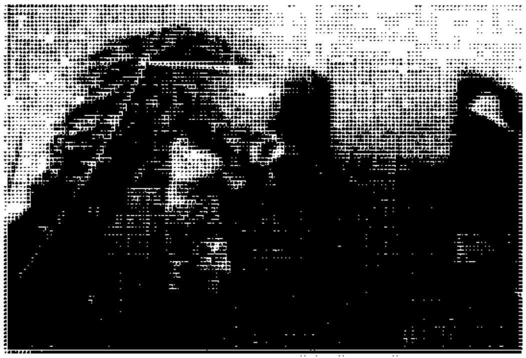


Figure 4

Figures 1—4. 1: Outrigger and bridle in position just before last of web is retrieved; 2: Bridle holding bunt open during brailing; 3: Behaviour of fish in open bunt; 4: Brailing from bunt to holding tank.

Even within the range of weather conditions under which seines can be fished, the success of return is reduced when rough seas cause appreciable injury. Table 1 illustrates the success of return of red salmon tagged south of Adak, according to their general condition at release. The 82 fish released on 5 June 1960 classified as "poor" yielded only 1.2% return as compared to at least 9.0% return for comparable groups classified as "good". The condition referred to is based primarily on the degree of scaling since this is an index of the amount of chafing injury by the web. The example shown is an extreme case, since in addition to very heavy swell and chop, there were mechanical difficulties in completing the haul, which allowed the web to confine the fish and delayed brailing. Results illustrate the seriousness of gear injury, however, and the importance of improving methods and gear to minimize such injury.

Table 1

Numbers of tagged red salmon released and returned, according to general condition of fish at release

(3 days' operations south of Adak Island, 1960, vessel "Renown")

Date of Release	Number Released	Number Returned	Percent Returned	General Condition of Fish
5 June	82	1	1.2	Poor
6 June	155	14	9.0	Good
7 June	110	10	9.1	Good

In comparing the several types of gear for taking salmon at sea, seines have shown an unexpected advantage over gill nets or long lines in that the direction of fish movement at time of catch is indicated by the direction of set of the seine. Seines are set in a semi-circle and held open for approximately 30 minutes, thus catching salmon moving generally toward the opening of the net. By observations of results of repeated sets in several directions it has been found that salmon move in very definite and consistent patterns in some areas at sea. In five seasons' operations in the area south of Adak Island, for instance, 185 sets with the seine open toward the east averaged 142 salmon, while 31 sets open west yielded an average of only 9 salmon. Thus in interpreting tag results, direction of movement at time of release is known as well as subsequent movement toward point of recapture. Under ideal conditions gill nets also may indicate approximate direction of movement of fish caught, by observing the relative numbers of fish gilling from each side of the net. When wind or tide shifts the direction of the lie of the gill net, such information is lost.

Gear selectivity is another important problem in catching salmon for tagging, and is probably more pronounced at sea than in coastal areas. Of the 3 types of gear discussed, the purse seine probably takes a more representative cross-section of species and sizes, since mesh size is small enough to retain the smallest fish and the depth of fishing is considerably greater than the standard surface gill nets and long lines being used at present. Canadian workers bave experimented with gill nets at various levels to a depth of 200 feet in the Gulf of Alaska, and have shown salmon present as deep as 160 to 200 feet during the daytime, and as deep as 120 to 160 feet at night (Neave, 1960). Since Neave showed a considerable decrease in numbers of fish at the greater depths, it is probable that the 210-foot depth of the seines used by the United States is sufficient to reach the great majority of feeding salmon. The 210-foot depth is the measured depth while the net is in towing position and collecting fish.

Finally, in evaluating gear for tagging purposes, the size of catch or gear efficiency should be mentioned. Gill nets or long lines several miles long, and being fished for 4 to 8 hours, are undoubtedly more efficient in areas where salmon are few and scattered. Since a purse seine set requires about 2 hours and causes much wear and tear on a very heavy piece of gear, it is not practical to seine where fish are scarce. However, many areas have been found at sea where salmon are present in satisfactory numbers for seining. By seeking such areas, seiners have averaged 80 to 100 salmon per set, with some hauls netting over 1000. In this manner the more important concentrations of fish are tagged and released which is desirable at this stage of our knowledge.

Holding Tanks

Live tanks as pictured in Fig. 5 have been used aboard the tagging vessels since 1956. Little or no scaling injury is caused after fish are placed in the tanks, regardless of weather conditions, and fish are

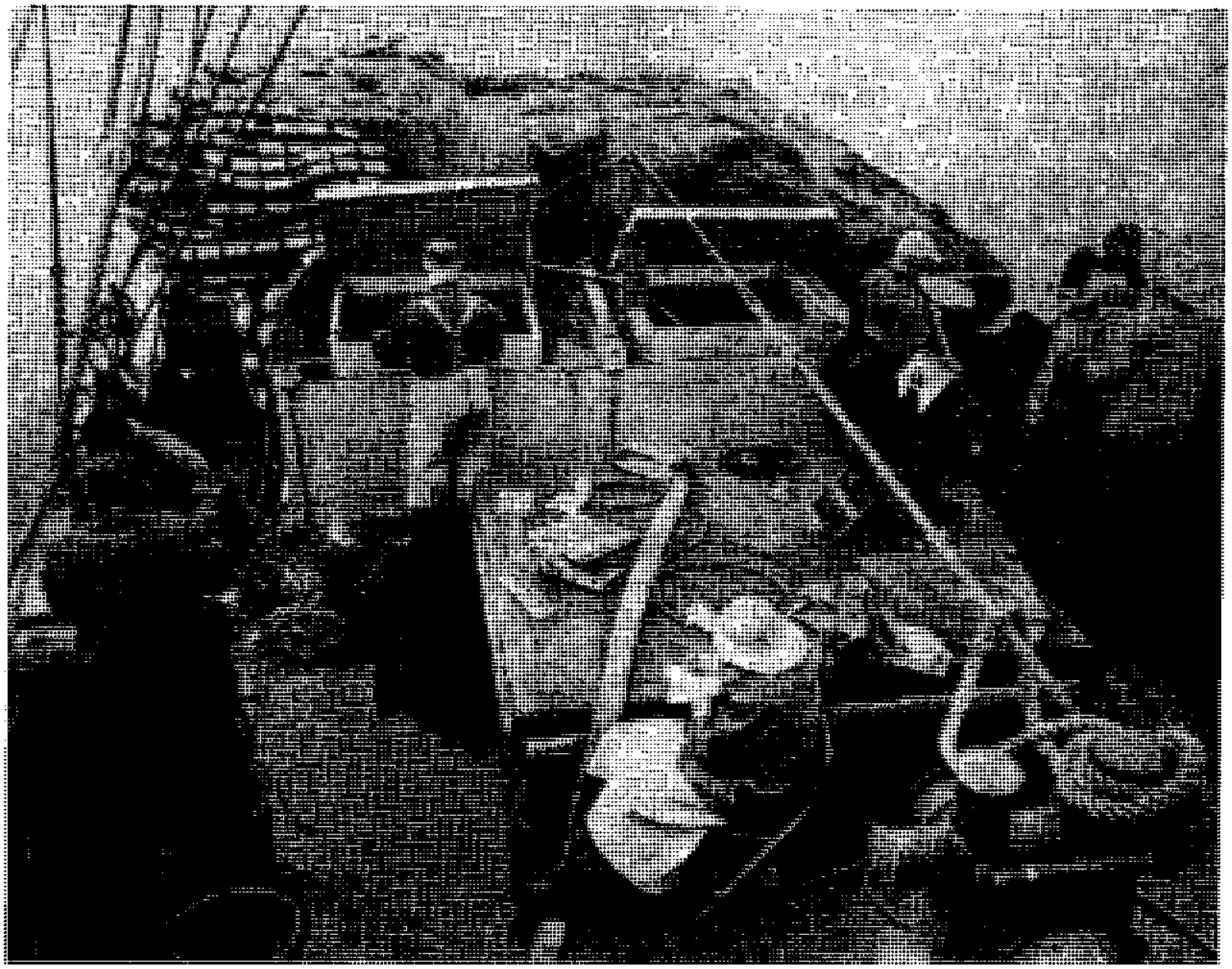


Figure 5. Tagging operations aboard vessel *Commander*, showing holding tanks and disposition of personnel.

in a convenient location for dipping and tagging. Since tag returns from seine-caught tank-held fish have been better than from gill net- or longline-caught fish, it has been assumed that the tank itself causes no appreciable mortality. However, it has been noticed that in large catches the success of return was usually poorer than in average or small catches, and further, that in some large samples, rate of return declined among the later fish released. The overall reduced return was thought to be due to injury previously sustained in the net due to the press of numbers, and to the additional time taken to brail large catches. The poorer return from the later fish released was thought to be due to fish in poorer condition remaining near the bottom of the tank, thus being among the last released.

In 1960, it was obvious in analyzing results of a series of directly comparable experiments, that not only was there a decline in percent return with time spent in the tanks, but also salmon held in the tank on the port side yielded much better returns than those held in the starboard tank. The decline in success of return with time spent in the tanks had been noted in previous years, but an example from our 1960 data will be cited since data may be shown also for the individual tanks. Earlier no record was kept of which tank the fish came from. In set No. C52 on 17 June, 536 salmon of mixed species were released. This required approximately $2^1/_2$ hours tagging from each tank. Table 2 shows the percent return by hour of tagging for the red salmon contained in this catch. Red salmon results were chosen because the percent return was much higher for this species. From both tanks there was a sharp reduction in the rate of return from the second and third hours' operations. The third hour's results might have shown a further decline had there been sufficient fish to require a full hour's tagging. (It should be explained that the 100 reds occurring in the first hour's tagging in the port tank was due to selection by the man dipping. This should not bias results but it greatly reduced numbers of reds released in the second and third hour's tagging in this tank.) Thus is illustrated the adverse effect of length of time spent in the tanks, and also the poorer rate of return from the starboard tank at least during the first hour.

For a more convincing illustration of the disparity between tanks in rate of return, Table 3 shows that 7 samples from the port tank yielded an average return of 36.3% while simultaneous releases from the starboard tank yielded only 21.7%. In all but one case (16 June) the port tank yielded consistently higher returns. The reason for the reversal on 16 June

Table 2

Rate of return of tagged red salmon according to length of time in two holding tanks

(Set C 52, 17 June 1960, near Umnak Island)

	Port tank		Starboard tank	
No. released 1st hour	100		40	
No. returned	36		8	
Percent returned		36		20.0
No. released 2nd hour	14		42	
No. returned	2		5	
Percent returned		14.3		11.9
No. released 3rd hour ($^1/_2$ hour)	8		34	
No. returned	1		4	
Percent returned		12.5		11.8

Table 3

Percent returns of tagged mature red salmon released from port and starboard holding tanks on vessel "Commander", 1960

Date Released	Set No.	Total released (all sp.)	Port tank: No. Reds released (1st hr. only)	Port tank: No. returned	Port tank: Percent returned	Starboard tank: No. Reds released (1st hr. only)	Starboard tank: No. returned	Starboard tank: Percent returned	Difference in percent return (Port-Starboard)
9 June	C42	296	83	27	32.5	66	10	15.2	17.3
10 June	C43	253	69	23	33.3	48	9	18.8	14.5
10 June	C45	176	82	27	32.9	50	8	16.0	16.9
16 June	C49	216	77	22	28.6	43	13	30.2	— 1.6
17 June	C51	188	63	27	42.9	31	6	19.4	23.5
17 June	C52	536	100	36	36.0	40	8	20.0	16.0
21 June	C58	158	46	27	58.7	44	16	36.4	22.3
		Total	520	189	36.3	322	70	21.7	$\bar{x} = 15.6$

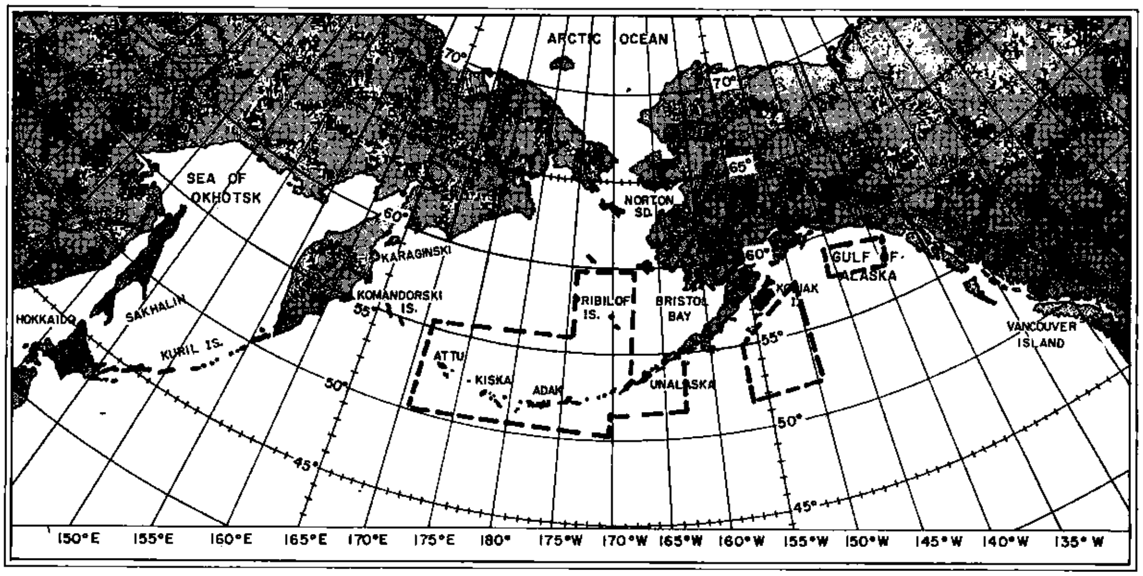


Figure 6. Areas of United States high seas salmon tagging operations, 1956—1960.

is unknown. Nevertheless the 15.6% advantage enjoyed by the port tank is strongly significant. A t-test indicates less than 0.01 probability that the true mean of the difference in return rate between tanks is zero. The 7 samples were released near the Aleutian Islands between 168° and 173° W (Fig. 6), and all were returned in Bristol Bay approximately 600 miles distant. Time at liberty was 20 to 50 days.

Faced with such an obvious defect in our gear or methods, we have recently reviewed the physical properties of the tanks, and water supplies, as well as details of fish handling and tagging personnel which might be causing the mortality. This, plus a preliminary investigation of literature on the subject strongly suggests that the trouble is due to an excess of dissolved air in the water supply, and possibly also to air bubbles and/or turbulence in the starboard, or inflow tank.

The following description of the water supply, tanks, and tagging procedures will assist in explaining the probable source of mortality.

The water supply on both the "Renown" and "Commander" comes from a 4-inch sea cock located near the bow, 5 or 6 feet below the water line. It is delivered to the tank through a 4-inch pipe by means of a centrifugal pump powered by the vessel's main engine. On the "Commander" the 4-inch line is reduced to $2^1/_2$ inches prior to entering the tank. At the point of reduction a $1^1/_2$-inch hose is provided to supply additional water to the port tank when catches are large. On both vessels, the pipe enters through the side of the starboard tank near the bottom. An elbow directs the flow against the bottom of the tank. Tanks (Fig. 5) are made of $^3/_4$-inch marine plywood with outside measurements of the pair about 11 feet by 5 feet by $2^1/_2$ feet deep. Capacity is about 1000 gallons. Port and starboard compartments are separated by a plywood partition for the purpose of reducing surge of the water. Numerous $1^1/_2$-inch holes drilled in the partition insure free exchange of water between tanks, so that they have essentially a common water supply. Each compartment has a 4-foot square opening at the top bordered by an 8-inch coaming. At full flow the "Commander" tank can be filled in 5 minutes, or at the rate of 200 gallons per minute. The "Renown" rate is somewhat greater. Overflow is through holes drilled in the side and back panels of the coaming. Drains in the bottom are provided for emptying. The white fire hose illustrated in Fig. 5 is a standby supply from a separate pump available in case of failure of the main supply. It was not used in the experiments herein discussed.

Salmon were dipped 2 or 3 at a time from the bunt of the seine to the holding tanks, using long-handled dipnets hung with fine-meshed knotless webbing (Figs. 2 and 4). Fish were then individually transferred in short-handled shallow dipnets to the tagging trough mounted on the rail of the vessel (Fig. 5). Tagging troughs were lined with foam rubber and covered with smooth sheet plastic to minimize injury during tagging. If less than about 100 fish were caught, all were placed in the port tank, and tagging was done on the port side of the vessel. With large catches, fish were dipped randomly into both tanks in approximately equal numbers. Two tagging crews then proceeded to tag simultaneously on opposite sides of the vessel (Fig. 5). The same type of tag was used on each side of the vessel, and studied efforts were made to standardize techniques of application.

The behavior of fish in both tanks was similar. They characteristically milled quietly in random circles at all depths, occasionally nosing to the surface. Visibility into the starboard tank was poorer because the turbulence of the inflow distorted the surface.

It was at first suspected that the difference in results between tanks was due to personnel, since each tagging crew always operated on the same side of the vessel whenever 2 crews were needed. Unfortunately teams did not reverse sides during simultaneous tagging for a directly comparable test, but they reversed once when anesthesia was being tested, with results as shown in Table 4. It is strongly indicated by Table 4 that the tank and not the personnel is the factor causing the disparity in success of return. The improved return from the second hour's tagging is very unusual, and reasons for this are unknown.

It is apparent then from Tables 2, 3, and 4 that there is a mortality factor in the tanks, that it is more pronounced in the starboard (inflow) side, and that it probably increases with time.

Turbulence is a logical factor to suspect, since there is much more turbulence in the inflow tank where mortality appears higher. Although the inflow is directed against the bottom of the tank, it still causes a rolling "boil" from bottom to surface. The flow into the port tank, through holes in the partition described earlier, causes noticeably less turbulence. The $1^{1}/_{2}$-inch hose, often used in the port tank to augment the water supply, caused much less turbulence than the $2^{1}/_{2}$-inch pipe feeding the opposite tank.

The question of air bubbles is mentioned because excess air bubbles are a known cause of mortality among bait fish held in tanks (Kimura, 1935; Suehiro, 1936). Whether air bubbles are a factor in the salmon tanks is unknown. At idling engine speed, very little, if any, air is visible in the water supply. Foam forms at the water's surface in varying degree, probably as a result of the turbulence. When seas are choppy, the vessel is usually put underway at slow speed which increases the water flow (since pumps are run by the main engine), thus increasing turbulence and perhaps volume of air bubbles also. Since this problem was not earlier recognized in our work, no records were kept of such conditions. It was noted occasionally that fish accumulated a layer of fine air bubbles on their skin, usually in small patches at various points on their body. Suehiro (1936) found a similar condition on sardines which had died due to abnormal amounts of air bubbles entering a bait tank. He further found such bubbles on gill lamellae of those which died, and surmised that such disruption of respiration was an important cause of mortality. He clearly showed by tests that the bubbles on the fish were not due to supersaturation of dissolved gas in his water supply.

The amounts of free oxygen in the tanks have not been measured, but data available suggest that oxygen deficiency is not a problem. It would seem that if it were, survival on the port side would be worse rather than better, since fish here must utilize water that has already passed through the fish mass in the starboard tank. Further, the tank on the vessel "Renown" has a much greater volume of water available (4" inflow), and in samples where results between vessels may be compared, survival was no better than in "Commander" samples.

Another important possible factor is supersaturation of dissolved air in the water supply, which according to Marsh and Gorham (1904) can be a serious cause of mortality among fish held in aquaria with a pump-fed water supply. Marsh and Gorham noted a serious mortality among fish held in tanks at Woods Hole, Massachusetts. The difficulty was traced to air entering through defects in the saltwater intake pipe. Compression of the water during pumping from sea level to elevated tanks caused supersaturation in the water. Fish, being unable to compensate internally for the increased gas tension in the water, became

Table 4

Percent returns from red salmon released from port and starboard tanks by tagging teams No. 1 and No. 2

(Set C 46, 11 June 1960)

	Port tank*			Starboard tank		
	No. released	No. returned	Percent returned	No. released	No. returned	Percent returned
First hour	56	(Team No. 1) 21	37.5	69	(Team No. 2) 12	17.4
Second hour	32	(Team No. 2) 13	40.6	42	(Team No. 1) 10	23.8

* Anesthesia was used on fish from Port tank only, but since in all comparable tests anesthesia has shown no advantage, this factor should not bias results shown here.

flooded with excess gas entering the blood through the gill membranes. The excess collects in various parts of the body, causing lesions and "pop-eyes" and finally asphyxiation from gas embolism in the gill filaments, or heart, or both. Marsh and Gorham reported a cessation of such symptoms and mortalities when the defective inflow pipe was replaced.

It is not certain that bubble disease was a factor in our tanks at sea, but conditions closely paralleled those described by the above authors. In both cases, fish were held in very cold saltwater supplied by centrifugal pumps. Films of minute bubbles were sometimes seen on fish in our tanks similar to those seen at Woods Hole. Mortalities at both places apparently increased with time of exposure. Our fish were not held long enough for lesions to be noted.

It is difficult to surmise how air could enter the water supply on the vessels, unless there were flaws in the pipe fittings or pumps. Water is raised approximately 8 or 10 feet from the intake to the tank through a closed system. As explained earlier, the intake is too deep for air to enter there. Leaks on the intake side of the pump do not give out water, but suck in air, and are therefore not always obvious. There is now no way of checking whether air leaks existed, since the problem was not recognized until recently, and pumps are overhauled from time to time. Tests made in the spring of 1961 aboard the vessel "Renown" showed no difference in O_2 content between samples from the tank and samples from the source water (Puget Sound, 8.8 mg/l). This indicates that the pumps do not introduce excess gas when working properly, but defects may have existed in the past.

In future high seas operations, a separate inflow compartment will be added to tanks so that fish in both port and starboard compartments will be protected from the turbulence of the inflow. Personnel will be rotated between tanks during simultaneous tagging, to positively check this possible source of variation. Oxygen content of water will also be tested with varying numbers of fish in the tanks and with varying amounts of inflow, to determine optimum circulation needs and to check for supersaturation. In addition, floating pound-nets will be tried for holding fish during tagging on calm days, to compare with results from those held in the tank.

Long-term tests of holding salmon in the tanks with full flow of water are also needed. In 1958, 4 pink salmon were kept in the starboard tank of the "Commander" for 4 days with only an occasional refreshing of the water, and all appeared vigorous when removed. In this case, however, flow of water was not at all comparable with conditions during tagging.

Marsh and Gorham founds some species much more resistant to gas disease than others. Generalizations from behavior of other species are therefore probably not directly comparable with salmon. For example, approximately 25 Atka mackerel (*Pleurogrammus monopterygius*) caught together with the salmon were kept in the starboard tank for 60 days with no observable ill effects. They fed avidly, and were subjected to the full flow of water for several hours whenever a catch of salmon was being released. At other times, the pumps were run once or twice daily to refresh the water. During the period of full flow, they were seen feeding on the parasitic copepods on the backs of salmon.

It is possible also, that injury sustained in the net renders fish more susceptible to the mortality factors in the tank. This might partially explain the much lower return rate of chum salmon as compared to red salmon. Chums characteristically remain deep in the seine and are therefore chafed and scaled more severely by the web. Because they remain deeper they are among the last to be brailed aboard and among the last to be tagged. Thus injury and tank mortality must be more severe with this species.

Relation of Size and Susceptibility to Injury

Salmon released in coastal areas are usually mature fish of a relatively uniform size and physiological condition, so that injury during catching and tagging, and subsequent probability of survival, are reasonably similar for all fish released. At sea, however, a far more extensive range of sizes and ages is caught, and it has become evident that the smaller and younger immature salmon are much more susceptible to injury than the larger fish. (For range of sizes see Fig. 7.) This has been manifested by greater scaling of small fish in the net and by additional scaling during tagging. In seine catches which included large masses of jellyfish the smaller salmon frequently showed welts on their sides, presumably from repeated contact with jellyfish in the bunt prior to brailing. Larger fish are apparently protected by thicker skin.

The rate of return of all chum salmon released in 1958 is shown by age in Table 5 and is further illustrated by length in Figure 7. Chum salmon were chosen for this comparison because of the range of ages available: from 1 to 6. In comparing the total return for each age group (Table 5) there is a sharp decline in percent return from the oldest to the youngest fish. It is possible that a few additional fish from among the youngest ages will be returned in 1961, but certainly not enough to alter the trend shown. If the smaller fish could be released with no more injury than the larger fish, it might be possible to compare mortality rates for fish returning in the year of tagging with those returning 1 or 2 years later. Using present methods, however, differential tagging mortality according to size must completely mask the true natural mortality from year to year.

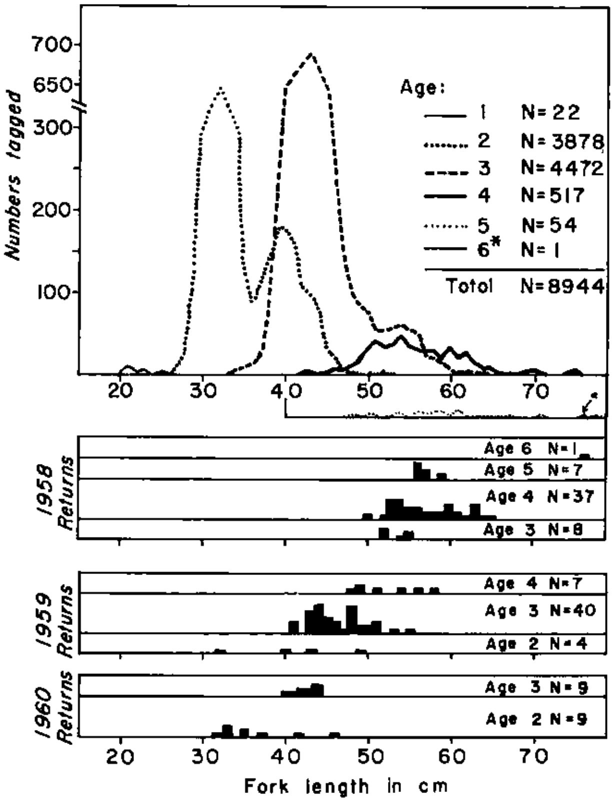


Figure 7. Lengths of tagged chum salmon released in 1958, by ocean age, and lengths at tagging of returns in 1958, 1959, and 1960.

There are also problems in comparing rates of return between two age groups of similar size such as the 4 and 5 year old chums (Fig. 7 and Table 5). The 13% return of 5 year old fish in 1958 may or may not be comparable with the 8.5% return (1958 plus 1957) of 4 year old fish. The 5 year olds may be considered mature, since very few remain an additional year. However, in the case of 4 year old fish, there might be considerable variation (according to source of the fish) in the proportion which are due to spawn at 4 years or 5 years. Thus, even within this group the annual natural mortality may not be inferred by comparing annual return rates with those of 5 year olds.

Table 5

Numbers of chum salmon released in 1958, by ocean age, and returns in 1958, 1959, and 1960

Age	1	2	3	4	5	6	All ages
No. released*	22	3878	4472	517	54	1	8944
1958 returns	0	0	8	37	7	1	53
Percent	0	0	0.2	7.2	13.0	100.0	0.6
1959 returns	0	4	40	7	0	0	51
Percent	0	0.1	0.9	1.4	0	0	0.6
1960 returns	0	9	9	0	0	0	18
Percent	0	0.2	0.2	0	0	0	0.2
Total return	0	13	57	44	7	1	122
Percent	0	0.3	1.3	8.5	13.0	100.0	1.4

* Omitting 19 fish without scale samples.

There are other problems in making such comparisons of return rates. It is possible that the 4 year olds returning in 1958 and those returning in 1959 were destined for altogether different spawning areas where tag return efficiencies are not comparable. Also, an appreciable proportion returned from the Japanese high seas fishery may not even be maturing in the year of return, as are coastal returns. The same problems exist also with 2 and 3 year old fish. Finally, the larger fish within one age group undoubtedly have a better chance of survival than smaller fish of the same age. The 2 and 3 year old fish in Fig. 7, for example, show a secondary mode of much larger fish. These were mostly fish taken in the Gulf of Alaska, while the smaller fish of the same age were caught near the Aleutians. Such great differences in size would have to be considered in evaluating success of return by age.

The actual mechanism by which net and handling injuries cause mortality has not been determined. In studies of mortalities among bait fish held in tanks, Brock and Takata (1955) test the hypothesis that slime and scale loss cause loss of body fluids through osmosis to the hypertonic sea water medium. A 50 percent reduction in the salinity of water in their holding tanks was accompanied by a substantially reduced mortality, a result which agrees with their hypothesis. Brock and Takata further show a higher mortality among the smaller fish, similar to our experience with salmon. The above authors also found great variability in survival rates at both low and high salinities, and conclude there are other important causes of mortality not measured or controlled in their experiments. The same must be true in our salmon-holding procedures.

C. M. Child (1915) did considerable experimentation which indicates that a higher mortality in younger organisms should be expected. His general thesis is that the ability to become acclimatized to adverse conditions is inversely related to the rate of metabolism, and that the rate of metabolism in the older, larger animals is normally lower per unit of mass than in the younger and smaller of the same species, under the same external conditions. Further, Child (1923) states that susceptibility to any adverse conditions depends on rate of oxidative metabolism, and that effects on different organs may differ according to concentrations and time of exposure.

Such physiological reactions probably underlie the higher mortality of the smaller fish, and may account for their greater susceptibility to the adverse conditions in the tanks, as previously discussed. We have only begun to investigate problems of this nature, and further studies of literature on the subject as well as field tests are contemplated.

Anesthesia

The anesthetics MS 222 and Quinaldine were tried experimentally in 1958, and were used in numerous samples in 1959 and 1960. This treatment rendered fish easier to handle during tagging, and practically eliminated scaling during tagging. Since scaling at this step in handling was a problem only with smaller fish it was anticipated that the use of anesthesia would materially increase returns of small fish at least.

A comparison of rate of return of anesthetized and non-anesthetized samples of *mature* salmon shows no advantage in using anesthesia (Tables 3 vs. 4). Similarly, past samples of *immatures* show no increased rate of return among anesthetized samples, but since the variables between tanks were not earlier recognized, further tests using immature salmon are required.

Tag Retention and Visibility

It is very desirable that tags used on salmon at sea be capable of remaining attached on rapidly growing fish for at least two years. Disc tags and tube or "spaghetti" tags have been used in experiments to date. Disc tags have yielded almost double the rate of return of spaghetti tags in the year of tagging and also one and two years later (Hartt, 1962). Reasons for this are thought to be better visibility of discs and their greater probability of recapture in gill nets. The great majority of returns from the high seas experiments have been from the Japanese high seas fleet and from Bristol Bay estuaries. Both fisheries employ gill nets. In the U.S.S.R. and in Japan coastal areas, traps and seines are the principal gear used.

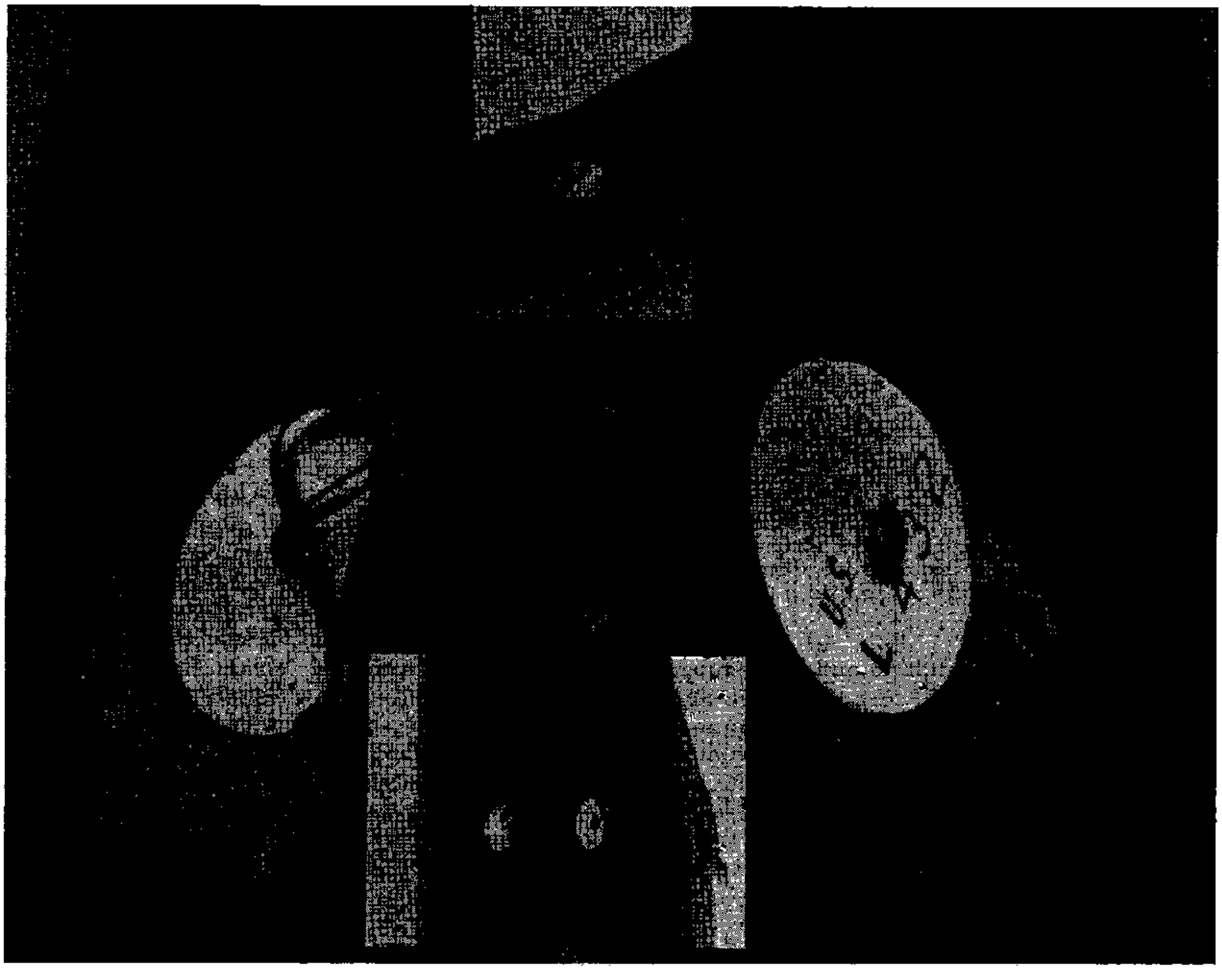


Figure 8. Disc tag in position on red salmon released in 1958 and recaptured in 1960. (Two views).

We have no direct data on the shedding of either disc or tube tags from salmon at sea. Observations of tags on many returned salmon show no serious tendency toward shedding or deterioration of materials. If such a problem exists, it would, of course, bias return rates of younger fish remaining longer at sea.

Tests of many types of tags on rainbow trout held in freshwater ponds from 1955 through 1958 also showed no serious shortcomings in either discs or tubes. Such tests, however, may not be applicable to salmon at sea, because of the difference in physiological condition of the fish. The rainbows used were extremely hardy, were very resistant to handling injury, had a heavy mucus covering, and relatively thick skin. Tags might logically be expected to remain firmly attached to fish in this condition.

Figure 8 illustrates a disc in position at recapture on a red salmon released in the summer of 1958 and returned in the summer of 1960. The fish grew from 33.0 cm at tagging to 61.0 cm at return. It appears from the side view that the tag had migrated upward about one-half its diameter leaving a path of smooth dark scar tissue in its wake. The un-numbered disc is obviously imbedded and overgrown in scar tissue at the upper edge, and the remainder of the tag is forcing a depression in surrounding tissue. The numbered disc is forcing a depression in smooth scar tissue on all sides with a slight rim of overgrowth forming at the top. It would seem that in this example, retention is excellent. Obscuring by overgrowth might become a problem on fish growing much more than this.

In order to test the return rate of a larger and more obvious tag, $^{3}/_{4}$ inch red and white discs were tried on some mature salmon in 1959, while others were tagged with the standard $^{1}/_{2}$ inch white discs and $^{1}/_{16}$ inch white tubes as in previous years. The larger discs yielded much better results, as shown below for mature pink salmon:

Type of tag	No. released	No. returned	Percent returned
$^{3}/_{4}$" red & white disc	1970	157	8.0
$^{1}/_{2}$" white disc	447	7	1.3
$^{1}/_{16}$" white tube (13" long)	452	4	0.9

Return rates of the $^{1}/_{2}$ inch discs and of the tube tags were similar to rates in 1957 and 1958, showing that the larger discs greatly enhanced tag returns. Red and chum salmon tag returns also indicated a better return rate for the larger tags, though in 1959 too few mature fish of these species were released with the three types of tags for a critical comparison. Improved visibility is probably the key factor in the higher return rate for the larger tags.

In 1960 nearly all salmon were tagged with the larger red and white discs. The rate of return of mature red salmon from experiments in the eastern Bering Sea, where results may be directly compared, increased from 23.3% ($^{1}/_{2}$" discs) in 1958 to 41.8% ($^{3}/_{4}$" discs) in 1960. The increase was partly due to increasing the reward from $ 1.00 to $ 25.00 and to increased fishing effort in 1960, but since the fishery in 1960 took less than half the estimated total run, the 41.8% return must indicate that the tags are very efficient as to retention and visibility. Data are not yet available for evaluating the $^{3}/_{4}$ inch tags on immature salmon.

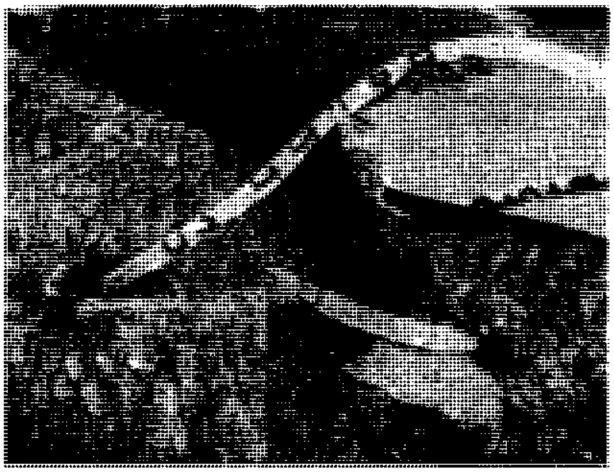


Figure 9. Tube tag wounds on chum salmon two years after tagging. (Showing both sides)

We have also had opportunity to observe tube tags after two years at liberty. Tags were still firmly attached, although the puncture wound was elongated posteriorly due to chafing by the trailing portion of the tag. Figure 9 shows a tube tag after 2 years on a salmon at sea. Because of the much lower rate of return, tube tags will be discontinued in future experiments.

Data on tag returns in 1960 indicate that the tangling of disc tags in gill nets is an important factor in the retention in the nets of salmon which otherwise might escape. Further, it is not infrequent that tags are left tangled in gill nets while the fish pulls free and escapes. From a total of 512 tags recovered in Bristol Bay in 1960, there were 9 instances when fishermen included the unsolicited remark that the tag alone was found in the net while the fish had escaped. Personnel doing tag recovery personally observed one such case. The fact that Bristol Bay reds were small in 1960 probably increased the incidence of fish escaping.

The retention in gill nets of salmon by the tags, together with retention of tags even when fish escaped, was sufficient in 1960 that the usual size selectivity by gill nets was not evident among disc-tagged salmon recaptured in this type of gear. In the upper half of Fig. 10 the usual selectivity of the Bristol Bay gill-net catch is illustrated by the catch versus escapement

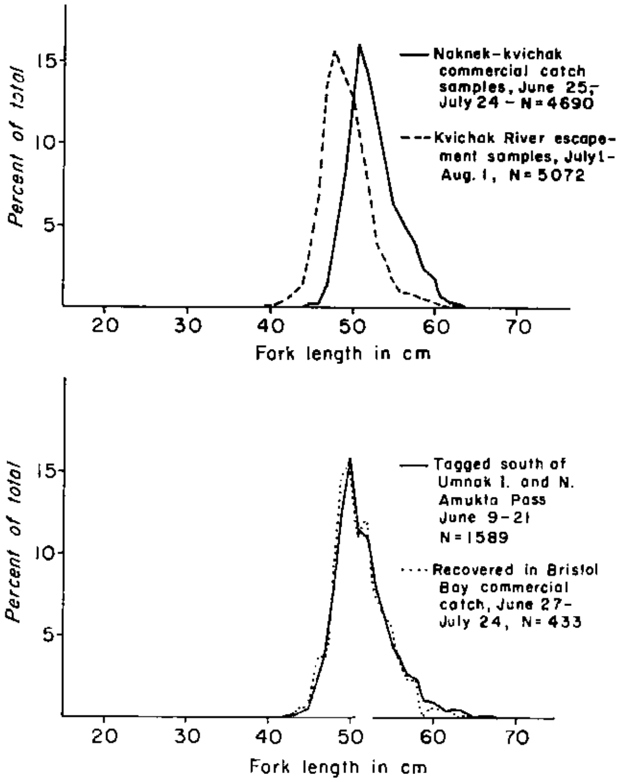


Figure 10. Upper: Lengths of red salmon, 1956-catch vs. escapement. Lower: Lengths of red salmon, 1960-tagged vs. recovered.

length-frequency curves for 1956. It should be explained that there is some bias in this figure because escapement lengths only show Kvichak River fish, whereas catches show a mixture of Naknek and Kvichak River fish, but the overwhelming proportion of Kvichak fish in 1956 renders such bias unimportant. Further, the selectivity shown is typical for other rivers in Bristol Bay where exactly the same stocks have been measured in both catch and escapement.

The lower part of Fig. 10 is in sharp contrast and indicates practically no selectivity by the Bristol Bay fishery of fish released at sea in 1960. Thus, the presence of disc tags renders all sizes of fish equally vulnerable to gill nets. This suggests that visibility accounts for only a part of the higher return rate of discs as compared to tubes. An important advantage is in the effectiveness of gill nets to hold disc-tagged salmon. This is further attested by our 1955 results when we tagged in the Gulf of Alaska, where seines, traps, and trolling gear accounted for a large part of tag returns. In that case, discs yielded 13.7% (83 of 604) returns; only slightly better than tubes; 12.6% (98 of 775) (INPFC Annual Report for 1955).

Summary and Conclusion

Considerable progress has been made in recent years in developing methods for successfully tagging salmon on the high seas. Gear and methods have been constantly observed, tested, and modified as the need was seen to improve survival of released fish.

It is apparent that the success of return of salmon tagged on the high seas is dependent upon a series of interdependent variables, many of them yet unmeasured. Survival depends upon condition of the fish as taken from the fishing gear, their species, size and age, numbers in haul, time spent in holding tanks (plus the physical conditions in the tank) and mechanics of handling. The type of tag used, the gear used in recapture, and the length of time that fish may be at liberty before recapture also affect success of return, as in coastal experiments.

A principal problem now requiring solution is that of mortality caused by holding tanks. This will require investigation of the chemical and physical properties in the water supply and perhaps of the physiology of the fish while in the tanks. A satisfactory solution to this problem should result in improved return rates, particularly of the younger age groups, and is a necessary first step in evaluating survival of the several age groups.

References

BROCK, V. E., and M. TAKATA. 1955. Contribution to the problems of bait fish capture and mortality together witb experiments in the use of *Tilapia* as live bait. *Indust. Res. Advisory Council* (Terr. Hawaii) Grant No. 49, Final Report, Honolulu. 39 p.

CHILD, C. M. 1915. *Senescence and rejuvenescence.* Univ. Chicago Press, Chicago. 481 p.

CHILD, C.M. 1923. The general relation between susceptibilty and physiologic condition. *Arch. Intern. Med.*, **32**: 647—662.

HARTT, ALLAN C. 1962. Movement of salmon in the North Pacific Ocean and Bering Sea as determined by tagging — 1956—1958. *Int. N. Pacif. Fish. Comm.*, Bull. 6, 157 p.

International North Pacific Fisheries Commission. 1956—1960. Annual Report for the years 1955—1959.

Japan, Fisheries Agency. 1958. Salmon tagging experiments conducted by Japan in the North Pacific, with data on recoveries, 1952—1957. *Int. N. Pacif. Fish. Comm.*, Doc. 184. 6 p.

KIMURA, KIMOSUKE. 1935. On the deaths of sardines kept in bait tanks and the oxygen content of the water. *J. Imper. Fish. Exp. Sta.* No. 6, p. 239—280.

LARSEN, KNUD. 1950. *Laks og laksefiskeri, saerlig i Danmark, Sverige og Norge.* J. F. Clausen, Copenhagen. 123 p.

MARSH, M. C., and F. P. GORHAM. 1904. The gas disease in fishes. *Rep. U. S. Bur. Fish.* 1904 (1905): 344—376.

NEAVE, FERRIS. 1960. Observations of the vertical distribution of salmon in the northeast Pacific, 1960. *Int. N. Pacif. Fish. Comm.* Doc. 408. 5 p.

PARKER, ROBERT R., and E. C. BLACK. 1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). *J. Fish. Res. Bd Can.*, **16** (1): 95—106.

POWELL, DONALD E., and ALVIN E. PETERSON. 1957. Experimental fishing to determine distribution of salmon in the North Pacific Ocean, 1955. *U. S. Fish Wildl. Serv., Spec. Sci. Rep.* No. 205. 30 p.

SUEHIRO, Y. 1936. A study of the causes of death of bait fishes. *J. Imp. Fish. Exper. Sta.*, No. 7, papers 52—60, p. 51—90., Translated by W. G. Van Campen. *U. S. Fish Wildl. Serv. Spec. Sci. Rep.* No. 62, 1951. 57 p.

25.

Tests of Efficiency of Various Kinds of Tags and Methods of Attachment on Plaice, Cod, Sole and Whiting

By

T. WILLIAMS*

Introduction

Many of the tagging experiments carried out by the Fisheries Laboratory, Lowestoft, between 1957 and 1960 were designed to test the efficiency of different types of tags, the materials used to attach the tags to the fish, and also the position in which the tag was attached to the fish. This paper summarises the results of these experiments.

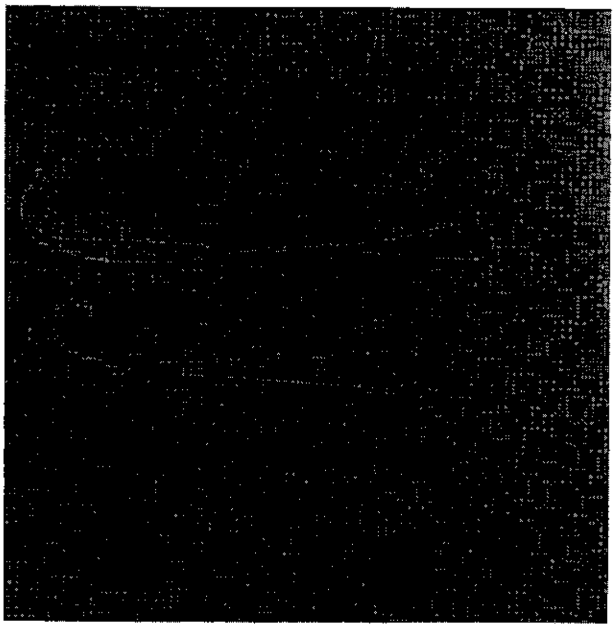


Figure 1. Types of tags used.

Types of Tags Used and Species of Fish Tagged (Fig. 1)

Lea Tag (Cod)

A hydrostatic tag consisting of a streamlined transparent plastic cylinder. The cylinder contains a short visible text, instructing the finder to remove the ends of the cylinder and read the letter inside (Fridriksson, 1952).

Lowestoft Plastic Flag Tag (Cod, Whiting, Plaice, Sole)

The tag is made of 0.012" thick P.V.C., of double thickness at the end where the bridle is attached, and is usually bright yellow in colour. Two standard sizes of tag are used, either 4 cm × 1 cm or 5 cm × 1.3 cm, depending on the size of fish being tagged. A message, requesting the finder to report recapture details to the appropriate authority, is printed in English on one side and in either French or Norwegian on the other.

Both the Lea and the Lowestoft plastic flag tags are attached to the fish by means of a bridle. The materials used as bridles during the experiments were monofilament nylon, nylon wool, braided nylon twine and stainless steel wire.

Petersen Disc (Plaice, Sole)

Two ivorine buttons 16 mm in diameter attached either by silver, stainless steel or titanium wire. Buttons coloured either yellow on upper side of fish and red on lower side, or both black. One button engraved with a serial letter and number.

Plastic Arrow Tag (Albrechtsen tag) (Sole)

An arrow-shaped tag 11 cm long made from P.V.C. sheet 0.01" in thickness, bearing a serial letter and number and coloured either yellow or red.

Prototype Button Tag (Whiting)

A small button 1 cm in diameter held tightly against the fish by means of latex nylon elastic passing through the body and secured by a stainless steel wire toggle.

Results of Tag Comparisons

Lea v. Plastic Flag (Cod (*Gadus morhua*))

During the August and September 1958 cruise of the "Ernest Holt", 2193 cod were tagged in the Bear Island/Spitzbergen area, and in January 1959, 945 cod were tagged off the Norway Coast. On both these cruises equal numbers of fish of similar length distribution were tagged with Lea tags, and with plastic flag tags. Each tag was attached between the first and second dorsal fin by means of the bridle normally used, i.e. monofilament nylon with the Lea tag and braided nylon twine with the plastic flag tag. For each type of tag, the total number of returns and their distribution in time were almost identical, as shown in Table 1.

---

* Fisheries Laboratory, Lowestoft, England.

Table 1

Comparison of Lea hydrostatic tag with plastic flag tag (cod)

Species Tagged	Tag Type	Number Liberated	Number Returned	% Returned	Numbers Returned in 100-day Periods <100	100	200	300	400	500+	?	Significance
COD Bear Island Spitzbergen Aug./Sept. 1958	LEA HYDROSTATIC Monofilament Nylon attached between 1st and 2nd Dorsal	1099	183	16.7	32	14	49	23	11	50	4	Total Returns N.S.
	PLASTIC FLAG Braided Nylon attached between 1st and 2nd Dorsal	1094	180	16.5	27	25	46	29	6	41	6	
COD Norway Coast Jan. 1959	LEA HYDROSTATIC Monofilament Nylon attached between 1st and 2nd Dorsal	472	81	17.2	58	2	4	5	1			Total Returns N.S.
	PLASTIC FLAG Braided Nylon attached between 1st and 2nd Dorsal	473	81	17.1	77	1	2	5	6			

Plastic Flag Untreated v. Plastic Flag Antifouling (Whiting (*Gadus merlangus*))

A whiting tagging cruise in the Brixham area during August 1959 was the first trial of plastic flag tags incorporating an antifouling compound. Five per cent phenyl mercury acetate (P.M.A.) was added to the P.V.C. chip before the sheet was extruded. Returns from earlier tagging experiments had shown that marine organisms attached themselves to the surface of the tag and bridle. In Arctic waters this growth was negligible, but in the North Sea, English Channel and Irish Sea growth was often 15 cm long. This fouling of the tag must have greatly increased the amount of drag upon the fish, and may well have reduced the number of returns after the first few months at liberty.

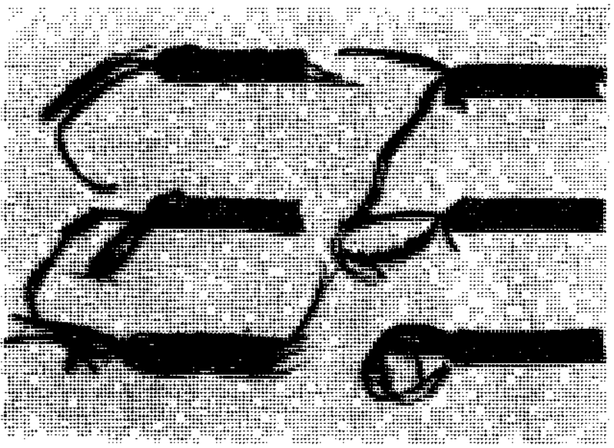


Figure 2. Plastic flag tags used on whiting; left: untreated; right: treated with antifouling compound (nylon loops for attachment were not treated).

The efficiency of the P.M.A. in preventing the fouling on the tags can be seen in the photograph (Fig. 2) of treated and untreated tags returned from fish tagged during this experiment which had been at liberty for 40 days.

There was no significant difference in the total number of returns from either type of tag, but the rate of return after 100 days at liberty suggests that the antifouling tag gives a higher rate of return after this length of time (Table 2).

Petersen Disc. v. Plastic Flag (Plaice (*Pleuronectes platessa*))

A plaice tagging experiment in the North Sea in June 1958 compared the Petersen disc attached by stainless steel wire in the orthodox manner with the plastic flag attached by braided nylon through the body of the fish. The bridle was inserted, by means of a needle, in the dark upper side of the plaice, passed between the neural spines and out of the under side. The needle was then reinserted at the exit point, and the bridle threaded back to the upper side, emerging about 1 cm from the point of entry. The flag was thus anchored by the bridle passing under at least one and probably two neural spines.

The results (Table 3) show the Petersen disc to be a far more efficient tag for plaice, the returns of the plastic flag falling off very rapidly after a period of 200 days at liberty. An examination of returned fish suggested that one of the reasons for this was the method of attachment of the flag. The braided nylon bridles were observed to be cutting through the neural spines under which they were anchored and in some cases had sawn through them completely.

Table 2
Comparison of plastic flag tag, untreated, with plastic flag tag, antifouling (whiting)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Numbers returned <100 Days	>100 Days	Significance
WHITING Brixham Aug. 1959	PLASTIC FLAG *Untreated* Braided Nylon Attached between 1st and 2nd Dorsal	1164	200	17.2	197	3	Total Returns *NS* (P = 0.5—0.3)
	PLASTIC FLAG *Antifouling* Braided Nylon Attached between 1st and 2nd Dorsal	1177	188	16.0	177	11	>100 days at Liberty P = 0.05—0.02

Table 3
Comparison of Petersen disc with plastic flag tag (plaice)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Numbers returned in 100-day periods <200	200	300	400	500	600	700	800+	Significance
PLAICE North Sea June 1958	PETERSEN DISC Stainless Steel Wire	879	418	47.6	241	39	26	31	15	26	25	11	Total Returns *S*(P = <0.01)
	PLASTIC FLAG Braided Nylon attached through body	885	245	27.7	215	10	8	8	1	1	0	1	

Table 4
Comparison of Petersen disc with plastic flag tag (sole)

Species Tagged	Tag type	Length (cm)	Number Liberated	Number Returned	% Returned	Numbers returned in <200 days	200–399 days	400+ days	Significance
SOLE N. Sea English Channel June, 1958	PETERSEN DISC	< 30	180	34	18.9	19	9	6	
	Stainless steel wire	> 30	60	21	35.0	11	4	6	
			+1?						
		TOTAL	241	55	22.8	30	13	12	Total Returns
	PLASTIC FLAG	< 30	269	23	8.6	14	6	3	*S* (P = <0.01)
	Braided Nylon	> 30	46	8	17.4	5	3	—	
	Attached through body		+1?	+1?		+1?			
		TOTAL	316	32	10.1	20	9	3	
SOLE N. Sea English Channel Sept., 1958	PETERSEN DISC	< 30	187	27	14.4	9	10	8	
	Stainless steel wire	> 30	35	11	31.4	4	6	1	
		TOTAL	222	38	17.1	13	16	9	Total Returns
	PLASTIC FLAG	< 30	259	13	5.0	5	5	3	*S* (P = <0.01)
	Braided Nylon	> 30	24	9	37.5	2	5	2	
	Attached through body	TOTAL	283	22	7.8	7	10	5	
SOLE N. Sea June, 1958	(a) PETERSEN DISC	< 30	71	14	19.7	7	3	4	
	Stainless steel wire	> 30	20	7	35.0	2	2	3	
		TOTAL	91	21	23.1	9	5	7	
	(b) PLASTIC FLAG	< 30	134	12	9.0	9	2	1	a × b *S* (P = <0.01)
	Braided Nylon	> 30	11	3	27.3	2	1	—	a × c *NS* (P = 0.2—0.1)
	Attached through body	TOTAL	145	15	10.3	11	3	1	b × c *NS* (P = 0.3—0.2)
	(c) PLASTIC FLAG	< 30	85	9	10.6	5	3	1	
	Monofilament Nylon	> 30	16	6	37.5	4	1	1	
	Attached through body	TOTAL	101	15	14.9	9	4	2	

Petersen Disc. v. Plastic Flag (Sole (*Solea vulgaris*))

Further comparisons of Petersen disc v. plastic flag, attached in the same way as for plaice, were carried out on two sole tagging cruises in June and September 1958. The percentage of fish returned varies, but the relative efficiency of the Petersen disc to the flag tag is constant. On the June cruise a few fish were tagged using a monofilament nylon bridle instead of braided nylon. These fish show a slightly higher percentage return, but it is not a significant difference.

The difference in percentage returns of fish > 30 cm in length compared with fish < 30 cm from both types of tag was a noticeable feature. The recaptures of the larger fish were considerably greater in every instance (Table 4).

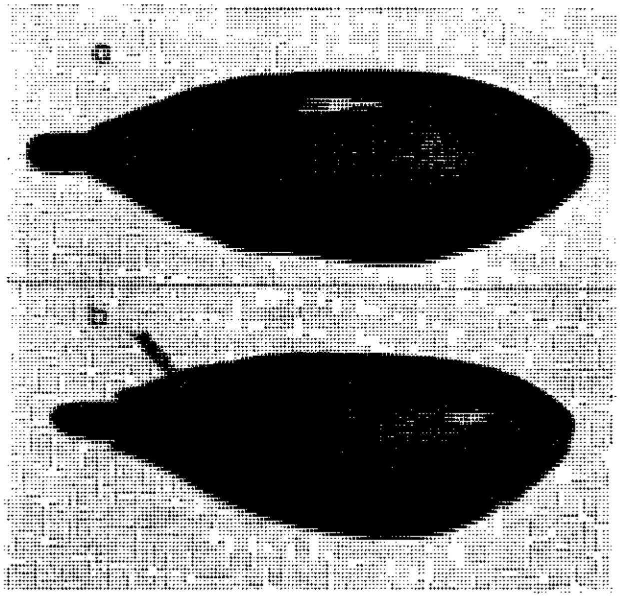


Figure 3. Plastic arrow tag used on sole: (a) sewn through skin on upper side of fish, (b) sewn through body of fish.

Petersen Disc. v. Plastic Arrow (skin attachment) (Sole)

In July and September 1959 two sole tagging cruises compared the Petersen disc with the plastic arrow, a new tag of Danish design. The arrow was sewn under the skin on the upper side of the fish for about 2 cm before being locked in position by threading the head of the arrow through two holes in the end of the shaft (Fig. 3a).

Rather small numbers of fish were tagged in both experiments, and there was no significant difference between the returns of the two tags (Table 5). The Petersen disc did, however, appear to be slightly more efficient, particularly for more than 200 days at liberty.

Petersen Disc v. Plastic Arrow (attached through body) (Sole)

The Petersen disc and plastic arrow were again compared in March 1960 when 1,244 soles were tagged. The method of attaching the arrow was changed and it was sewn through the body of the fish near the tail (Fig. 3b). The Petersen disc gave significantly better returns than the arrow tag in this position (Table 6), and once again fish above 30 cm in length gave a better percentage return than fish below 30 cm, particularly those tagged with the Petersen disc. Differences in reporting of these tags have been discussed by de Veen (this Symposium).

Plastic Flag v. Prototype Button (Whiting)

In August 1957, the first year in which any large-scale tagging of whiting was accomplished, the plastic flag was compared with the prototype button. The prototype button was being developed for herring tagging, but when used on whiting produced no returns, compared with a 20% recapture rate for the flag tag (Table 7).

Table 5

Comparison of Petersen disc with plastic arrow tag, skin attachment (sole)

Species Tagged	Tag Type	Number Liberated	Number Returned	% Returned	Numbers returned in <200 Days	> 200 Days	Significance
SOLE Irish Sea July 1959	PETERSEN DISC Titanium wire	250	24	9.6	10	14	Total returns *NS* (P = 0.7—0.5) > 200 days at liberty (P = 0.2—0.1)
	PLASTIC ARROW Attached under skin	209	17	8.1	11	6	
SOLE North Sea Sept. 1959	PETERSEN DISC Stainless steel wire	116	24	20.7	14	10	Total returns *NS* (P = 0.1—0.2) > 200 days at liberty (P = 0.3—0.2)
	PLASTIC ARROW Attached under skin	123	16	13.0	10	6	

Table 6
Comparison of Petersen disc with plastic arrow tag attached through body (sole)

Species Tagged	Tag type	Length (cm)	Number liberated	Number returned	% Returned	Numbers returned in <30 days	30—99 days	100+ days	Significance
SOLE North Sea March 1960	PETERSEN DISC	< 30	255	57	22.4	50	5	2	Total returns
	Titanium wire	> 30	375	116	30.9	101	14	1	*S* (P = <0.01)
			630	173	27.5	151	19	3	Petersen <30 cm v. >30 cm P = 0.02—0.01
	PLASTIC ARROW	< 30	313	54	17.3	52	2	—	
	Attached through body	> 30	301	69	22.9	67	1	1	Arrow <30 cm v. > 30 cm
			614.	123	20.0	119	3	1	P = 0.10—0.05

Table 7
Comparison of plastic flag tag with prototype button tag (whiting)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
WHITING Irish Sea August 1957	PLASTIC FLAG Braided nylon and nylon wool, attached between 1st and 2nd dorsal	125	25	20	Total Returns
	PROTOTYPE BUTTON attached between 1st and 2nd dorsal	54	Nil		*S* (P = <0.01)

Comparison of Materials Used for Tag Attachment

In addition to direct comparisons of different type of tags, a number of experiments were made using the same types of tags attached to the fish in the same position by means of different materials.

Lea — Monofilament Nylon Bridle v. Lea — Nylon Wool Bridle (Cod)

Two cod tagging cruises in July 1957 — one by the "Ernest Holt" in the Bear Island/Spitzbergen area, and one by the "Platessa" in the North Sea — produced similar results. During both cruises Lea tags were attached by monofilament nylon bridles or by nylon wool bridles between the first and second dorsal fins. The much larger Arctic tagging showed no difference between the percentage of the total number of recaptures from each material, nor was there any difference in the rate of recapture (Table 8). Both materials appeared equally effective up to 1000 days at liberty.

Petersen Disc — Silver Wire v. Petersen Disc — Stainless Steel Wire (Sole)

In an earlier plaice tagging experiment a number of fish were double tagged with Petersen discs attached by silver wire (Gulland, this Symposium). The rate of loss of these tags was considerable, up to 30% per year. The results of a sole-tagging cruise in May 1957 also showed that stainless steel wire gave a significantly higher rate of return than did silver wire after fish had been at liberty for over 500 days (Table 9). Before 500 days there was no apparent difference in the rate of returns.

Petersen Disc — Stainless Steel Wire v. Petersen Disc — Titanium Wire (Sole)

A comparison of Petersen discs attached by stainless steel wire and titanium wire to soles in the Bristol Channel in April 1959 showed that up to January 1960 there was no apparent difference in the number of returns from the two kinds of wire (Table 10). The fish have not yet been at liberty long enough for the effect of wear on the wire to be fully determined.

Effect of Position of Tag

Plastic Flag between 1st and 2nd Dorsal v. Plastic Flag in front of 1st Dorsal (Cod)

Two positions of attachment of the plastic flag tag were used on the "Ernest Holt" cruises in July and August 1959 in the Bear Island/Spitzbergen area. Although the results of the earlier cruise suggested that the position between the dorsal fins was more satisfactory, this was not confirmed by the results of the later August cruise (Table 11).

Table 8
Lea tag. Comparison of monofilament nylon bridle with nylon wool bridle (cod)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Numbers returned in 200-day periods							Significance
					<100	100-299	300-499	500-699	700-899	900-999	?	
COD Bear Island Spitzbergen July 1957	LEA HYDROSTATIC Monofilament nylon Attached between 1st and 2nd dorsal	745	102	13.7	16	18	31	21	7	5	4	Total Returns *NS* (P = 0.5—0.3)
	LEA HYDROSTATIC Nylon wool Attached between 1st and 2nd Dorsal	1597	201	12.6	40	25	57	31	20	10	18	

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
COD North Sea July 1957	LEA HYDROSTATIC Monofilament nylon Attached between 1st and 2nd dorsal	137	17	12.4	Total Returns *NS* (P = 0.3—0.5)
	LEA HYDROSTATIC Nylon wool Attached between 1st and 2nd Dorsal	125	21	16.8	

Table 9
Petersen disc. Comparison of silver wire with stainless steel wire (sole)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Numbers returned in 100-day periods							Significance
					<500	500	600	700	800	900	1000+	
SOLE North Sea May 1957	PETERSEN DISC Stainless steel wire	133	20	15.0	13	1	1	2	1	—	2	Total Returns *NS* (P = 0.3) > 500 days at liberty *S* (P = <0.01)
	PETERSEN DISC Silver Wire	130	14	10.8	14	—	—	—	—	—	—	

Table 10
Petersen disc. Comparison of stainless steel wire with titanium wire (sole)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
SOLE Bristol Channel April 1959	PETERSEN DISC Stainless steel wire	317	21	6.6	Total Returns
	PETERSEN DISC Titanium wire	290	19	6.6	*NS*

Table 11
Plastic flag tag. Comparison of differences in position of tag — between 1st and 2nd dorsal, and in front of 1st dorsal (cod)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
COD Bear Island/ Spitzbergen July 1959	PLASTIC FLAG Braided nylon Attached between 1st and 2nd dorsal	561	111	19.8	Total Returns
	PLASTIC FLAG Braided nylon Attached in front of 1st dorsal	541	83	15.3	*NS* (P = 0.1—0.05)
COD Bear Island/ Spitzbergen Aug. 1959	PLASTIC FLAG Braided nylon Attached between 1st and 2nd dorsal	473	54	11.4	Total Returns
	PLASTIC FLAG Braided nylon Attached in front of 1st dorsal	470	57	12.1	*NS* (P = 0.7)

Table 12
Comparison of tag types, materials, and position of attachment (cod)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
COD Bear Island/ Spitzbergen Sept. 1957	(a) LEA HYDROSTATIC Monofilment nylon Attached between 1st and 2nd dorsal	207	25	12.1	a × b *S* (P = <0.01)
	(b) PLASTIC FLAG Nylon wool Attached laterally under skin	220	10	4.5	a × c *S* (P = <0.01)
	(c) PLASTIC FLAG Monofilament nylon Attached laterally under skin	210	1	0.5	b × c *S* (P = <0.01)
COD Bear Island/ Spitzbergen Oct. 1957	(a) LEA HYDROSTATIC Monofilament nylon Attached between 1st and 2nd dorsal	191	17	8.9	(b) excluded — too few fish involved
	(b) LEA HYDROSTATIC Nylon wool Attached between 1st and 2nd dorsal	24	3	12.5	a × c *NS* (P = 0.7—0.5)
	(c) PLASTIC FLAG Nylon wool Attached between 1st and 2nd dorsal	214	22	10.3	a × d *NS* (P = 0.7—0.5)
	(d) PLASTIC FLAG Braided nylon Attached between 1st and 2nd dorsal	214	16	7.5	c × d *NS* (P = 0.5—0.3)

Miscellaneous Comparison of Tag Types, Material and Position of Attachment

During the period under review experiments were carried out comparing the different combinations of tag types, materials and methods of attachment. In many cases only small numbers of fish were involved, but in spite of this many of the results were sufficiently positive to be of considerable help when planning future tagging techniques.

The following are the comparisons made on cod:—

1. *Lea, monofilament nylon dorsal attachment*, compared with *Plastic flag*
   (a) *nylon wool, attached laterally under skin*
   (b) *monofilament nylon, attached laterally under skin*
2. *Lea, monofilament nylon, dorsal attachment*, compared with *Plastic flag*
   (a) *nylon wool, dorsal attachment*
   (b) *braided nylon, dorsal attachment*
3. *Lea, nylon wool, dorsal attachment*, compared with *Plastic flag*
   (a) *nylon wool, dorsal attachment*
   (b) *braided nylon, dorsal attachment*
4. *Lea, monofilament nylon, dorsal attachment*, compared with *Lea, nylon wool, dorsal attachment*
5. *Plastic flag, nylon wool, dorsal attachment*, compared with *Plastic flag, braided nylon, dorsal attachment.*

Lea and plastic flags attached to Arctic cod in a variety of positions by means of different materials during September and October 1957 showed once again that there was very little difference between the efficiency of the two tags when the normal position between the 1st and 2nd dorsal was adhered to (Table 12). Attaching the tag laterally by threading the bridle under the skin was not successful; nevertheless, nylon wool gave better results in this position than monofilament nylon.

The comparisons made on whiting were as follows:—

Plastic flag Nylon wool, dorsal attachment
v.
Braided nylon, dorsal attachment
v.
Nylon wool, attached laterally under skin
v.
Braided nylon, attached laterally under skin
v.
Stainless steel wire, dorsal attachment.

This final experiment showed a similar pattern to the preceding one. Irish Sea whiting tagged by the "Platessa" in August 1957 once more confirmed that the position between the 1st and 2nd dorsal was the most satisfactory and that tags attached laterally under the skin showed a very poor rate of recovery (Table 13). None of the flags attached by stainless steel bridles were recovered. Although very small numbers of fish were tagged during this experiment, the results suggested that the more flexible bridles (i.e. nylon twine and wool) were the most satisfactory.

Summary

1. The Lea tag and the Lowestoft plastic flag tag appeared to be equally efficient for tagging cod, and the factors of availability and cost are most likely to influence the choice of tag.
2. Of the attachment positions investigated, the best for either the Lea tag or the plastic flag tag for both cod and whiting was a dorsal one. The position between 1st and 2nd dorsal fins was most

Table 13

Plastic flag tag. Comparison of differences in materials and methods of attachment (whiting)

Species Tagged	Tag type	Number Liberated	Number Returned	% Returned	Significance
WHITING Irish Sea Aug. 1957	(a) PLASTIC FLAG Nylon wool Attached between 1st and 2nd dorsal	67	12	17.9	a × b *NS* (P = 0.7—0.5)
	(b) PLASTIC FLAG Braided nylon Attached between 1st and 2nd dorsal	58	13	22.4	a × c *S* (P = <0.01) a × d *S* (P = <0.01)
	(c) PLASTIC FLAG Nylon wool Attached laterally under skin	69	1	1.4	a × e *NS* (P = 0.1—0.05)
	(d) PLASTIC FLAG Braided nylon Attached laterally under skin	46	0		b × c *S* (P = <0.01) b × d *S* (P = <0.01)
	(e) PLASTIC FLAG Stainless steel wire bridle Attached between 1st and 2nd dorsal	17	0		b × e *NS* (P = 0.05—0.02)

commonly used and there was no indication that the position in front of the 1st dorsal fin was more suitable.

3. Monofilament nylon, nylon wool or braided nylon twine, used as bridles, all gave similar results when attached in the dorsal position. Braided nylon twine was the easiest material to handle when tagging the fish; it was both flexible and durable. The flexible quality of braided nylon seemed particularly important when marking whiting, an extremely soft fish which damages easily.
4. The Petersen disc proved the most satisfactory tag for use on soles and plaice, and stainless steel or titanium wire in place of silver wire increases its efficiency. It was much easier to attach to flat fish than any of the other types of tag used.
5. Plastic flag tags incorporating phenyl mercury acetate as an antifouling compound inhibited the growth of marine organisms, and for periods of more than 100 days at liberty showed a higher rate of return.

References

FRIDRIKSSON, A. 1952. Marking of fish in Europe during 1927—1951. *Rapp. Cons. Explor. Mer.*, **132**, 55—64.

GULLAND, J. A. 1963. On the analysis of double-tagging experiments. *This symposium*, No. 36.

de VEEN, J. F. 1963. On the tag reporting efficiency of Dutch fishing vessels. *This symposium*, No. 43.

26.

The Benefit of Plaice Transplantation as Estimated by Tagging Experiments

By

K. P. ANDERSEN and OLE BAGGE*

Tagging Technique

During the transplantation of plaice from Nissum Bredning (Broad) to the eastern broads of the Limfjord, Petersen's ebonite discs (Fig. 1) were exclusively used in the years 1895—1952 for judging the results obtained. Almost all recoveries of tagged fish during these years were made in the first 6—7 months after the fish were released. Therefore, information of migrations and growth in the following year after the transplantation was scarce.

The reason why the recoveries of the plaice tagged with Petersen's ebonite discs were made relatively soon after release is, presumably, that the plaice fishery in the parts of the Limfjord to which the fish were transplanted was mainly carried out by nets, and the Petersen's discs are very easily caught in the thin meshes of the net, so that plaice of a size which would ordinarily pass through the meshes were captured because the discs got caught.

FIG. 1

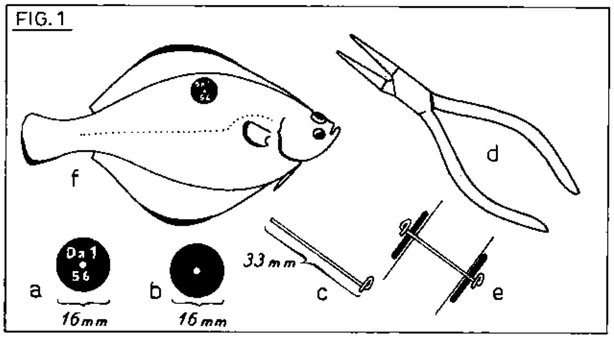


Figure 1. Petersen discs and the method of attachment.

In order to obtain information of the growth over a longer period, the possible dependence of the growth on the type of marking and of the number of fish emigrating from the area, it was necessary to use a tagging technique which in connection with the net fishery did not possess the adverse qualities of the ebonite discs. For this purpose Dr. E. Bertelsen devised three types of tags: 1) The roll tag, 2) the internal tag, and 3) the internal tag in connection with tattooing on the blind side of the plaice. These tags were used in addition to Petersen's ebonite discs in the years 1953—1957. In each of these years a series of transplantation experiments was made in March/April, lasting for about one to one and a half months. In the Limfjord plaice are protected by law for the first four weeks after the beginning of transplantation, and the returns have therefore been summarised in four week periods from the end of the protection period.

Details of the tags used are as follows: —

FIG. 2

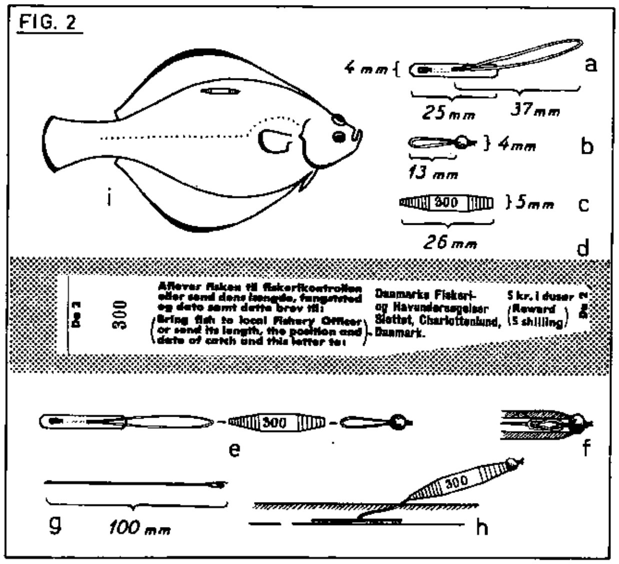


Figure 2. Roll tag and the method of attachment.

(1) *The roll tag* (Fig. 2) consists of three parts: the anchor tag (a), the roll (c), and the locking bead (b). The anchor tag consists of a disc, 25 mm long, 4 mm broad, and 0.2 mm thick, to which a nylon loop (0.40 mm) 37 mm long is attached. The roll is made of a band of plastic (d) which is 165 mm long and tapers towards the ends (22 mm—13 mm) in order to give the roll a hydrodynamic shape. Text and two numbers are printed on the band, so that on opening the roll the address to which the fish should be sent can be seen. One number is visible on the roll, while the other cannot be seen before the roll is opened.

The tag is attached to the fish in the following way. In the middle of the dorsal part of the blind side, just inside the radials, where a lymphatic duct is running, an incision is made in the skin (about 5 mm) at right angles to the longitudinal axis of the fish. The nylon loop is put through the eye of the needle, and the needle (g) is pushed about 30 mm in under the skin

---

* Danmarks Fiskeri-og Havundersøgelser, Charlottenlund.

towards the tail, whereupon the needle is pushed obliquely through the musculature and through the pigmented side, the nylon loop is pulled through, and the anchor plate is inserted under the skin on the blind side so that it is placed as shown in Figure 2 (h). Now the needle is pushed through the roll, and the nylon loop is pulled through this (e). The needle is taken out of the loop, to which a locking bead is then fastened by a reef knot (Fig. 2, f and h).

FIG. 3

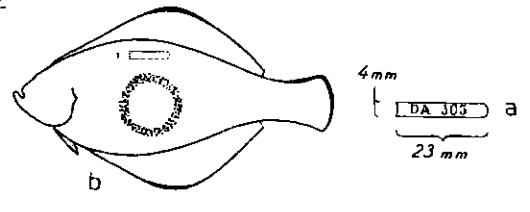


Figure 3. Internal tag and method of tattooing.

(2) *Internal tags.* The internal tag consists of a piece of red plastic 23 mm long, 4 mm broad, and 0.1 mm thick with rounded corners. On the tag are numbers and letters of nationality (Fig. 3 a).

The tag is attached in the same place as the anchor plate of the roll tag (see above). A similar incision is made in the skin, and by means of a forceps the tag is inserted under the skin into the lymphatic duct (see Fig. 3 b).

(3) *Internal tags and tattooing.* After the internal tag has been placed, as described above, a circle is tattooed on the middle of the blind side (Fig. 3 b). The tattooing apparatus consists of a hollow bottom piece which by means of an acentric slot is moved forward and back in a tube. At one end of the bottom a hypodermic needle is affixed and around it an adjustable collar which regulates the tattooing depth. At the opposite end there is a perforated stopper, which is connected to a rubber tube through which the tattooing liquid (black india ink) is administered. The acentric slot is worked by an electromotor; the transmission of power is effected through a Bowden's pull.

Growth

From the calculation of the growth of the transplanted plaice during the first summer after their release, it appeared that in all the years there was a difference in the growth of the tagged plaice with the different kinds of tags used. Growth rates of the fish tagged with Petersen's ebonite discs and with roll tags were not significantly different, but there was a difference between fish marked with internal tags with or without tattoo, and those with Petersen's ebonite discs and roll tags. This difference in growth was significant in all the years except 1957. Figure 4 illustrates the growth of the plaice tagged with the three different kinds of tags in 1954. The growth is assumed to follow a straight line in the time between May to November 1.

Figure 5 illustrates the growth per four weeks, of plaice tagged with the three kinds of tags, in relation to their length at the time of tagging.

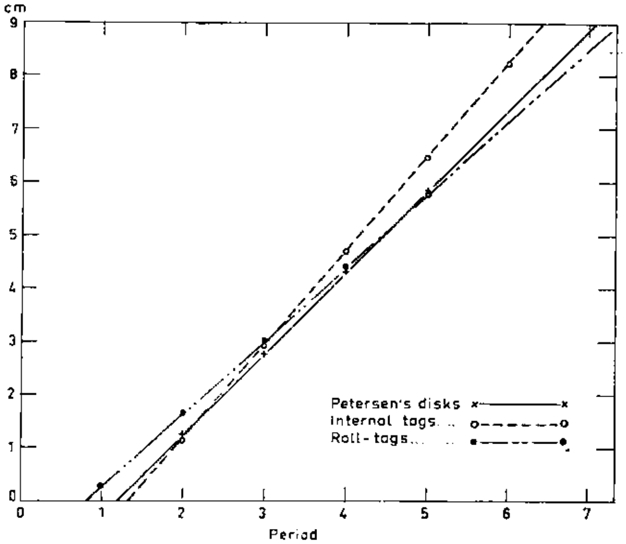


Figure 4. Growth of plaice transplanted to Thisted Broad in 1954, tagged with Petersen disc, internal tags and roll tags.

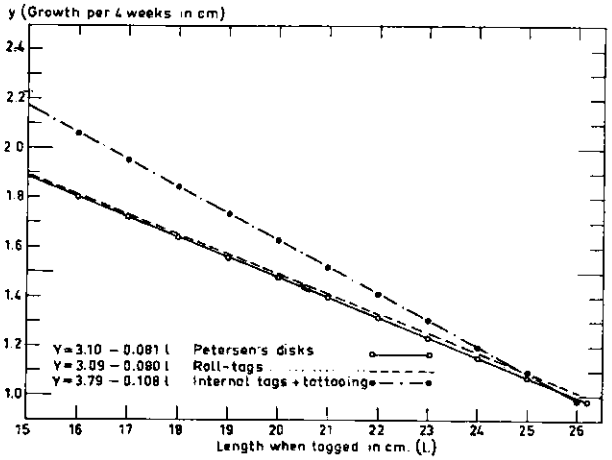


Figure 5. Growth of plaice in relation to length when tagged.

It appears that there is no difference in growth between plaice tagged with Petersen's ebonite tags and roll tags, but a considerable difference between the plaice tagged with these external tags and plaice marked with internal tags.

Return of tagged plaice in set nets and eel trawls

Plaice were marked with Petersen's ebonite discs, roll tags, internal tags plus tattooing and internal tags minus tattooing. Fig. 6 illustrates the return percentage in set nets per four weeks after the termination of the protection period for plaice.

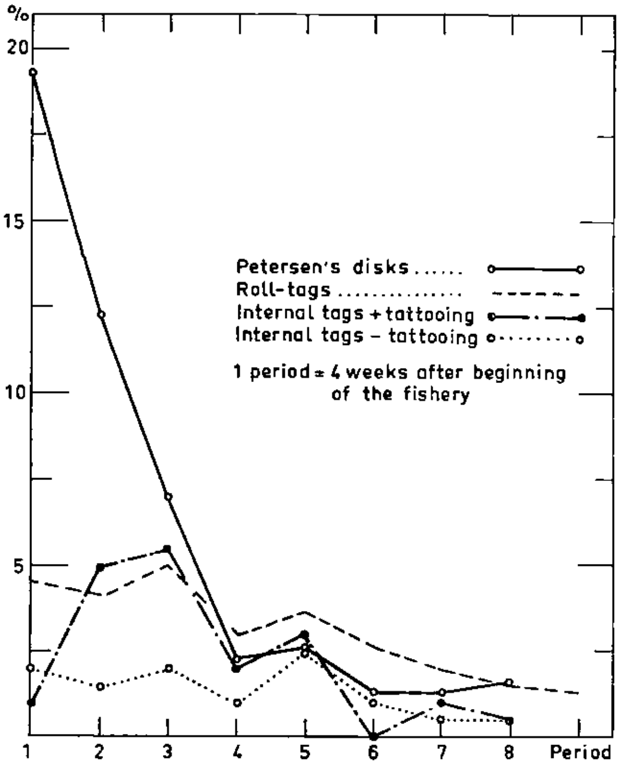


Figure 6. Catches by set nets of plaice tagged in 1954 with Petersen discs, roll tags and internal tags + or — tattooing.

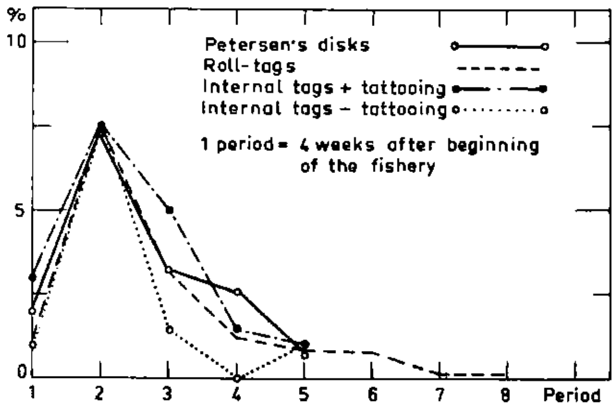


Figure 7. Catches by eel trawl of plaice tagged in 1954 with Petersen discs, roll tags and internal tags + or — tattooing.

It appears that the plaice tagged with Petersen's ebonite discs are caught extensively in the first four week period after commencement of the fishery, whereas the greatest percentage recovered per period, of fish tagged with the other types of tags, occurs in the third period. This is due to the fact that all the plaice marked with Petersen's ebonite discs are caught when they come into contact with nets, regardless of whether their size would allow them to pass through the meshes, because the discs get caught in the net.

The fish marked with other kinds of tags are — as said above — caught in the greatest number during the third four week period after the commencement of the fishery, when the majority have reached a size not allowing escape through the meshes. Plaice marked with internal tags minus tattooing are recovered during all periods in smaller numbers than fish marked with the other types; plaice tagged with internal tags plus tattooing are recovered from the fourth to eighth period, to the same extent as plaice marked with internal tags minus tattooing. This is due to the fact that after three months the tattooing disappears, so that fish marked in this way are overlooked to the same extent as those not tattooed.

If it is desired to have the recoveries extended over a longer period of time, the roll tags appear to be the most suitable in those areas where mainly nets are used in the fishery.

Fig. 7 illustrates the recoveries by eel trawl, per four weeks, of plaice tagged with Petersen's ebonite discs, roll tags and internal tags plus and minus tattooing.

It appears that the percentage returned per period is very uniform for all kinds of tags. This is partly due to the fact that the eel trawl used here has 18 mm for the largest mesh size, so that no selection at all takes place. The recoveries per period, of plaice marked with internal tags minus tattooing, are fewer than the recoveries of the fish tagged with the other types of tags. This is due to the fact that the tags are difficult to see, especially as this eel fishery is nocturnal.

The comparatively low number of returns in the first period is due to the fact that the fishing intensity of the eel fishery then is low. The fact that the eel fishery ceases by the end of September explains why there are no returns after the fifth period.

Calculation of the Benefit of the Transplantation in the Limfjord from Results Obtained in 1954

The most important aspects of a transplantation experiment are its benefits to the fishery, but often the fishery statistics are not accurate enough to permit the estimation of these benefits. In the following an attempt is made to determine the yield resulting from the transplantations of plaice to the Limfjord. The principal material for this calculation are the data on the length distribution of the transplanted fish and tagging experiments with the transplanted fish. The discussion of the calculation will be illustrated by examples, in particular from 1954.

The transplantations are, as a rule, made in March-April, before the temperature of the water has become too high. As a matter of fact, there are indications that high temperatures completely spoil the chance of survival of the plaice. This is illustrated in Fig. 8 which shows the relation between the temperature and the chance of survival (in percent). The survival percentages have been taken from serveral years, and in the following an explanation of the calculation of these figures is given.

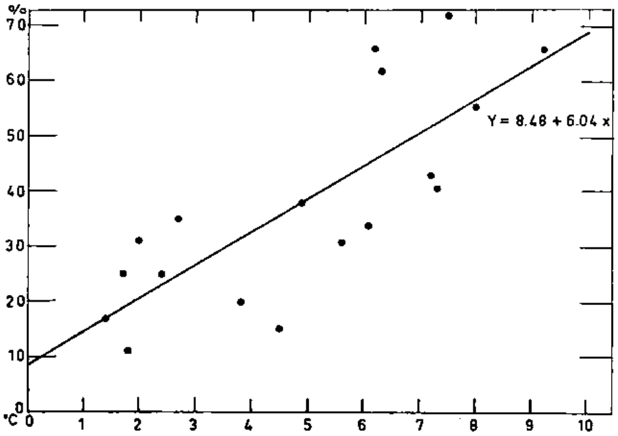


Figure 8. Percentage mortality of transplanted plaice as a function of temperature.

For four weeks after the beginning of the transplantation, the plaice are protected by law in the Limfjord. This is very fortunate, for it facilitates the treatment of the results of a tagging experiment. This protection gives the tagged fish the opportunity to mix with the total population, and this, naturally, simplifies the calculations.

The different experiments seem to show that the effects of transplantation cause a number of fish to die in the course of the first one to two weeks after. The fish which survive this first critical period have a natural mortality equal to that of the plaice in their own area of distribution. It is assumed, therefore, in the calculations, that a certain number of the transplanted fish die at the moment of transplantation, while the rest will die the natural death of plaice in the North Sea.

The fundamental assumption in all calculations is that the number of surviving fish at the time t, N(t) can be characterized by an instantaneous mortality coefficient Z, so that we can write

$$N(t) = N\,(o).e^{-Z.t} \qquad \text{(i)}$$

(see e.g. Beverton & Holt, 1957). It is assumed as usual that

$$Z = F + M \qquad \text{(ii)}$$

where Z is the total mortality coefficient, F the fishing mortality coefficient, which is proportional to the fishing intensity, and M the natural mortality coefficient. When the time t is measured in years, M is assumed to be equal to 0.15, this being the approximate size of the natural mortality for North Sea plaice.

The fishery in the Limfjord is mainly performed by gill nets and eel trawl. Trawling for plaice is prohibited, but the trawl fishermen receive a reward for the tagged plaice accidentally caught. The recoveries made by the trawl fishermen show that the number of trawl-caught plaice is not insignificant. Since it is unrealistic to believe that plaice of legal size caught in the trawl are released, the fishery yield will be calculated as a gill net yield plus an eel trawl yield. In order to determine these two yields it is supposed that F can be split up in the following way:

$$F = F_G + F_T$$

where F_G is the gill net fishing mortality and F_T is the trawl fishing mortality.

The fishery in the Limfjord develops approximately in the following way during the course of a year. The trawl and net fisheries start four weeks after the beginning of the transplantation, and both continue with constant intensity throughout the summer, i. e. for about five months. Hereafter, the eel season ends and with it the trawl fishery, and the fishermen begin to fish plaice with gill nets. This fishery is continued to about the 1st January, when the cold water reduces the activity of the fish so much that a fishery with passive gear becomes uneconomical. It is therefore natural to assume the following as to the different fishing mortalities: —

F is constant from about 1 May — 1 January;

F_T is constant from 1 May — 1 October, whereafter it falls to nil;

F_G is constant from 1 May — 1 October, whereupon it rises to F.

It goes without saying that the above mentioned assumption can only apply to fish of legitimate size (fish ≥ 28 cm), and it is supposed that the fishing mortality for fish of illegal size is nil. This means that all fish below the legal size caught survive capture and are released.

It is shown in the following how F, F_G and F_T and the number of plaice which survive the transplantation, N (o), can be determined on the basis of tagging experiments.

Determination of the Fishing Mortalities F, F_G and F_T

In connection with every transplantation experiment a number of tagging experiments have been made with the types of tags previously described. The best kind of tag for the determination of the F's is Petersen's ebonite discs. As mentioned above, tagged fish which because of their size could escape from the fishing gear, are nevertheless caught. This means that all fish tagged with this type are subject to the same fishing mortality as the fish of legitimate size, since the tagged fish of illegal size caught are not released. In any tagging experiment, if N' is the number of fish surviving by the end of the protection period, while n (T, T') represents number of recoveries in the period between the times T and T' we get:

$$n(T, T') = \int_{T}^{T'} F.N'.e^{-(F+M)t}\,dt =$$

$$= \frac{F.N'}{F+M}\left(e^{-(F \div M)t}\right)_{T}^{T'} \qquad \text{(iii)}$$

(t = o at cessation of protection).

From (iii) it follows that for equal intervals log n (rT, (r + 1)T) = — (F + M).T.r +

$$\log\left[\frac{FN'}{F+M}\left(1-e^{-(F+M)T}\right)\right] \qquad \text{(iv)}$$

From (iv) it follows that the logarithm of the number of recoveries, in equal intervals, is a linear function of the period number. Z can therefore be determined by means of the recoveries, as this line has the slope Z = F + M. Fig. 9 shows a number of recoveries in five periods of four weeks each in 1954. It will be seen that the points fall on an almost straight line with the slope 6.78. We therefore put Z = F + M = 6.78 for 1954, and F is determined as Z — 0.15 = 6.63. (iii) therefore contains only one unknown quantity, i.e. N', which can now be determined.

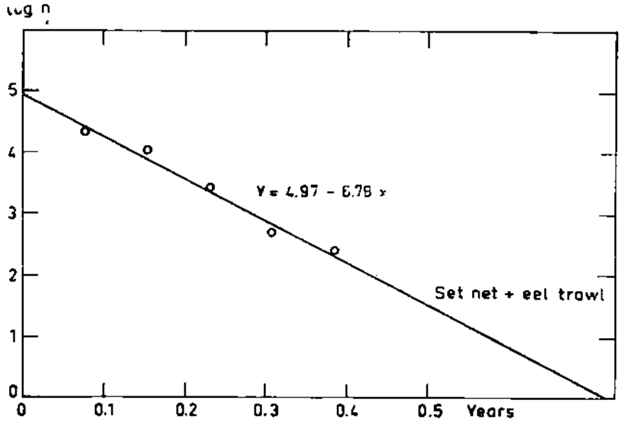


Figure 9. Exponential decline of total returns (Petersen discs) in successive four-week periods in 1954. (End of close season 7.5.54).

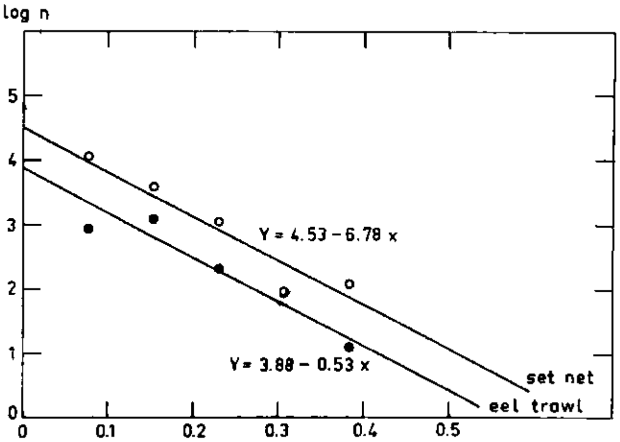


Figure 10. Exponential decline of tag returns (Petersen discs) for set-net and eel-trawl recaptures separately, in 1954.

The experiments of a single year consisted of several separate single transplantations covering a period of one to one and a half months in all, at a time of increasing temperature of the water. In the course of this period a number of tagging experiments were made, and Z = F + M was determined on the basis of the recoveries from all the experiments combined and regarded as a single experiment. By means of the common Z and (iii) it is possible to find N' for the individual experiments, and the number of fish which have survived the transplantation is given by $N(o) = N'.e^{+qM}$, where q is the protection period. These survival numbers have been used as the one variable in Fig. 8.

Fig. 10 shows the same recoveries, but separately for gill net and eel trawl. Here the points should lie around lines with slopes $Z = F_G + M$ and $F_T + M$. The figure shows that the linearity is fairly good.

For the number of recoveries in the net fishery in the period between the end of the protection period and the time T we get from (iii)

$$n_G = \frac{F_G}{F+M}\,N'\cdot\left(1-e^{-(F+M)T}\right). \qquad \text{(v)}$$

(v) shows that F_G can be determined, and this of course means that F_T has also been determined. For 1954 $F_G = 4 \cdot 43$ and F_T then is $2 \cdot 35$.

Determination of the Weight Yield

In order to find the weight yield it is necessary to know, in addition to the mortality figures, the weight distribution of the plaice, as a function of time. We take it for granted that this weight distribution has been determined if the following items are known.

1. The length distribution of the surviving fish at the moment of transplantation.
2. The growth of the fish as a function of time.

1 was determined from random samples of the transplanted fish, and 2 from recovered tagged plaice. As said above, the Petersen discs in particular check to some degree the growth of the plaice. In the calculation we therefore used the increase in length for fish with internal tags; these fish show the best growth and must therefore be supposed to come closest to the growth of non-tagged plaice. For the sake of simplicity a linear mean growth function is used, i.e. we assume that the growth in length is independent of the initial length of the fish. As already stated, this is not correct, because a mean growth function underestimates the growth of the small fish and overestimates the growth of the big fish, but the approximation is usable. We thus work on the supposition that a fish which was l cm long when transplanted, at the time t is $(l + at)$ cm long where a is the mean growth for plaice tagged with internal tags.

Finally, the weight at time t of a plaice which at the time of transplantation was l cm is determined in the usual way as $p(l + at)^3$, where p is determined by means of transplanted (possibly tagged) fish.

The plaice which survive the transplantation will throughout their life be subject to a natural mortality of M, and they will also have a fishing mortality which is nil outside the fishery periods and during the time until they have reached the legal size. The fishing mortality of the fish of legal size in the fishing periods is, however, as already mentioned, F.

If the relative length distribution of the plaice during the transplantation is $f(l)$ the catch in numbers between t and $t + dt$ of the plaice which at the time of transplantation had a length of between l and $l + dl$ will be

$$N(O) \cdot f(l) \cdot F \cdot e^{-(F+M)\left(t-\frac{28-l}{a}\right)} \cdot e^{-\left(\frac{28-l}{a}\right)M} \cdot dl\,dt \quad \left(t \geqslant \frac{28-l}{a}\right)$$

$$0 \qquad \left(t < \frac{28-l}{a}\right)$$

These fish give the following total yield in the first season after the transplantation.

$$dl \int_{\frac{28-l}{a}}^{A\ (\text{end of season})} p(l+at)^3\, N(0)\, f(l)\, F\, e^{-(F+M)\left(t-\frac{28-l}{a}\right)}\, e^{-\left(\frac{28-l}{a}\right)M}\, dt$$

The total yield for all lengths will finally be

$$\int_0^{+\infty} \left[\int_{\frac{28-l}{a}}^{A} p(l+at)^3\, N(0)\, f(l)\, F\, e^{-(F+M)\left(t-\frac{28-l}{a}\right)}\, e^{-\left(\frac{28-l}{a}\right)M}\, dt \right] dl \qquad \text{(vi)}$$

(For fish which reach the legal size before the end of the closed season $\frac{28-l}{a}$ is replaced by q.)

Normally not all transplanted fish are caught in the first season; there will also be a not inconsiderable yield in the next season. This can be calculated in a similar way to the yield of the first season, but it is necessary to use a different growth function for the now fully grown fish. This function is determined by means of the recoveries of the second season and by direct tagging experiments on the fish of the second season, it being assumed that the growth of the fish stops between the fishing periods. It is also possible to determine the trawl yield by means of (vi). Here the first F should only be replaced by F_T, and A by the time for the cessation of the trawl fishery. The gill net yield is found as the difference between the total yield and the trawl catches.

For 1954 the following figures are found for the period May 1 to December 31. Total yield: 177 tons (here we reckon that the growth stops on 1 January. If we reckon, however, that the growth stops on 1 November a total yield of 162 tons is obtained); net yield: 153 tons (138 tons); trawl yield: 24 tons.

At the time of transplantation the transplanted fish weigh 76 tons. The weight yield of the first season will thus be 233% (213%).

The weight of the plaice surviving the first season will be about 45 tons. In the second season these fish will be practically fished out, giving a catch of about 40 tons. In 1954 the transplantation thus gives a total weight yield of about 275%.

The calculation shown above can be carried through directly for the majority of the transplantations of recent years, but in one year circumstances occurred which necessitated a modified calculation of the yield. In 1953 in the three first months after the closed season, a strong decrease in oxygen content occured. This decrease accelerated the activity of the plaice, resulting in an increased effectiveness of the gill nets. Thus no constant fishing intensity can be expected, and this is, of course, detrimental to the direct application of the above mentioned formula. Direct observations showed that the lack of oxygen during its maximum, even though of short duration, caused a large scale mortality of plaice. The yield of 1953 was therefore determined on the basis of the general pattern by making the following modifications.

It was assumed that the plaice were subject to the following mortalities during the time from the day of transplantation to the end of the fishery season: —

1) A transplantation mortality; 2) thereafter in the period to the end of the season a natural mortality of $M = 0.15$; 3) an increased fishing mortality in the first twelve weeks after the closed season; 4) a momentary suffocation mortality during the oxygen minimum which is supposed to have occurred twelve weeks after the beginning of the season, and 5) a normal constant fishing mortality in the remaining part of the season.

These different mortalities were determined in the following way: 1) could not be determined in the normal way and therefore was determined by means of Fig. 8. 2) Was determined as a constant value in each of the three four-week intervals of the period. The determination of F_1 (F in the first four-week interval) was made by means of recoveries and by the following equation:

Number of recoveries $= \frac{F_1}{F_1+M} N' (1—e^{-(F_1+M)\,28/365}$

F_2 and F_3 were found in the same way

For the three periods, the Fs were found to be $F_1 = 7.1$, $F_2 = 9.3$ and $F_3 = 27.8$.

The ebonite discs were now practically fished out, but internal (+ tattooing) tags were still left, and the number was calculated as N′ — number of recoveries in the first three four-week intervals. (This figure is a little too high as M has not been considered, but error is slight as M is small). Both the transplanted and especially the tagged fish were big in 1953, and therefore it should be theoretically possible to determine 5) by means of recovered fish with internal tags; as, however, only the last part of the season can be used for the determination the accuracy is small. Since the variation in the number of fishermen and fishing gear from one year to another is small, the fishing mortality must vary little and 5) is therefore determined as $^1/_2(F_{1952} + F_{1954}) = {}^1/_2\,(6.62 + 6.63) = 6.62$.

If no suffocation mortality had taken place, the number of recoveries n″, in the time after the first twelve weeks, would be determined by (iii) which gives n″ = 308. Actually only 86 were caught. It is therefore reasonable to put 4) at 1—86/308 = 72%.

The yield can now be determined by (vi), as the season is divided into three four-week periods and a period which is equal to the rest of the season. This calculation gave a yield of 39 tons. The weight of the transplanted fish was 41 tons. The lack of oxygen therefore damaged the transplantation to a rather high degree.

Summary

During the years 1895—1952 only the Petersen discs were used in tagging plaice for transplantation to the Broads of the Limfjord. Practically all recaptures occurred within the first few months after the transplantation and for this reason the tagging gave but little information about migration and growth after this period.

During the years 1953—1957 an extensive experiment was carried out to throw light on the profit of the transplantations and on the migration and growth of plaice.

As the plaice fishery in the eastern areas of the Limfjord is primarily net-fishing it is supposed that the rapid recaptures of plaice tagged with the Petersen disc was due to the fact that these discs catch on the fine yarn of the net, so that the plaice was taken although its size would permit it to pass through the meshes of the net. To extend the period of recaptures it was necessary to invent a new type of tag which did not have this drawback in relation to net-fishing.

Dr. E. Bertelsen made three types of tags: 1) the roll tag, 2) the internal tag, and 3) the internal tag in connection with tattooing of the eyeless side. Concurrent markings with these three tags and the Petersen disc verified the supposition that the Petersen discs catch on the net so that the fish is taken irrespective of its size.

Returns of plaice marked with internal tags + tattooing were fewer than returns of fish marked by roll tag or Petersen disc, because after about three months the tattooing fades and escapes notice. Plaice marked with the internal tag without tattooing were overlooked to a still larger extent.

Difference in growth between plaice marked with the Petersen disc and those with the roll tag was not significant, whereas there was a difference between plaice marked with these two types and those marked with the internal tag ± tattooing.

A comparison of the growth in plaice marked with the four tags shows that whereas the internal tags seem to have no effect, the growth of the smallest plaice marked with the Petersen disc or the roll tag is considerably retarded.

An important aspect in transplantation experiments is the question of economy. The profit from the transplantations in the Limfjord was calculated from the tagging data. The profit cannot be estimated from the fisheries statistics, as these are unreliable.

Some transplanted fish inevitably die at the time of transplantation (i. e. within one to two weeks). Those which survive this period are presumably subject to the same mortality as plaice in their natural area of distribution. Transplantation mortality and fishing mortality were estimated by means of the common equation of survival

$$N(t) = N(o)\ e^{-(F+M)\ t}.$$

When these quantities are known it is possible to calculate the yield of the fisheries.

The results of the tagging experiments with the Petersen disc have especially been applied to these calculations. The reason is that the fishing mortality for fish marked in this way is independent of the size of the fish and may be taken to be equal to the mortality of fish that have reached minimum legal size, whereas fish below minimum size are assumed to be subject only to a natural mortality (minimum size in the Limfjord is 28 cm).

Examples from the year 1954 illustrate the calculation, but it is also shown how calculations are modified for the year 1953 when a marked lack of oxygen to some degree ruined transplantations.

Reference

BEVERTON, R. J. H. & HOLT, S. J. 1957. On the dynamics of exploited fish populations. *Fish. Invest., Lond.*, Ser. 2, 19.

27.

Tagging Experiments with the Greenland Shark (*Somniosus microcephalus* (Bloch and Schneider)) in Subarea 1

By

PAUL M. HANSEN*

Tagging experiments with Greenland shark have been carried out in Subarea 1 in 1936, 1939, 1948 and 1949. In all, 411 sharks have been tagged and released. Different techniques have been used in the different experiments. In the following a description is given of the technique used in fishing and handling of the fish at tagging, the type of tags used, and how and where they are attached to the fish.

Fishing Technique

In all experiments bottom long lines of the type used in the Norwegian shark fishery were used. The hooks were the biggest cod hooks, Kirby Nos. 1 and 2. Fresh or salted seal blubber was used for bait. In the experiments in 1936 and 1939 lines with 50 hooks were used in each setting, while 100 hooks were used in the settings in 1948 and 1949. In 1936 and 1939 the lines fished in 4—7 hours, while in 1948 and 1949 it was necessary to let the long lines stay in the sea overnight owing to scarcity of sharks. The fishing time was therefore 12—20 hours on the average.

Tagging Localities

Tagging experiments were carried out in coastal waters and fjords as follows: —

Year of Tagging	Month	Division
1936	August	1 A
1939	July	1 E
1948	June—Sept	1 A, 1 B
1949	August	1 A

Fishing Depth

The sharks used for tagging were caught in depths between 250 and 500 m. The largest numbers were taken in 300—400 m depth.

Size of Sharks Used for Tagging

The size of sharks used for tagging varied from 125—400 cm in total length measured from the snout to the upper lobe of the caudal fin. The greatest number measured had a total length between 200 and 325 cm.

Condition of Sharks Used for Tagging

Only fish which seemed to be intact were used for tagging. When a shark had swallowed the hook or the hook was stuck in the gills, it was not used. Also in cases where a strong bleeding indicated severe injuries to a shark it was rejected. In some few cases especially when the lines had stayed for a long time in the sea it happened that the shark had died when it was hauled up. Owing to the sluggishness of this fish, it could sometimes be a little difficult to judge if it was dead or alive.

Handling the Sharks

In the 1936, 1948 and 1949 experiments the sharks were treated in the following way. When a shark was hauled up to the surface an unharbed hook on a long stick was used to haul its tail out of the water where a loop was wound around it. After the rope end had been fastened on board the ship, the snood was untied from the long line and the hook was removed from the mouth of the shark by means of a boathook. In 1936 the sharks were tied by the tail to the lifeboat and towed to the shore where the tagging was carried out. Before the tagging the sharks were kept in shallow water close to the shore. Each shark was pulled ashore and then measured from the snout to the peak of the upper lobe of the caudal fin. After tagging the shark was pulled out into the sea and released. Only a little more than 50% were able to swim out to deep water again. Many had swallowed so much air that they were unable to dive. In such cases the sharks were towed to the shore again and the tags were removed.

In 1939 the sharks were not towed to the shore but were tagged at the fishing place as soon as they were hauled up. By the snood and sometimes helped by a boat-hook, the shark's head was pulled a little above the surface, where the tagging was carried out by a man sitting in the lifeboat; the lifeboat was tied to the side of the ship. After tagging the hook was removed and the shark released.

In the experiments carried out in 1948 and 1949 each shark was hoisted up by the tail along the side of the ship. In that position it was measured and tagged; then the hook was removed and the fish released.

---

* Greenland Fisheries Investigations, Charlottenlund, Denmark.

Types of Tag Used

In the experiments in 1936 the same type of tags was used as for cod, small black Petersen discs, diameter 1.6 cm, with white numbers. Silver wire with a diameter of 1 mm was used for attaching the tags. In 1939, 1948 and 1949 a larger Petersen disc of ebonite, with a diameter of 2.5 cm, was used. Silver wire of the same dimension as in the previous experiments was used.

In 1948 each shark was tagged with two tags with the same number. One was attached with silver wire, the other with stainless steel wire, by means of a hollow needle about 10 cm long. In 1936 a few sharks were tagged in one of the pectoral fins, but most were tagged in the cheek. In 1939 all sharks were tagged in the cheek. The reason for choosing this position was that the skin of the cheek is very thick and tough. Furthermore, in that position the tag could not easily be overlooked when recaptured, owing to the fact that the Greenland fishermen usually tow the sharks to the shore by means of a rope put through a hole cut in the cheek. In 1948 and 1949 the tags were attached to the first dorsal fin.

Results

The number of sharks tagged in each year and the number and percentage of returns are given below. (It is believed that the Greenlanders return all tags from recaptured sharks):

Tagging Year	Nos. Released	Nos. Returned	% Returned
1936	50	6	12.0
1939	77	7	9.1
1948	198	14	7.1
1949	86	1	1.8
Total	411	28	

The total number of 411 sharks tagged gave 28 returns. Omitting the experiments in 1949, which gave only one single return, the percentage of returns was 8.3.

In Table 1 the number of returns in the year of tagging and following years is shown, together with the distances between the place of tagging and the place of recapture, in nautical miles (the numbers in the body of the table). It is seen that ten sharks were recaptured before the fifth year, nine between five and nine years, six between ten and fourteen years and one in the sixteenth year after tagging. The table shows that the distance between the place of tagging and the place of recapture in many cases has been very great. Only six have been recaptured within 10 miles from the tagging place, seven between 10 and 99 miles, nine between 100 and 199, three between 200 and 299, and two in a distance of 700 miles. Long distance migrations are shown on the map (Figure 1).

It was hoped that from these experiments important information would be obtained on the growth rate of the Greenland shark, which is still unknown. Unfortunately very little progress has been made in that direction, mainly owing to unreliable measurements of the recaptured sharks. Omitting the seven returns from taggings in 1939, when it was impossible to measure sharks before they were released, and two other returns of sharks tagged in 1936 and 1948 which were not measured at tagging, six recaptures have been reported without information about total length at recapture, seven have been reported with lengths smaller than at tagging, while six have heen reported with a length greater than was measured at tagging. In three of the six last-mentioned returns, the increment in length was so large that it was obvious that the reported measurements were wrong. Only in one single case was a fully correct measurement of a recaptured shark reported and fortunately it was from the shark which was recaptured sixteen years after tagging. The difference between the total length at tagging and at recapture was only 8 cm (262—270). If we take into consideration that it is nearly impossible to measure such a big fish with extreme exactitude, we must consider that this

Table 1

Distance, in miles, travelled by each returned tagged shark, arranged according to time since tagging

Year of Tagging	Year since Tagging																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	?
1936			10				190						25		55		152	50
1939				0 160	?			0? 160 700	700									
1948	0 40				0 25 50	190	0 190	10			0 190	170 210						200
1949			230															
Total	2	—	2	2	4	1	3	4	1	—	2	2	1	—	1	—	1	2

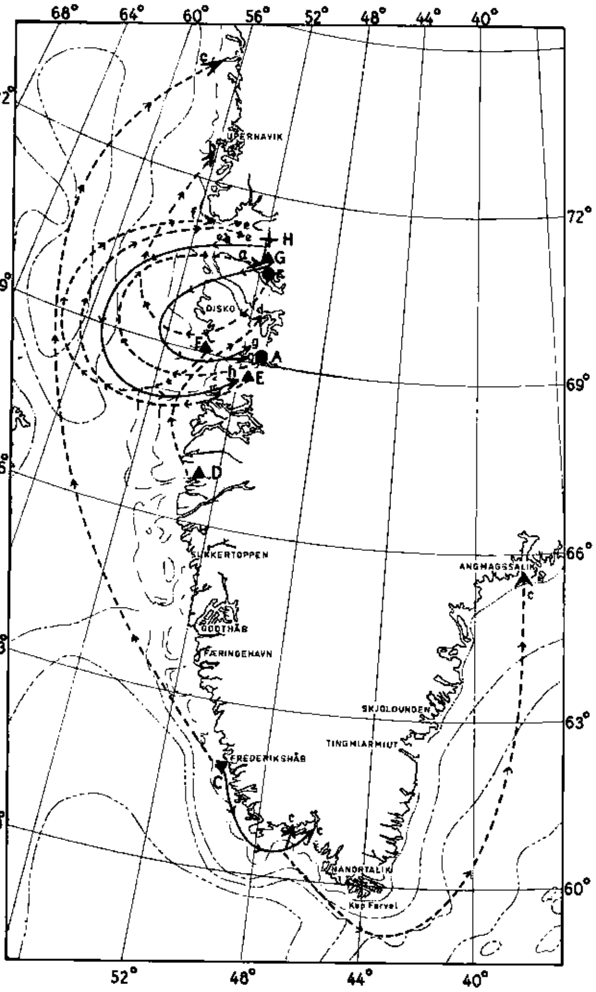


Figure 1. Long distance migrations of Greenland shark. Northward migrations in broken lines. Southward migrations in full lines. Capitals indicate tagging places, small letters places of recapture. The different years of tagging experiments are indicated as follows: ● 1936, ▼ 1939, ▲ 1948, + 1949.

fish had not grown in the long period between tagging and recapture or that the growth must have been negligible. Another recaptured shark showed an increase in total length of 1 cm after two years in the sea (271—272 cm). A third specimen, which was recaptured fourteen years after tagging, showed an increase in total length of 15 cm (from 285 cm at tagging to 300 cm at recapture).

Discussion

Four years' tagging experiments with Greenland shark in Subarea 1 have shown that tagging of this big deep sea fish can be carried out quite successfully. The total percentage of returns from three years' experiments was 8.3. In many cases, the sharks were recaptured several years after tagging and often at a great distance from the tagging place. In only one year (1949) was the experiment unsuccessful, with only one recapture from 86 tagged fish. The tagging in 1936 and 1948 was carried out in the same regions. It is seen from page 173 that the percentage of returns was 12.0 in 1936 and 7.1 in 1948. The better result of the experiment in 1936 than in 1948 may be ascribed to the following two causes: first, there is the difference in fishing time of the long lines, namely four hours in 1936 and 12—20 hours in 1948. It is obvious that the less time a fish is attached to a hook, the better chance it has of surviving. The second reason is found in the difference in the way the fish were handled before and during tagging. By towing the sharks to the shore and keeping them in shallow water for a short time after tagging, as was done in 1936, there is an opportunity to examine the condition of the tagged fish and to discard the specimens which have no chance to survive. This opportunity is missed in the method used in 1948, when the fish were released just after tagging.

Probably it is equally injurious to the shark to be towed by the tail over a rather long distance as in 1936, as it is to be hoisted up above the surface by the tail along the ship's side, as done in 1948 and in 1949. However that may be, the handling of the sharks in both cases may be considered as very rough, implying a danger of injury to the fish. For that reason both methods should be avoided in future tagging experiments.

Neither can the method used in 1939, which is described above, be recommended owing to the following facts. 1. It can only be used in absolutely calm weather. 2. Tags can be lost by movements of the fish. 3. It is impossible to measure the length of the shark. 4. The tagging work is very disagreeable to the person who tags the fish, partly because it is done in ice cold water and partly because of the spiky skin of the shark which hurts the hands.

As mentioned before, in 1948 some sharks were tagged with two tags, one attached by silver wire and the other by stainless steel. For eight recaptures both tags were returned together with the wire. The stainless steel wire did not show corrosion, and the corrosion of the silver wire was only slight, even though the tagged fish had been in the sea several years before recapture. The only exception was the silver wire from the shark which was recaptured sixteen years after tagging. This silver wire showed a very strong corrosion. The upper lobe of the wire had fallen off and the lower was worn down from a thickness of 1 mm to 0.35 mm. The part of the wire between the two ebonite discs showed only a slight corrosion. It is obvious that stainless steel is to be preferred to silver.

In accordance with the experience obtained from the tagging experiments with Greenland shark mentioned above, it is planned to employ the following method in the future. In order to injure the sharks as little as possible, the hooks used on the long line should be fairly small, as for instance the biggest cod hooks or halibut hooks, Kirby Nos. 1 and 2. The long lines should stay in the sea as short a time as possible; ten hours should perhaps be the maximum. Only sharks which have not swallowed the hook and are not bleeding from wounds in the gills should be used for tagging. Even if the shark is generally very sluggish when it comes to the surface, the work of measuring and tagging it can often be a rather difficult task as can be seen from the descriptions of the tagging experiments given in this paper. The best way to facilitate the work would probably be to narcotize the shark by a special narcotic which could be sprayed on the gills. When a rope is tied around the tail and the shark is lying at the surface, along the ship's side, it will be quite easy to measure and tag. The tag should be a Petersen disc of white plastic, 2.5 cm in diameter, and attached by means of a stainless steel wire (1 mm in diameter) to the first dorsal fin or to the cheek. It will be necessary to keep the shark at the surface until the effect of the narcotic is over. If the shark was released in a narcotized condition, it would be an easy prey to its companions when it sank to the bottom.

Summary

In tagging experiments with Greenland shark in the years 1936, 1939, 1948 and 1949 a total of 411 sharks have been tagged in Divisions 1A, 1B and 1E. The experiments in the three years first mentioned have been fairly successful, with an average percentage of return of 8.3, while the tagging in 1949, when 86 sharks were tagged, gave only one return. Ten sharks were returned within five years, nine between five and nine years, six between ten and fourteen years and one sixteen years after tagging.

Recaptures have been reported up to 700 nautical miles from the place of tagging.

It was hoped that some information on the growth of Greenland shark would be obtained by the tagging experiments. The results have been very disappointing owing to unreliable information about the length of the fish at recapture. In one single case the recaptured shark was measured perfectly by an experienced fisheries officer. This shark was recaptured sixteen years after tagging, and the difference in total length between tagging and recapture was only 8 cm. This indicates that the Greenland shark has a very slow growth rate.

A description is given in the paper of the different techniques which have been used in the experiments, including fishing techniques, condition of sharks used for tagging, tagging techniques, types of tags, etc. The different methods used are discussed.

28.

Marking Experiments With the Commercial Whelk (*Buccinum undatum*)

By

D. A. HANCOCK*

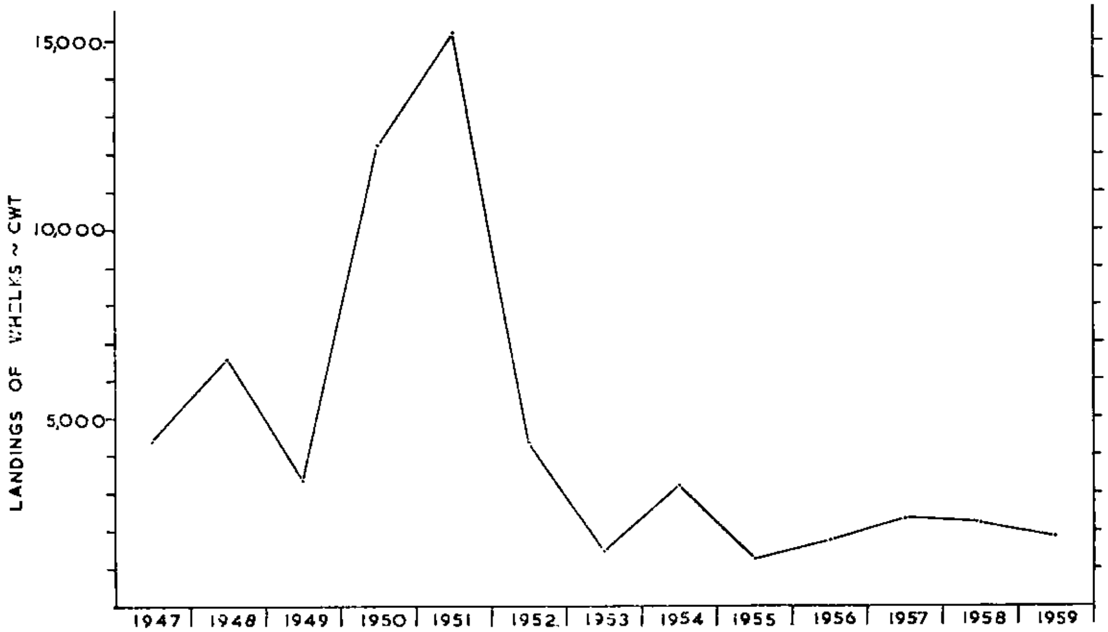


Figure 1. Annual landings of whelks at Whitstable, 1947—1959.

Introduction

Whitstable, in Kent, is the most important centre in the southern part of the whelk fishery on the east coast of England. The landings of whelks have become considerably reduced in recent years (Figure 1) and it was suggested that this was the result of overfishing, and, since there are no size regulations, of the landing of very small whelks. Complete records of the boats fishing between 1947—1959 are not available, but in 1950—51 there was roughly double the present number. There are at present only six or occasionally seven boats working a fairly circumscribed area of roughly 28 square miles. The whelk is a bottom-crawling gastropod captured in special pots. Each pot is made from an iron frame laced with tarred rope; it is baited with salted fish, fish offal and shore crabs (*Carcinus*). Pots are usually tied in strings or 'shanks' of 24 pots, with about six separate shanks for each boat. In favourable weather the pots are hauled daily by hand, the bait changed and pots relaid in the same or a different place depending on the size of the catch. The present marking experiments were designed to make estimates of population size, rate of fishing, growth and mortalities. This paper is not intended to present a complete analysis of results, but to outline factors which require careful consideration before the final calculations are made.

Design of the Experiment

It had previously been found that although the main area covered by the fishery was only 28 square miles, there was considerable variation in the growth rate over the area, and also in the distribution of fishing effort. It was therefore decided to divide the area into 9 equal plots, each of about 3 square miles (Table 1), and to mark the whelks from each plot separately. A fleet of pots was fished each day in one of the plots. The original objective was to mark a fixed proportion of each day's catch, so that the total numbers marked would be in proportion to the unmarked whelks throughout the area. However, on certain days the catch was small, so that each individual caught had to be marked to complete a reasonable number, and when catches were large in certain plots only a proportion of the catch could be marked in the time available. However, since the whelks released in each plot were separately identifiable and since separate fishing effort figures were to be obtained for each plot, each plot could be considered independently for recapture data and growth rates. We were most fortunate in having at Whitstable a Ministry's collector of statistics, who was an active whelk fisherman, and who made himself responsible

---

* Fisheries Laboratory, Burnham-on-Crouch, Essex, England.

not only for the collection of marked whelks from fishermen and the payment of rewards, but also for recording the number of days fished by each fisherman, the number of pots each was using and the plot being fished. It was often difficult to locate an exact position in the area, both when marked whelks were released, and when they were recaptured by fishermen, who would notify the position of recapture. The greatest accuracy of information on migrations which could be expected, therefore, was whether any whelks had been recaptured in a plot other than that in which they were released.

Method of Marking and Release

Details of the marking methods have been described elsewhere (Hancock and Urquhart, 1959). The spires of the shells were cleaned and painted with a quick drying paint, and a separate colour or combination of two colours used in each of the nine plots. Whelks were placed in containers of seawater for a short period after the paint had dried, in order to reduce the time taken for them to recover properly on the sea bed, and thus to keep to a minimum post-marking mortality due to attacks by crabs and other predators. In July 1957 a total of 4,898 whelks were marked in this way, and the whelks from each day's marking scattered as evenly as possible over the plot in which they were caught. In July 1958, greater attention was paid to marking a larger number in a smaller area, and 5,140 whelks were marked and released on the central plot (V) which had borne a high proportion of the fishing effort during the previous year. From the high numbers of recaptures expected it was hoped to obtain more useful information on growth rates, and on whether marking a higher proportion of the population would lead to more reliable results. In addition smaller numbers were marked in plots IV (601) and VIII (791). Using experience gained from results of the 1957 marking, in July 1958 the shell lip of each whelk was scrubbed free from the outer brown periostracal layer. On subsequent recapture the position of the clean shell lip at release would be distinguishable from any new shell growth which would be covered by periostracum, and shell length increments easily measured. It should be noted that it was impracticable to paint the smallest whelks in each day's catch, and generally marking was confined to whelks of more than 40 mm shell length. This will need to be taken into account in the analysis of recapture data.

Recaptures

Painted whelks taken in day to day catches were returned by fishermen who were paid a reward of threepence for each whelk, together with information on its position of recapture. A number of marked whelks had died, and their shells had become inhabited by hermit crabs, some of which were attracted by the bait into the whelk pots. These were recorded and rewards given just as for live painted whelks. The colours of paint used were selected for their brightness, and showed up well in commercial catches. As a safeguard against the loss of marked whelks which might be overlooked by fishermen, each fisherman was issued with a number of duplicated letters for despatch to his customers asking them to return painted whelks.

The numbers of returns in each plot during the years 1957—60 are shown in Table 1. Only one whelk of the thousands recaptured during the experiment was taken in a plot in which it was not released.

Table 1

Diagrammatic representation of the Whitstable whelk fishery, subdivided into 9 equal plots (I—IX) showing releases, returns, catch and effort during 3 years

Returns
Marked 1957 | Marked 1958

		AUG. 1957 — JULY 1958	AUG. 1958 — JULY 1959	AUG. 1959 — JULY 1960
I	Number of whelks marked	*432*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	6/0	1/0 | —	0 | —
	Annual catch (cwt)	*70*	*82*	*87*
	Pots hauled during year	5,422	7,038	5,582
II	Number of whelks marked	*750*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	59/8	29/3 | —	14/0 | —
	Annual catch (cwt)	*322*	*413*	*472*
	Pots hauled during year	23,989	31,583	24,080
III	Number of whelks marked	*356*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	1/0	2/0 | —	— | —
	Annual catch (cwt)	*116*	*67*	—
	Pots hauled during year	9,362	4,727	0
IV	Number of whelks marked	*684*	*601*	*0*
	Returns—: Whelks/Hermit Crabs	35/6	15/1 | 1/0	0 | 26/1
	Annual catch (cwt)	*89*	*75*	*86*
	Pots hauled during year	6,285	7,120	5,144
V	Number of whelks marked	*509*	*5140*	*0*
	Returns—: Whelks/Hermit Crabs	67/19	40/1 | 1656/48	3/0 | 479/5
	Annual catch (cwt)	*385*	*640*	*808*
	Pots hauled during year	27,072	46,307	46,992
VI	Number of whelks marked	*542*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	87/0	15/1 | —	4/0 | —
	Annual catch (cwt)	*253*	*196*	*290*
	Pots hauled during year	15,348	12,321	12,360
VII	Number of whelks marked	*448*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	5/5	10/0 | —	29/2 | —
	Annual catch (cwt)	*160*	*61*	*224*
	Pots hauled during year	11,996	5,199	14,377
VIII	Number of whelks marked	*536*	*791*	*0*
	Returns—: Whelks/Hermit Crabs	49/25	16/5 | 252/2	10/0 | 49/2
	Annual catch (cwt)	*485*	*328*	*246*
	Pots hauled during year	33,886	25,644	15,757
IX	Number of whelks marked	*641*	*0*	*0*
	Returns—: Whelks/Hermit Crabs	40/0	85/0 | —	14/3 | —
	Annual catch (cwt)	*184*	*288*	*167*
	Pots hauled during year	14,587	19,780	10,634
TOTAL CATCH INSIDE AREA		2,064 cwt	2,150 cwt	2,380 cwt
TOTAL EFFORT		147,947 pots hauled	159,719 pots hauled	134,926 pots hauled
TOTAL RETURNS whelks/hermit crabs		349/63	213/11 | 1909/50	74/5 | 554/8

Commercial dredging for oysters took place over part of the area, and occasional marked whelks were taken, but since no information on the unmarked whelks taken in dredges was available for comparison a correction for losses by oyster dredging must be made to the number of releases in each plot.

Sources of Error Arising during Analysis of Recapture Data

For the purpose of this paper it is proposed to examine the conditions which Ricker (1958) suggested must be satisfied in order to be able to apply the accepted methods of analysing recapture data from single census (Petersen type) experiments with recaptures throughout one or more time intervals, and to see how far the errors arising can be estimated and corrected. Errors may arise from: —

1. Effect of non-random distribution of marked and unmarked populations

The ratio of returns/catch each month (Figure 2) shows considerable variation, particularly in plot V following 1958 marking, even more than a year after marking. This variation may have resulted from either non-random distribution of released whelks, or non-random distribution of the unmarked population, or from both causes.

Even spreading of marked whelks over the same plot from which they were caught in pots was attempted by scattering them as evenly as possible from the ship, which pursued a zigzag course up and down the plot. The need for releasing marked whelks within the ill-defined boundaries of each plot may have resulted in a smaller number of releases near the edges than towards the centre of each plot, and the scattering of a small number of individuals (Table 1) over a relatively large area might also have contributed to an uneven distribution. It was hoped that any uneven distribution would be reduced to some extent by the movement over the sea bed of marked whelks so that they became evenly mixed with the unmarked population. However, from the recapture data it is clear that practically no mixing of marked animals occurred between adjacent plots, which suggested that either the whelks were released too far from the boundaries for their movements to take them into another plot or that their movements

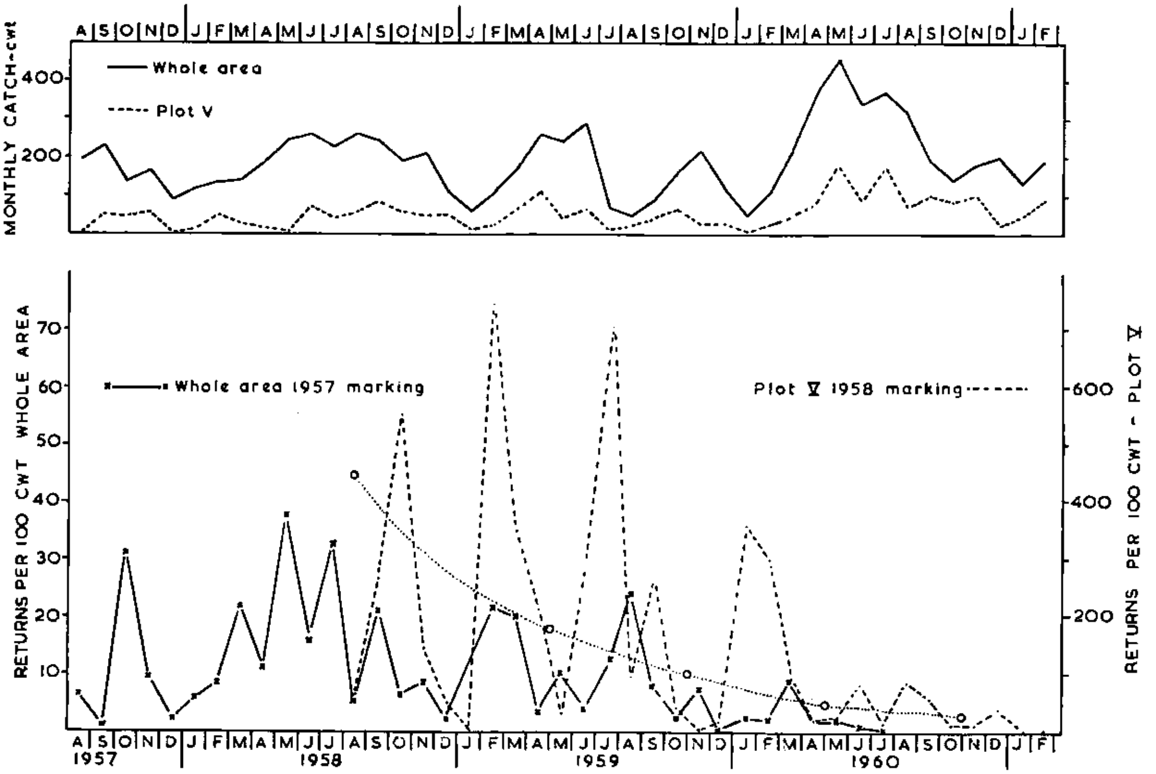


Figure 2. Monthly returns per 100 cwt of whelks landed following marking in July 1957 (whole area x————x) and July 1958 (plot V.— — — —.) Dotted line o..........o represents the fitted line from data smoothed at six monthly intervals following July 1958 marking (see Fig. 3). Total monthly catches are also shown (above).

are very limited. It has been found experimentally that although whelks are able to crawl at least 10 yards in one day in response to bait, a large proportion of their time may be spent quiescent, sometimes partially buried in bottom deposits. This comparative immobility would have helped to prolong any effects of non-random distribution of marked whelks.

The fluctuations recorded in Figure 2 could also have arisen from a random distribution of marks among a non-randomly distributed unmarked population. An indication of the patchy distribution of whelks in the area was shown by the considerable variation which occured between the catches of pots used to obtain whelks for marking (Table 2). If non-random distribution of the unmarked population was the only cause of the variable results obtained, a correlation between the ratios of returns/catch and the size of the catch each month would be expected. Figure 2 shows, however, that the highest values of the ratio returns/catch did not always occur during months of poor catch and vice versa. Most probably both marked and unmarked animals were non-randomly distributed, though the results obtained may equally have arisen from non-random distribution of effort on randomly distributed marks in a non-random unmarked population.

Table 2

Actual numbers of whelks caught in iron pots baited with fish and crab bait during marking experiments

A. July 1957

Plot	Number of whelks per pot	Mean	Variance
I	21, 12, 27, 29, 58, 20, 6, 6, 4, 4, 11, 22.	18.3	236
II	26, 62, 35, 8, 3, 20.	25.7	453
III	34, 28, 3, 0, 4, 45, 20, 10, 36, 20.	20.0	243
IV	30, 30, 29, 31, 42, 24, 10, 20, 5, 1.	22.2	171
V	120, 94, 90, 39, 48, 21, 37, 76, 35.	62.2	1141
VI	44, 74, 60, 58, 55, 28, 15, 23, 2, 32.	39.1	520
VII	21, 2, 28, 6, 30, 8, 10, 0, 10, 5.	12.0	113
VIII ...	47, 9, 48, 56, 22, 84, 99, 41, 52, 31.	48.9	723
IX	62, 37, 70, 121, 71, 50, 36, 44, 38, 14.	54.3	854

B. July 1958 — plot V only

Whelks from adjacent pots (15 yards apart) in the same string or shank

Shank	Number of whelks per pot	Mean	Variance
1.	1, 31, 49, 49, 88, 70, 28, 118, 2, 56.	49.2	1339
2.	8, 29, 38, 50, 39, 25, 35, 12, 48, 18, 51.	32.1	227
3.	120, 136, 85, 25, 123, 126, 33, 42, 70, 80, 72, 61.	81.1	1447
4.	48, 58, 51, 72.	57.3	114
5.	190, 111, 166, 79.	136.5	2563
6.	55, 42, 47, 14, 95, 83, 34, 55, 33, 9.	46.7	739
7.	21, 54, 60, 25, 43, 26, 16, 43, 47, 31, 6.	33.8	284
8.	69, 53, 55, 87.	66.0	247
9.	87, 65, 78, 91, 70, 50, 55, 41, 32, 36, 17.	56.6	570
10.	16, 22, 60, 50, 78, 56, 62, 26, 78, 78.	52.6	564

2. Effect of non-random distribution of effort

Fishing effort data on the number of pots used by each fisherman and the days on which pots were lifted were recorded for each plot separately throughout the experiment. It was therefore possible to make population estimates from each plot separately, and thus to reduce to some extent errors arising from non-random distribution of effort between plots. The usual method of fishing is for the pots to be lifted daily in one locality until catches become uneconomical, after which pots are moved to another position in the same or a different plot. The distance moved may be quite large, particularly if it follows knowledge of density obtained from "test" pots or the catches of other boats.

Table 3

Distribution of effort. Number of days fished in each plot by each boat, August 1957—July 1958

PLOT FISHED	BOAT						Total number of days pots lifted in each plot	Mean number of days per boat
	A	B	C	D	E	F		
I	30	5	6	0	0	0	41	7
II	9	80	62	10	0	0	161	27
III	0	31	31	0	0	0	62	10
IV	13	8	10	0	10	8	49	8
V	117	8	56	5	14	0	200	33
VI	52	35	24	0	0	0	111	19
VII	0	14	15	2	36	35	102	17
VIII	9	9	19	65	89	100	291	49
IX	26	0	0	61	25	4	116	19
TOTAL ..	256	190	223	143	174	147	1133	189
OUTSIDE THE PLOTS	0	23	0	21	3	0	47	

Table 3 shows the distribution of effort or days fished in each plot by each of the six boats, and this is obviously non-random, mainly as a result of attempts by the fishermen to fish areas of highest density. This process of "fish searching" must occur in every commercial fishery, so that randomisation of effort is only likely to be achieved if recapturing is done experimentally.

3. Effect of recruitment

The size distributions of year classes of the whelk population appear to overlap markedly and there is so far no way of distinguishing the age of an individual whelk, so that it was not possible to confine marking to certain year classes as suggested by Ricker (1958). In any case the catches landed by fishermen would contain all year classes, which would not be easily separable. In order to calculate population size it is necessary to obtain the best estimate of returns/

catch at the time of marking. The data shown in Figure 2 have been smoothed at 6 monthly intervals (Figure 3), bearing in mind the considerable spatial bias shown in paragraph 1. After transferring to a semi-logarithmic scale (Figure 4) the best line was fitted either by eye (1957 data) or by least squares (1958 data), and by extrapolation the best estimates of the ratio returns/catch at liberation obtained. This was the method used by Parker (1955) to overcome the high rate of dilution of marks caused by recruitment.

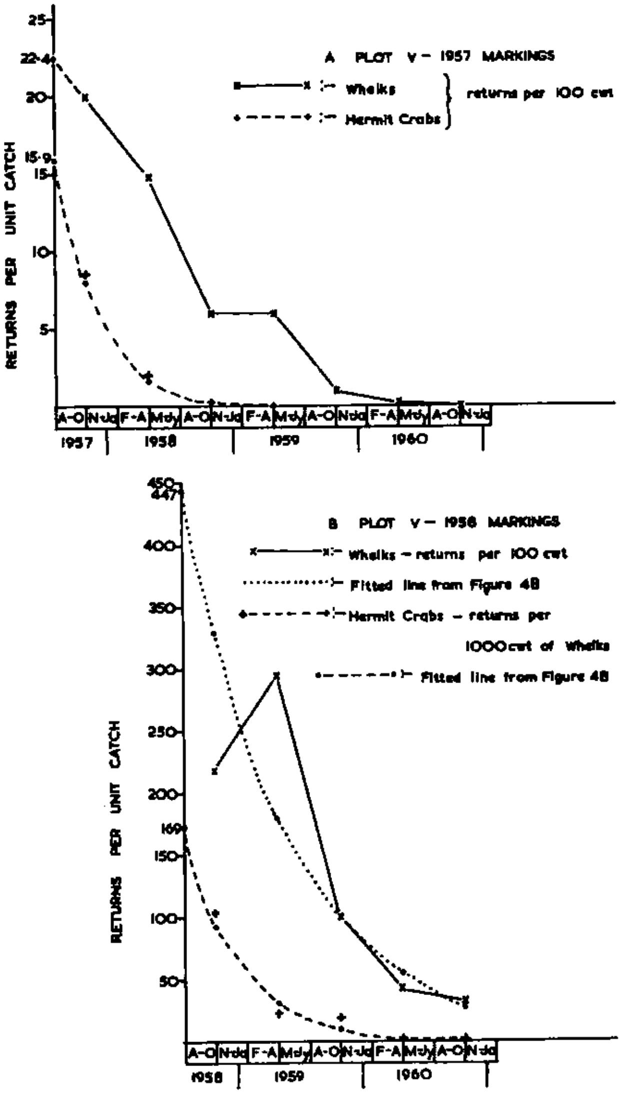


Figure 3. Data shown in Figure 2 have been smoothed at 6 monthly intervals. Broken lines also show returns of hermit crabs landed at 6 monthly intervals. Best fitting lines were obtained by converting the data to a semi-logarithmic scale (Figure 4).

4. Effect of marking

(a) Immediate post-marking mortality

On several occasions in 1957 it was not possible (due to bad weather etc) to return marked whelks to the beds on the day on which they were painted. On these occasions the painted whelks were retained in large wire keep-pots overnight on the bottom. Before relaying they were examined for condition. The results from four such occasions were:—

Total kept overnight	Number dead or nearly so	% mortality
244	12	$\frac{29 \times 100}{1058}$
267	6	
292	5	
255	6	= 3%

The figure of 3% gives an indication of the painted whelks which died within 24 hours of marking in 1957, when allowed to recover while protected from enemies. There is probably a recovery period on the bottom, during which whelks would be particularly susceptible to the attacks of enemies.

(b) Recaptured hermit crabs as a guide to mortality of marked whelks

The numbers of marked shells returned containing hermit crabs decreased with time in a similar manner to the return of marked whelks. Since no figures were available at the same time for catches of unmarked hermit crabs, the ratio of hermit crabs returned to commercial catch of whelks was plotted at 6 monthly intervals (Figure 3) and gave an approximately exponential relationship. By converting to a logarithmic scale and extrapolating (Figure 4), an estimate was made of the expected number of hermit crabs per unit catch of whelks which were present soon after marking, and this could be compared with the number of returns of marked whelks at the same time.

The sharp decline in number of hermit crabs with painted shells suggests that the major part of this mortality occurred soon after marking. In support of this, only 3 (plus 4 other doubtful ones) of the 58 returned shells containing hermit crabs showed any signs of growth, suggesting that most of these whelks had died soon after marking.

The relationship obtained between numbers of painted whelks and numbers of painted shells containing hermit crabs is not necessarily an absolute indication of mortality, because the catchability of whelks and hermit crabs may be quite different due to (a) differential attraction by bait and (b) intrinsic differences in behaviour varying independently throughout the year.

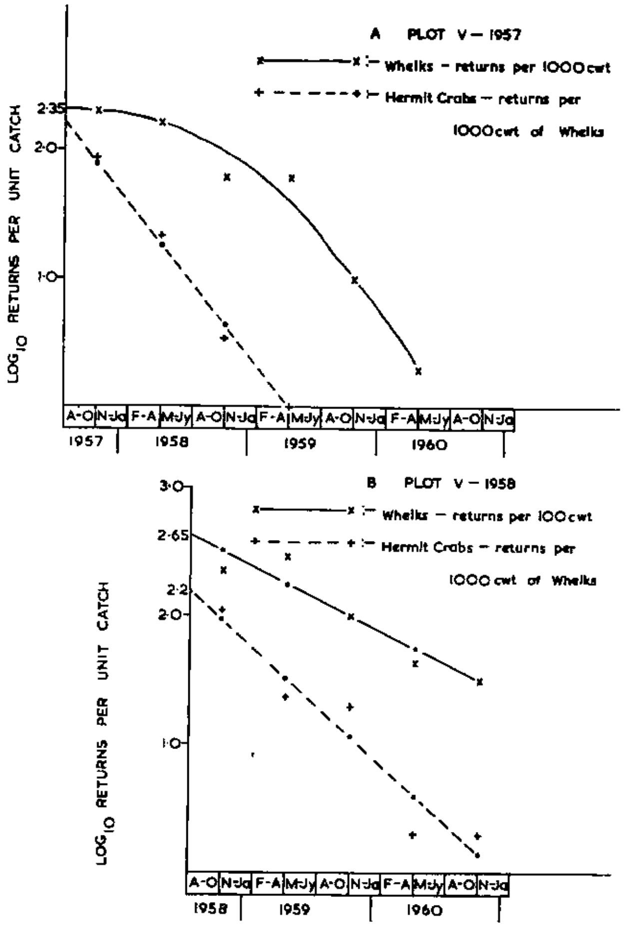


Figure 4. Logarithms of return data shown in Figure 3 plotted at 6 monthly intervals. Best fitting lines were obtained by least squares, except for graph A, whelks, which was fitted by eye.

If it can be assumed that the relative catchability of hermit crabs and whelks remains constant between periods of one year, it should be possible to use the percentage of returned hermit crabs to compare and adjust population estimates from two different marking experiments over the same area. For example in plot V, during the first year after marking in 1957, 22% of the returns were hermit crabs. The corresponding figure after marking in 1958 was 2.8%, suggesting a lower marking mortality. Population estimates from the two experiments calculated using Bailey's (1951) modification of the "Lincoln Index" may now be compared: —

	1957	1958
Number released ...	509	5,140
Catch (cwt)	362	640
Returned whelks ...	67	1,656
Estimate of population (cwt) ...	$\frac{(509+1)\times 362}{(67+1)}$ = 2,715	$\frac{(5,140+1)\times 640}{(1,656+1)}$ = 1,986

	1957	1958
% hermit crabs in returns	22	2.8
Amended figures for releases	509 × 78/100 = 397	5,140 × 97.2/100 = 4,996
New estimate of population (cwt) ...	$=\frac{(397+1)\times 362}{(67+1)}$ = 2,119	$\frac{(4,996+1)\times 640}{(1,656+1)}$ = 1,930
Efforts (pots lifted) .	27,072	46,307
Catch per 100 pots lifted	1.34	1.38

In this calculation, the number of releases in each year has been corrected as if the percentage hermit crabs was proportional to mortality of released whelks,

$$\text{i. e.}\quad \frac{\text{Returned hermit crabs}}{\text{Total returns}} = \text{some constant x}$$

mortality, where the constant will include relative catchability of hermit crabs and whelks, and the fraction of dead shells occupied by hermit crabs, and has been assumed to be constant from year to year. After correction the population estimates were found to give better agreement; they would be expected to be similar, since the figures of catch per unit effort in the two years were practically identical. When the corrected estimates obtained in Figure 3, of numbers of whelks and hermit crabs recaptured at the time of marking, were treated in the same way, similar agreement was obtained between population estimates of two years. It should also be possible to use the percentage of hermit crabs in the recaptures in each plot as a guide to marking mortality, and to make corrections to the estimates of population size in each plot.

5. Effect of loss of marks

The mark used here was a coat of paint, so that loss might have occurred either from (a) inefficient application, or (b) abrasion, caused either by burying movements of the whelk or movement of the substratum. Either would probably result in only partial loss of paint, which might increase the chance of their being overlooked by fishermen. This is not believed to be a serious problem, because in most cases the paint was still bright and in good condition on whelks recaptured even after 3 years.

6. Effect of incomplete recovery of marks

Here the fault may be either with the mark or with the observer. The paints used for marking in these experiments were all of bright colours chosen to avoid confusion with unpainted whelks, i.e. not brown (the natural colour of the whelk) or white (colour of encrusting barnacles). The only colour used which might have been confused was black, because it was subsequently found that many whelks have black deposits on the shell, but in the plot in which whelks were painted black (plot IV, 1957) the ratio of returns/catch was in fact higher than in any other.

To compare the efficiency of the fishermen, their returns have been reduced to unit effort (Figure 5) — individual catch data were not available. It was found that the returns by one fisherman were consistently above average, and those of another consistently below average. The returns of a fisherman known to be keenly interested in the experiment were often below average. Considering the uneven distribution of marked and unmarked whelks on the botom, and unless there was direct evidence to suggest otherwise, there was no reason why most of these variations in return rate by individual fishermen could not have occurred by chance. It is proposed to make corrections only for the fisherman with returns consistently below average, because he had been suspected of having less interest in the experiment than the others. Very few whelks were returned in response to the letter asking buyers of whelks to return any painted whelks overlooked by fishermen.

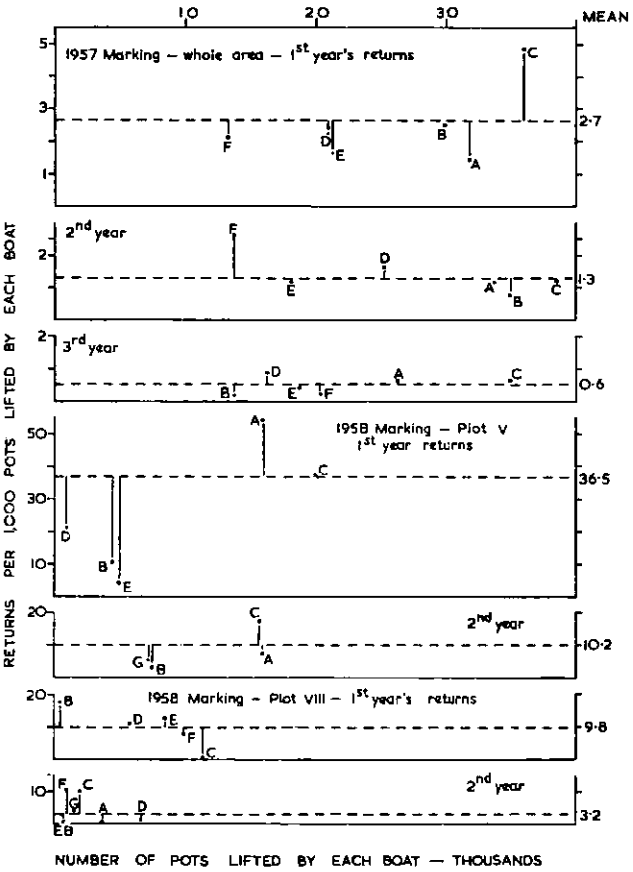


Figure 5. *Efficiency of recovery by individual boats:* — mean returns per 1,000 pots lifted, showing relationship of returns by each boat (A—G) to mean figure, for whole area (during 3 years after 1957 marking) and plots V and VIII (2 years following 1958 marking).

7. Effect of unequal vulnerability of fish of different sizes

Whelks for marking were caught by the same methods and the same bait as used by the fishermen who subsequently recaptured them. Generally few whelks of less than 40 mm shell length were painted, so that there was no problem of selection by gear. A factor which may be important when recapturing by baited pots is differential behaviour by animals of different sizes. For example, during the breeding season mature and immature animals may have different rates of feeding, and also it seems most likely that whelks, as with other invertebrates, will have a feeding rate varying with age and growth rate. Thorson (1960) suggested that young stages of invertebrate predators are extremely voracious, but the food uptake of adults may be much less.

Use of Catch/Effort Data

As a first approximation $C/f = qN$ where C = catch, f = effort, q = catchability, N = number of fish in stock, and $F = qf$ where F = fishing mortality coefficient (Beverton and Holt, 1957), so that if reliable estimates of catch per unit effort can be obtained from year to year, they can be used to compare annual levels of stock, and to confirm the validity of population estimates obtained from return data. Certain relationships such as the ratio Returns/catch and Returns/effort are commonly used in analysis of return data, so that it is important to know how catch and effort may vary with each other in time, and to obtain a correct interpretation of the unit of effective effort. In the whelk fishery factors affecting the relationship between catch and effort include: —

1. Influence of bad fishing weather

The normal routine is for fishermen to lift their pots daily unless prevented by bad weather, or in exceptional circumstances, as after unusually high catches in May 1960, when there is a poor demand for whelks. As a result pots may sometimes be left down for more than one day, and it is important to know how this affects effort and catch. One obvious problem is that of gear saturation, which may occur in any fishery employing baited pots, but since this may also occur when pots remain on the bottom for only one day, gear saturation will be considered separately. One fisherman, using a constant number of 125 pots throughout the year, recorded his daily catches which could be related to the number of days during which his pots remained untended. Since it has been established that catch per unit effort varies throughout the year (Figure 7), records of catches related to days the pots were left untended were averaged over periods of one month, and the mean of these calculated after one year. The results (Figure 6A) showed that on average there was little change between catches of pots lifted after one day, and those left on the bottom for longer periods even up to 7 days. Similar results were obtained experimentally and it was concluded that although whelks may continue to enter pots after one day, their number is roughly balanced by those which escape. The unit of effective effort thus approximates to the number of days on which pots are lifted.

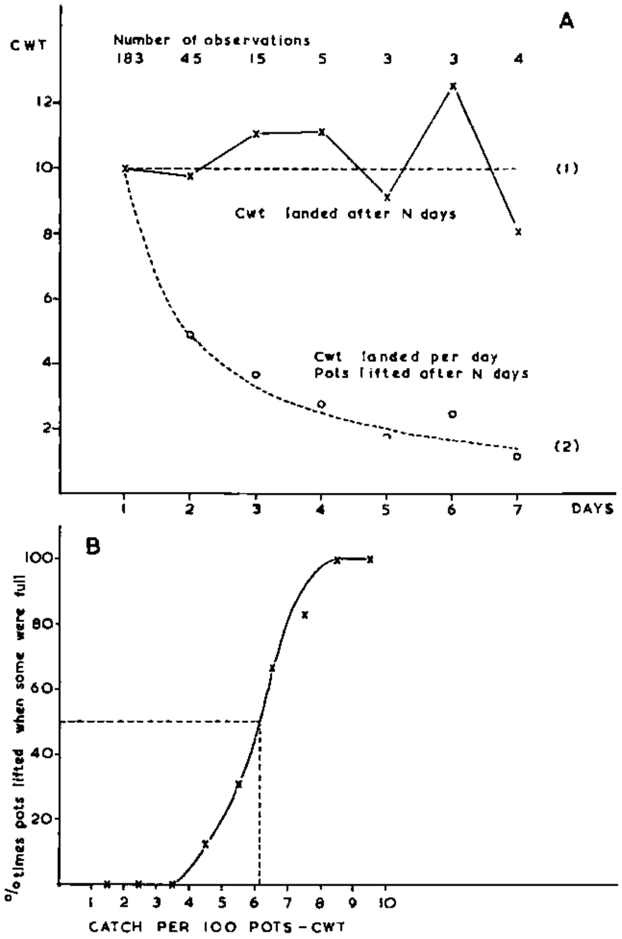


Figure 6.

A. *Effective effort:* — mean numbers of cwt landed after pots left untended for varying periods, related to a figure of 10 cwt landed after one day. (1) actual landings, (2) landings divided by number of days left untended, i.e. landings per day. Broken lines show the result expected from a catch of 10 cwt, which did not change after one day.

B. *Gear Saturation:* — percentage of times pots were lifted when some of the pots were full, at various levels of catch.

2. Gear saturation

Baited pots may, under favourable conditions, attract sufficient whelks to fill a pot completely and prevent the entry of others. Animals competing for bait e. g. starfish, shore crabs, hermit crabs etc. may help to fill the pots and prevent the entry of some of the whelks attracted to the pot. Either of these occurences represents "saturation" of the gear and will result in an underestimate of the potential catch per unit effort. In addition to supplying records of catch related to fishing time, the above-mentioned fisherman also noted the days on which any of his 125 pots were full. In Figure 6B the daily catches of his pots (only those lifted after one day have been included) have been analysed and at each level of catch, i. e. cwt per 100 pots, the percentage of occasions on which some pots were full has been related to the volume of the catch. It can be seen that with total catches up to and including 3 cwt per 100 pots, no pots were full, and with catches of 8 cwt per 100 pots and more some of the pots were always full. The 50% level of gear saturation i.e. the level of catch at which some pots were full on 50% of the occasions was 6 cwt per 100 pots. The records of the same fisherman showed that gear saturation occurred throughout May, June and July 1960, so that catch per unit effort figures during these monthsare underestimated. It might be assumed that gear saturation is of greater importance when pots are not lifted every day, but the interchange of whelks would probably balance this out. The frequency with which pots are left down for more than one day is in any case greatest during bad weather, and during the winter months catches are generally below average, so that gear saturation is less likely to be of importance then.

3. Seasonal relationship between catch and effort

Figure 7 shows the seasonal pattern of catch per 100 pots for the whole fishery. Generally the ratio is highest in spring and early summer, and lower in winter and high summer — this was particularly noticeable during the hot dry summer of 1959. There seems to be a good correlation between catch per unit effort and temperature, the largest catches being obtained in April/May of each year when surface temperatures are 12—14° C, with a general reduction in catch in both winter and summer (Figure 8) — anomalies which usually occurred in October each year are believed to be associated with the onset of the breeding season. In laboratory experiments, the feeding rate of whelks was lowest in summer and

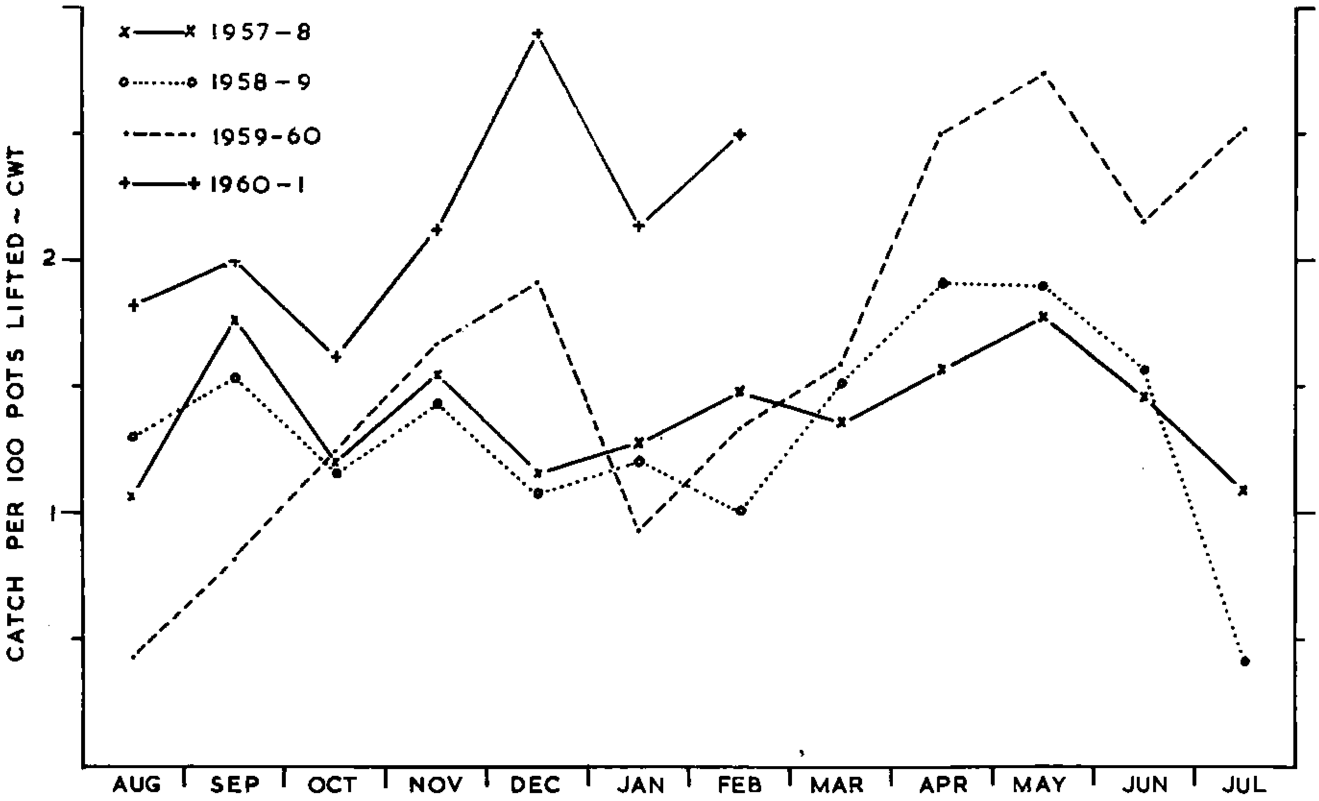


Figure 7. Monthly catch per unit of effort at Whitstable, August 1957—February 1961.

greatest during spring — this behaviour, too, was presumably related to temperature, and would affect the degree of attraction by bait. The influence of growing seasons, i. e. periods of rapid growth which would lead to heavy seasonal recruitment, on the pattern of catch per unit effort must also not be overlooked. It was important to understand the pattern of seasonal changes in the catch/effort relationship, because monthly catch statistics were available only as totals for the whole area, though effort data were available for each plot. It was necessary, therefore, to calculate the annual catch in each plot by subdividing the monthly catch from the whole area in proportion to the monthly effort in each plot. If the total annual catch had been apportioned according to annual effort in each plot, a biased result would have been obtained.

4. Bait

Experiments with different baits have shown that catches may be greatly influenced by the type of bait used. The following table gives a summary of the results: —

Average catch per pot using pots baited with: —

	Fish (salted skate)	Crab (Dead shore crab)	Fish and Crab
Whelks	10.2	22.5	33.8
Live shore crabs	3.6	0.7	1.4
Hermit crabs ..	1.1	1.8	0.8
Starfish	2.4	2.4	1.7

It was previously not understood why two kinds of bait, fish and crab, are normally used in the same pot by fishermen, but the results showed that the combined bait catches more whelks than either bait used separately. It can be seen that fish and crab baits are separately attractive to whelks. Dead crab bait does not attract live crabs, but fish bait is highly attractive to crabs. The presence of live crabs in the fish baited pots seems to act as a deterrent to the entry of whelks. The two baits used together, therefore, combine their attraction to whelks, but the inclusion of the dead crab reduces the entry of live crabs into the pots. The variable catching power of pots using different baits is of importance if any radical changes should occur in the type of bait used by fishermen, possibly as a result of availability. A shortage of the conventional types of bait might cause a change in bait habits, and in consequence in effective effort per pot, and should be considered when analysing data. It is also important to specify the type of bait when using a whelk pot as a sampling instrument (Table 2).

5. Presence of competing organisms in pots

There is a suggestion that the effective catch of whelks may be lowered by the deterrent effect of the presence of animals, e. g. crabs, competing for bait in the pots. Shore crabs (*Carcinus*), and particularly edible crabs (*Cancer*), also attack and break open whelks in pots, so that a great increase in the crab population may reduce the effective catch from either cause. The presence of these animals, and of starfish and hermit crabs, may therefore lower the catch by (a) consuming and reducing the effectiveness of bait, (b) partly filling the pots and (c) possible deterrent effects.

Other points worth noting are: —

6. Competition between bait and available natural food

on the bottom, which may vary from year to year.

7. Competition from the pots of other fishermen,

when pots are fished close together by several boats. This may be most pronounced in years when distribution of whelks is localised or patchy.

8. Design of pots

Normally, iron framed pots are used at Whitstable. Pots adapted from baskets, used elsewhere, have been found not to be as efficient there as the iron pots.

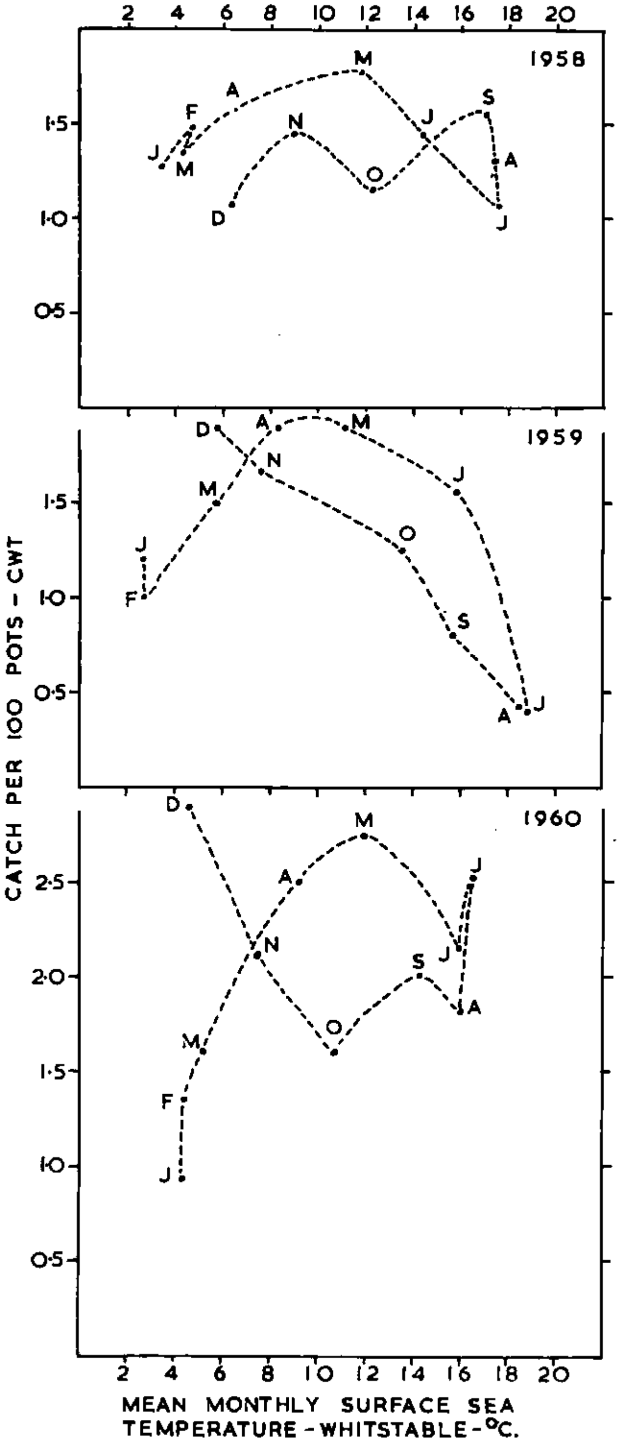


Figure 8. Catch per unit effort related to mean surface sea temperatures at Whitstable each month.

Estimation of Growth from Recaptures

Data from recaptures have not yet been fully analysed, but Figure 9 will give an idea of their potentialities. Shell length data from recaptures have been grouped at monthly intervals, and a series of Walford lines obtained by plotting length at recapture (L_t) against length at release (L_0). This method was used by Manzer and Taylor (1947). Using data from a month with a large number of recaptures (June 1959), separate plots were made for males and females, and the regression lines obtained were practically coincident, suggesting that it is permissible to combine data for the two sexes. This was found to be of particular value for months in which recaptures were fewer in number. The whelks under observation were released in July 1958, so that regression lines for recaptures in July 1959 and July 1960 can be used

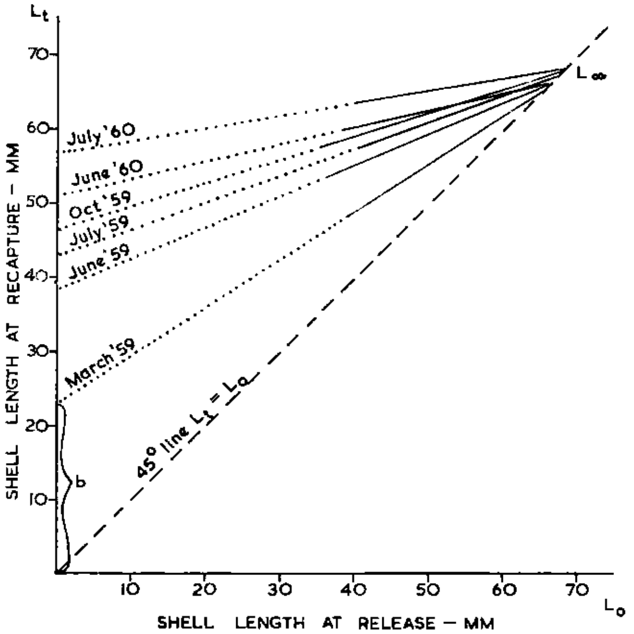


Figure 9. Walford lines from regression of data from plot V recaptures grouped at monthly periods after release. The solid part of each line shows the length range covered by the data.

to obtain annual and biennial increments for each size group. Regression lines obtained from recaptures in intervening months can be used (a) to confirm the validity of the July results and (b) to show the seasonal pattern of growth. Each Walford line can be used to give a separate estimate of the asymptotic length L_∞ and in accordance with von Bertalanffy's growth equation the slopes of lines obtained for July 1958 and July 1959 will give separate estimates of K, the coefficient of catabolism (Slope = e^{-Kt}, Table 4).

Values of Kt calculated from each line are shown in Table 4; these represent, in some way, the effective growth between release and recapture. It is clear that this is not proportional to the time interval, growth being greatest during the summer. This presumably results from the seasonal effects of temperature on K. It is only valid, therefore, to calculate the mean value of K, which is the value normally required in population analysis from data at yearly intervals. In addition to the values of K calculated at one year after marking, i. e. July 1959 and 1960, it is possible to relate Walford lines obtained in the same months of 2 successive years to obtain estimates of annual growth. As an example of this, data obtained in February 1959 and February 1960 are examined in the following table: —

Length at release mm	Length at recapture Feb. 1959 (L_t)	Length at recapture Feb. 1960 (L_{t+1})
20	29.0	52.0
30	37.0	54.5
40	45.0	57.5
50	53.5	60.5

The plot of L_{t+1} (Feb. 1960) against L_t (Feb. 1959) gives a straight line, and K can be calculated graphically from its slope (= e^{-Kt}) or its intercept (b) on the y axis (= $L_\infty (1 - e^{-Kt})$). The value obtained was $K = 0.92$, which compared reasonably well with the figure of 1.02 obtained for the period July 1958 — July 1959 (Table 4).

Summary

1. Marking experiments on the Whitstable whelk fishery in 1957 and 1958 were of the single census (Petersen) type with recaptures during several years.

2. Sources of error arising during analysis of recapture data have been discussed, in particular the effects of non-random distribution of marked

Table 4

Parameters of von Bertalanffy's growth equation calculated by regression of recapture data on growth at varying intervals after release (see Figure 9)

Date	b Intercept on Y axis	L_∞ Asymptotic length	e^{-Kt} Slope of regression	Kt	t Period of growth in years following release	K Coefficient of catabolism
February 1959	12.3	68.3	0.82	0.20	7/12	0.34
March 1959	22.9	64.7	0.65	0.43	8/12	0.65
June 1959	38.5	66.3	0.42	0.87	11/12	0.95
July 1959	42.9	67.1	0.36	1.02	12/12	1.02
October 1959	46.4	68.2	0.32	1.14	15/12	0.91
February 1960	46.0	64.8	0.29	1.24	19/12	0.78
March 1960	41.2	68.7	0.40	0.92	20/12	0.55
June 1960	51.1	66.4	0.23	1.47	23/12	0.77
July 1960	56.9	68.6	0.17	1.77	24/12	0.89

and unmarked population and of effort. An attempt was made to estimate and allow for the effects of recruitment and post-marking mortality.

3. Factors affecting the catch/effort relationship included the period of time the pots remained on the bottom, gear saturation, seasonal variation and the type of bait used.

4. Growth data from recaptures have been used to construct Walford lines, and to obtain estimates of growth parameters.

References

BAILEY, N. T. J. 1951. On estimating the size of mobile populations from recapture data. *Biometrika*, **38**: 293—306.

BEVERTON, R. J. H. & HOLT, S. J. 1957. On the dynamics of exploited fish populations. *Fish. Invest., Lond.*, Ser. 2, **19**.

HANCOCK, D. A. & URQUHART, A. E. 1959. Methods for marking whelks (*Buccinum undatum* L.). *J. Cons. int. Explor. Mer*, **24**: 494—96.

MANZER, J. I. & TAYLOR, F. H. C. 1947. The rate of growth in lemon sole in the Strait of Georgia. *Fish. Res. Bd Can., Progr. Rep. Pacif. Cst. Stas. Nanaimo & Vancouver*, No. 72: 24—27.

PARKER, R. A. 1955. A method for removing the effect of recruitment on Petersen type population estimates. *J. Fish. Res. Bd Can.*, **12**: 447—50.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd Can.*, No. 119.

THORSON, G. 1958. Parallel level-bottom communities, their temperature adaptation, and their "balance" between predators and food animals. *Perspectives in Marine Biology* edited by A. A. Buzzati-Traverso, 67—86. Univ. Calif. Press in Berkeley and Los Angeles.

29.

Marking Crabs and Lobsters for Mortality and Growth Studies

By

A. C. SIMPSON*

1. Introduction

The increased exploitation of crabs, lobsters and spiny lobsters in many parts of the world is requiring the investigation of the population dynamics of these crustacea, and it is to be expected that the principles and methods being worked out for fish will, to a large extent, be applicable. Tagging is an important tool in these investigations, but owing to the habit of growth by moulting, when all hard parts are lost, there are special problems in the use of external tags. The absence of any method for age determination for crustacea also increases the importance of marking for growth studies.

This paper aims at reviewing the methods being developed for marking crabs and lobsters, and discusses their use in the determination of mortality rates and growth rates.

Population studies with crustacea are in their infancy and there is a risk of methods developed for fish studies being applied to crustacea without adequate knowledge of the biology and behaviour of the species. A plea is therefore made for parallel critical studies of such features as spawning times, moulting times, movements and catchability, so that the use of mathematical models and the calculations of optimum minimum sizes and the appropriate fishing effort to obtain the maximum steady yields can be based on sound premises.

2. Types of Tag

It would be most useful if tags could be developed for crabs and lobsters which persist through moults, do negligible damage to the animal and are readily seen. However, with the possible exception of the tag used on the king crab (*Paralithodes camtschatica*) and described by Hayes (This symposium, No. 42), this has not as yet been achieved and two distinct groups of tag have been developed for different purposes. The first group (see A below) are used for fishing mortality estimations, in which it is important that the tags are not easily lost during the intermoult period and that they are readily seen and returned to the investigators when the animals bearing them are recaptured. The second group (see B below) are used for growth studies, in which the important feature is that they must be retained through the moult without impairing growth, it being not essential that a known or high proportion are recovered.

A. External tags that are lost during moulting

A considerable variety of tags have been used to mark crabs and lobsters for movement and mortality studies. Where the carapace bears well-developed lateral spines, as with the blue crab (*Callinectes sapidus*) of Maryland and Virginia, U.S.A., a brightly coloured plastic strip lying across the carapace and attached by stainless steel wire to the two lateral spines has proved very suitable (Cronin, 1949). These tags are readily seen, easily attached and can do no damage to the crabs (Fig. 1A).

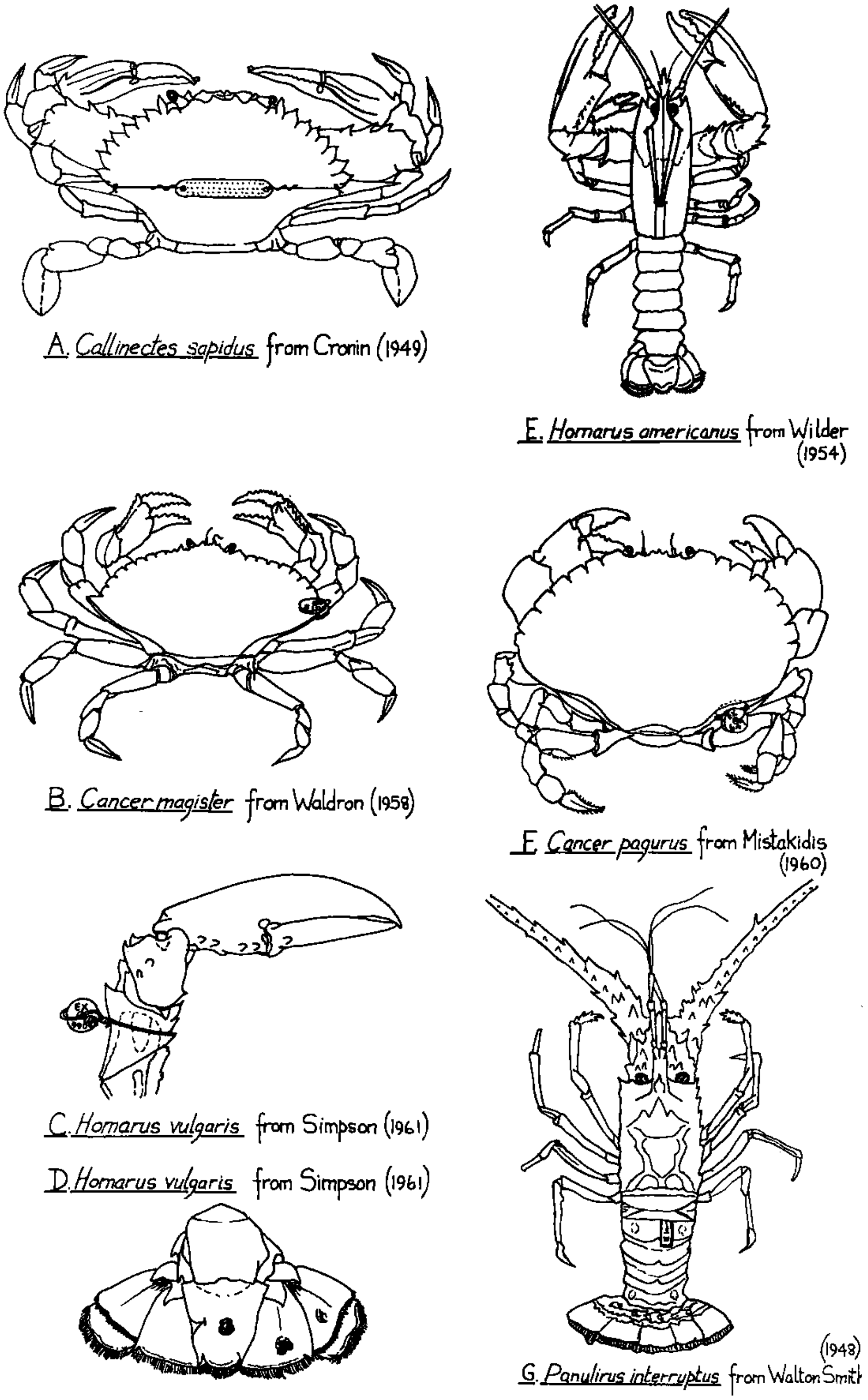
For the Dungeness crab (*Cancer magister*) on the Pacific coast of the U.S.A. (Waldron, 1958) and the horseshoe crab (*Limulus polyphemus*) on the Atlantic coast (Baptist, 1957), where there are no comparable large spines but lateral extensions of the carapace, Petersen type tags have been used, attached with wire through a hole in this extension (Fig. 1B). As the hole, made with an awl, may pass through soft parts there is a risk of some damage and therefore of death. Cronin (1949) has also used this method on *Callinectes sapidus*, with the wire passing through the base of the spines, but he obtained better returns from the tags fixed across the carapace between the spines.

The European edible crab (*Cancer pagurus*) does not lend itself to either of these methods. Williamson (1900) and Mistakidis (1960) have used metal and plastic Petersen type tags attached to the fourth segment of the cheliped. Tank experiments show that there is no interference with movement, provided that care is taken to attach the tag so that it stands away from the body, and that the wire, though firmly attached, is not tightened onto the soft parts between the segments of the limb.

Two kinds of external tag have been successfully used with lobsters (*Homarus vulgaris* and *H. americanus*). The first is a metal or plastic disc attached by wire to the second segment of the cheliped (Fig. 1C). This method has been used extensively by Wilder (1947, 1953) in Canada, by Thomas (1955) in Scotland and by Simpson (1961) in Wales; it is simple and quick to do, and appears to have wide application among the larger crustacea. An objection to this method is that crustacea so marked may shed the limb carrying the tag. There is little evidence of this, but it can be tested by attaching two tags on different limbs, determining the proportion recaptured which has

---

* Fisheries Laboratory, Burnham-on-Crouch, Essex, England.



A. *Callinectes sapidus* from Cronin (1949)

E. *Homarus americanus* from Wilder (1954)

B. *Cancer magister* from Waldron (1958)

F. *Cancer pagurus* from Mistakidis (1960)

C. *Homarus vulgaris* from Simpson (1961)

D. *Homarus vulgaris* from Simpson (1961)

G. *Panulirus interruptus* from Walton Smith (1948)

Figure 1. Tags used on crustacea.

lost a tagged limb and comparing this with the incidence of lost limbs in the population.

The second method for lobsters, used in Canadian investigations (Wilder, 1954), makes use of a numbered metal strip bent over at one end to form a hook which is hooked over the posterior margin of the carapace and kept in position along the mid-line of the carapace by an elastic band attached to the other end of the strip and passed over the rostrum. This type of tag is easy to attach and has proved very successful (Fig. 1E).

Edwards (1958), in a carefully designed experiment to study local movements of the crab (*Carcinus maenas*) in the intertidal zone, marked the crabs by cutting off with scissors one or more of the short spines which occur along the front edge of the carapace. There are ten spines, and by removing different spines the crabs could be allocated to one of a number of groups. This method did not damage the soft parts of the crabs and was quite successful, but is necessarily limited to experiments in which all the recaptures are made by trained observers.

B. Marks and tags that persist through the moult

To study the growth of crustacea in the field, it is necessary to determine the increase in size on moulting (moult increment) and the moult frequency. To determine the moult increment it is usually necessary to use a tag or a mark that persists and is recognisable after a moult. It should have the minimum effect on the growth and can afford to be less easily seen than the tags described above, as deductions are not affected if even a substantial proportion of the tagged individuals recaptured are not returned.

Dannevig (1936), following Appellof (1909), punched holes of $^1/_8$ inch diameter through different parts of the tail fan of lobsters, according to a code that gave the length of the lobsters at the time of marking (Fig. 1D). This method has also been used successfully by Wilder (1953), Thomas (1958) and Simpson (1961). The holes were punched with a standard paper or leather punch. There is a tendency for the flesh from round the hole to fill it, with the result that the new shell after moulting covers the hole. The resulting scar is not so readily seen as the hole which persists if the surrounding flesh heals without filling it. It is possible that the filling of the holes with a wax or similar substance immediately after they have been punched would help the healing and keep the hole open. As a hole through the telson is more easily seen than one through the lateral uropods, it is advisable to punch the telson of all punched lobsters and to form the code by the position of this hole and by extra ones punched through the uropods.

Smith (1948) and Lindberg (1955), working with the spiny lobsters *Panulirus argus* and *P. interruptus* respectively, have used barbed plastic strips ($1^1/_2$—2 inches long) bearing numbers and instructions, which were inserted between the second and third abdominal segments, and to one side of the mid-dorsal line in order to miss the gut (Fig. 1G). Lindberg reports that some 5 percent of these tags were lost during the first 48 hours after insertion, but the remaining 95 percent apparently retained their positions well. It was found that there was a tendency for a chitinous sheath to be laid down round the barb, so that a proportion of the tags which had been in position for several months before a moult were lost with the sheath during the moult.

Von Bonde (1928) and Bradstock (1950) studying *Jasus lalandii* in South Africa and New Zealand waters respectively used two tags, one an arrow-headed plastic strip, the other a stainless steel wire carrying a numbered disc on one end and bent into a hook at the other end. These tags were inserted in the same position as the barbed strips used by Smith and Lindberg.

There are very few published data on moult increments from spiny lobsters carrying these abdominal tags, and therefore it is not yet possible to assess their suitability for this purpose.

Following a method originally devised by Van Engel, Butler (1957) has marked *Cancer magister* with a suture tag in which a numbered plastic disc is attached by means of a stainless steel wire along the line of separation of the carapace during ecdysis. Two holes are made through the shell on this line, and by using a curved suture needle the wire is threaded through the shell and the underlying tissue and back again to the outside for the attachment of the numbered disc. Mistakidis (1960) has used the same method on *Cancer pagurus* on the North Sea coast of England (Fig. 1F). Both investigators have had promising results.

3. Fishing Mortality Estimates

It would be attractive in determining fishing mortality rates if one of the kinds of tag that persists through moulting could be used, as this would allow the recapture data to be used over the twelve or more months, irrespective of moulting. However, the small numbers of returns that have been obtained from experiments using the barbed abdominal tags, and in some cases with the suture tags, suggest either substantial losses of these tags or a high marking mortality. There is also no doubt that a considerable proportion of lobsters marked by tail punching are not recognised when recaptured. Thus these types of marking are not the most suitable for mortality estimates.

On the other hand, the external tags need do no damage to the crustacea to which they are attached, and tagging mortality can thus be reduced to a minimum. Use of these tags for mortality estimates is, however, restricted to the intermoult period and does therefore require a sound knowledge of the time of moulting, which may vary with the size of the animal and in many species differs between the sexes. This method also has the advantage that the experiment can be done at a time when there is no recruitment by growth into the fishable stock.

Where the fishing season is limited to a short period within the intermoult period, as with the lobster fishery in certain parts of Canada, the fishing mortality can readily be estimated by releasing lobsters carrying external tags immediately prior to the season, and obtaining the percentage recaptured during the season. Wilder (1947) used this method in 1943/46, and from a number of releases of about 1,000 each, obtained figures of between 40 percent and 70 percent for the fishing mortality in different areas.

However, where fishing continues all the year or at least over a moulting period, the estimation of fishing mortality will require to be of the kind in which an intense tagging experiment is done in the intermoult period to determine the size of the stock, while catch statistics are used to give the proportion of this stock that is removed by fishing per annum. For instance, if 900 tagged crabs were released shortly after moulting was complete, and if they were recaptured at a mean rate of 4.5 per 1,000 crabs landed from the area covered by the tagging, then the stock at the time of the liberation will have been $\frac{900 \times 1{,}000}{4.5}$ or 200,000. If the total landings from the area during a 12-month period were 55,000, then the fishing mortality will have been $\frac{55{,}000 \times 100}{200{,}000}$ or 27.5 percent. This method requires reliable catch statistics.

This was the type of observations and calculation made by Thomas (1955) during his investigations into the stock of lobsters on the southeast coast of Scotland, in which he calculated the fishing mortality to be 51 percent in 1950/51 and 47 percent in 1951/52.

As there is little migration with most lobsters and crabs, recruitment to the fishable stock is primarily by growth. Since growth occurs only at moulting, the fishable stock will rise following the moulting time and fall (due to fishing and natural mortality) during the intermoult period. Thus calculations of fishing mortality based on estimating the stock at the start of the intermoult period will be underestimates, since the figure for the stock will be the maximum and not the average.

Errors in mortality estimates due to the unevenness of distribution of the tagged individuals through the stock and the unevenness of fishing on the stock are a particular problem with crustacea. If either of these approaches a random distribution the other can be non-random. Where the fishing is typically centred on the areas of higher density of animals, or close to the home port, as occurs for lobsters in many parts of the British Isles, it is necessary to spread the tagged individuals as evenly through the stock as possible in a large number of small batches. However, the relative abundance of the stock over the fished area is often not known and therefore the tagged individuals are spread as evenly as practicable over the area covered by the fleet as a whole. In many cases this is probably the best method available, but it will tend to give an overestimate of the size of the stock (and therefore an underestimate of fishing mortality), because the fishing will tend to be concentrated where the stock is densest and will consequently have a below average concentration of tagged individuals.

In a tagging experiment with the lobster (*Homarus vulgaris*) on the Welsh coast (Simpson, 1961), when the returns of tagged males per 1,000 lobsters landed by commercial boats were plotted against time the graph shown in Fig. 2 was obtained. As the experiment was done when no males were moulting, the frequency of tagged individuals in the commercial catches should have remained constant. The temporary slight rise in the frequency at first and subsequent steady fall showed that the tagged individuals were probably not evenly distributed through the fished stock, and that after week 4 the fishing boats were probably moving increasingly onto grounds which had high densities of lobsters but which had been under-supplied with tagged individuals. Dilution of the tagged individuals in the stock due to immigration of lobsters into the area from outside is possible,

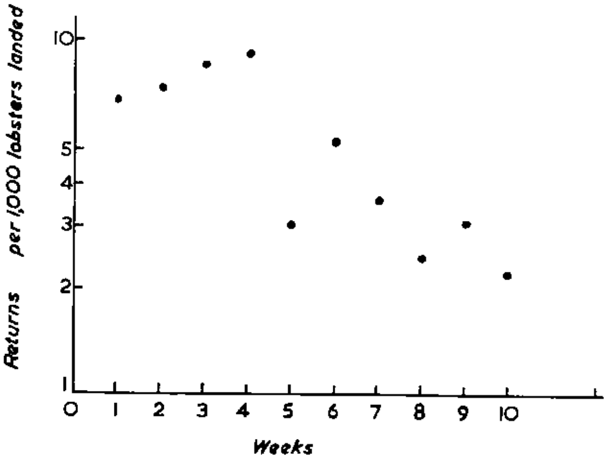


Figure 2. Proportion of tagged male lobsters in commercial catches, plotted against time since tagging.

but the evidence did not support this interpretation. A similar dilution of the tags in the commercial landings was found in a comparable experiment with crabs on the east coast of England (Mistakidis, pers. com.).

In his study of the mortality of lobsters off southeast Scotland, in order to avoid loss of tags by moulting and to obviate creel selectivity, Thomas (1955) used primarily non-berried females between $10^{1}/_{2}$ and $11^{1}/_{2}$ inches overall length. This probably had the desired effect, but, as stated by Thomas, necessitated the assumption that the fishing on this limited section of the stock was the same as the mean for the whole stock, which may not have been correct.

4. Growth Estimates

The growth rate in crustacea is a function of the increase in size on moulting (moult increment) and the frequency of moulting. As little is known on whether the one or the other is the more important in determining differences in growth rate between areas, a considerable amount of work on growth increments and moult frequencies is necessary before growth data can be used with confidence in population calculations.

A. Moult increment

Since most marks which persist through a moult cause some damage to the soft parts, it is possible that irritation will interfere with the normal pattern of life and reduce either the moult increment or moult frequency, and the degree of this reduction will need to be determined. In recent experiments with the crab *Cancer pagurus* Mistakidis (pers. com.) kept a number of measured crabs in concrete tanks and marked them all with an external numbered tag. About half were also marked with the suture tag. There was practically no difference between the increase in carapace width on moulting of crabs of the same size but marked with the suture tag compared with those carrying the external tag only. However these results need confirmation.

Data on growth from tank or aquarium experiments cannot be used to replace direct determinations of the growth rates of animals in specific areas, but tank experiments are useful in preliminary investigations and to test the effect of marking methods on the moult increment, etc. A method which is intermediate between field and tank observations is that used by MacKay and Weymouth (1935) in which the growth increment was determined by keeping in captivity crabs that were about to moult; they found that while the increments were less than under natural conditions for the smaller crabs, there was little difference between the increments of the larger ones. This method probably has wide application if the results from only those individuals that moult within a few days of capture are used, and if the holding conditions are very good.

It is to be anticipated that the growth of crustacea, like fish, is asymptotic; however the limited data available so far show that at least in some species the moult increment continues to increase with the size of the animal. For instance when the data available for the moult increment of lobsters on the Welsh coast are plotted against length (Fig. 3) it is seen that over the range of lengths available the increment in carapace length in mm is still increasing with the size of the lobster for males, though it is decreasing slightly for females. Similar results were found by MacKay and Weymouth (1935) for the Pacific edible crab (*Cancer magister*). It would therefore appear that a reduction in the frequency of moulting with age may prove the main factor in determining the growth rate and the asymptotic size.

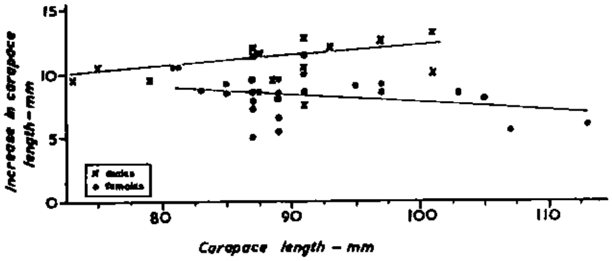


Figure 3. Increment of carapace length at moulting of Welsh lobsters, plotted against initial length.

B. Moult frequency

It is generally accepted that as an approximation the European and American lobsters moult more than once per year until sexual maturity, after which the male moults annually and the female every second year (Herrick, 1911). At maturity both the males and females of *Cancer pagurus* and *Cancer magister* (MacKay and Weymouth, 1935) are considered to make one moult per year. It would appear that with the spiny lobsters *Panulirus interruptus* of California and *P. argus* of Florida the mature females moult at least once a year (after the eggs have hatched) with possibly a second moult later in the year (Smith, 1948; Lindberg, 1955). Thus there is no common picture, and the moult frequency requires a good deal more attention than it has had so far.

Wilder (1953) used external tags that were lost on moulting to determine the percentage of lobsters of 22—25 cm overall length that failed to moult in a year. He liberated over 1,000 each of males and females at the start of one two-month fishing season, and from the numbers of tagged lobsters recaptured in the following fishing season (12—14 months later) calculated that 23 percent of the males and 32 percent of the females failed to moult. These figures were much higher than anticipated.

The determination of moult frequency of different sizes of the two sexes by tagging methods requires the liberation of very large numbers of individuals, and it would seem worthwhile to try to find other means of establishing it more directly by sampling the population. If a means can be found of establishing even approximately the time that has elapsed since a crab or lobster has last moulted, it should be possible by examining samples at intervals to establish with some precision the proportion of each size group that has moulted within the previous six months, and so build up the moult frequency picture for the whole population. It is probable that the changes in the integument and underlying tissues from one moult to the next will reveal a sequence that can be used for such an investigation.

References

APPELLÖFF, A. 1909. Untersuchungen über den Hummer. *Bergens Mus. Skr.* **1** (1): 1—79.

BAPTIST, J. P. 1957. Migrations of the Horseshoe Crab, *Limulus polyphemus* in Plum Island Sound, Massachusetts. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.*, No. 220.

BRADSTOCK, C. A. 1950. A study of the marine spiny crayfish *Jasus lalandii* (Milne-Edw.) *Zool. Publ. Vict. Univ. N. Z.*, **7**: 1—38.

BUTLER, T. H. 1957. The tagging of the commercial crab in the Queen Charlotte Island region. *Fish. Res. Bd Can., Progr. Rep. Pacif. Cst. Stas. Nanaimo & Vancouver*, No. 109: 16—19.

CRONIN, L. E. 1949. Comparison of methods of tagging the blue crab. *Ecology*, **30**: 390—94.

DANNEVIG, A. 1936. Hummer og hummerkultur. *Fiskeridir. Skr. Havundersok.*, **4**: (12).

EDWARDS, R. L. 1958. Movement of individual members in a population of the shore crab *Carcinus maenas* L. in the littoral zone. *J. Anim. Ecol.*, **27**: 37—45.

HAYES, M. L. 1963. King crab tagging methods in Alaska. *This Symposium*, No. 42.

HERRICK, F. H. 1911. Natural history of the American lobster. *Bull. U. S. Bur. Fish.*, **29**: 149—408.

LINDBERG, R. G. 1955. Growth, population dynamics, and field behaviour in the spiny lobster (*Panulirus interruptus*) (Randall). *Univ. Calif. Publ. Zool.*, **59**: 157—248.

MAC KAY, D. C. G.& WEYMOUTH, F. W. 1935. The growth of the Pacific edible crab *Cancer magister* Dana. *J. biol. Bd Can.* **1**: 191—212.

MISTAKIDIS, M. N. 1960. Movements of the edible crab (*Cancer pagurus*) in English waters. *Paper* No. 88, *Shellfish Committee*, ICES, 1960.

SIMPSON, A. C. 1961. A contribution to the bionomics of the lobster (*Homarus vulgaris*) on the coast of North Wales. *Fish. Invest., Lond.*, Ser. 2, **23**: (7).

WALTON SMITH, F. G. 1948. The spiny lobster industry of the Caribbean and Florida. *Fish. Ser. Caribb. Res. Counc.*, No. **3**: 1—49.

THOMAS, H. G. 1955. Observations of the recaptures of tagged lobsters in Scotland. *Mar. Res. Scot.* 1955, No. 2.

THOMAS, H. G. 1958. Observations on the increase in size at moulting in the lobster (*Homarus vulgaris* M.-Edw.). *J. Mar. biol. Ass. U. K.*, **37**: 603—06.

VON BONDE, C. 1928. Preliminary report on a method of tagging crustacea, with special reference to the problem of migration of the Cape crawfish (*J. lalandii*). *Rep. Fish Mar. biol. Surv. S. Afr.*, **8**, Spec. Rep. 1: 1—4.

WALDRON, K. D. 1958. The fishery and biology of the Dungeness Crab (*Cancer magister*, Dana) in Oregon waters. *Contr. Fish Comm. Oreg.*, No. 24.

WILDER, D. G. 1947. The effect of fishing on lobster populations as determined by tagging experiments. *Fish. Res. Bd Can., Progr. Rep. Atl. Cst. Sta.* No. 37: 10—13.

WILDER, D. G. 1953. The growth rate of the American lobster (*H. americanus*). *J. Fish. Res. Bd Can.*, **10**: 371—412.

WILDER, D. G. 1954. The lobster fishery of the southern Gulf of St. Lawrence. *Circ. Atlant. biol. Sta.*, No. 24.

WILLIAMSON, H. C. 1900. Contributions to the life-history of the edible crab (*Cancer pagurus*, Linn). *Rep. Fish. Bd Scot.*, **18**: 77—143.

30.

Further Field Experiments with Tags for Haddock

By
ALBERT C. JENSEN*

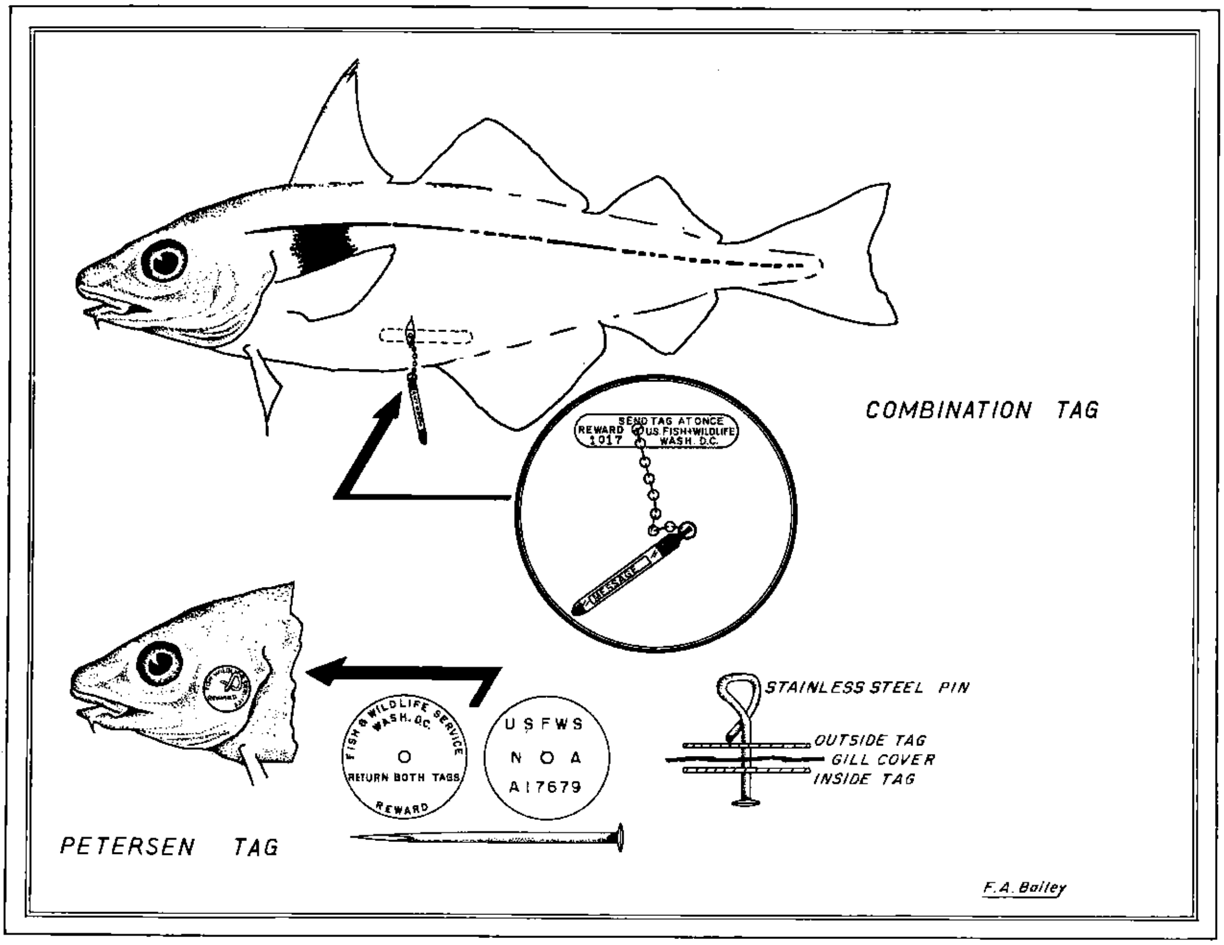


Figure 1. The Petersen tag and the combination tag used in haddock research.

Introduction

In the period from 1923 to 1932, nearly 11,000 tagged haddock (*Melanogrammus aeglefinus*) were released in the Gulf of Maine-Nantucket Shoals area as part of a migration study (Schroeder, 1942). The results of these experiments were extremely discouraging since only about 2 percent of the marked fish were returned, compared with about 12 percent returns for cod captured in the same manner, on the same grounds, and tagged with the same tag (Schroeder, 1930).

Fish for tagging were caught with hand lines and tagged with Monel strap tags (Rounsefell and Kask, 1945) attached to the dorsal part of the caudal fin. Schroeder (1942) concluded that the poor rate of return resulted from tags being shed, "...perhaps as many as 70 to 80 percent," within the first 3 to 6 months after tagging.

Subsequent haddock tagging, conducted by the Bureau of Commercial Fisheries Biological Laboratory from 1930 to 1932, and reported by Rounsefell (1942), also yielded poor returns. In these experiments the haddock were caught by otter trawls; 440 were tagged with bachelor button tags and 82 with body cavity tags (Rounsefell and Kask, 1945). None were

---

* U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts.

returned. In a later experiment, 259 haddock were tagged with bachelor button tags and 101 with body cavity tags. One bachelor button tag was returned. These fish were captured with line trawls fished from large commercial vessels. It was presumed that the poor returns were due to fish mortality caused by the method of capture and subsequent handling. Therefore, in 1933, tagging was conducted from a small line trawler near the coast of Maine. In this experiment 332 haddock were marked with bachelor button tags and 117 with body cavity tags. Rounsefell (1942) reports 26 returns (5.8 percent) but does not indicate a breakdown by tag type.

In 1938, 1939 and 1940 the experiments were resumed (Rounsefell, 1942). Haddock were again tagged from a line trawler, during the first part of June in waters ranging from 15 to 30 fathoms deep off Mount Desert Island, Maine. In all, 2,073 fish were tagged and by June 1941, 321 (15.5 percent) were recaptured.

Rounsefell used three types of tags in different combinations each year; the bachelor button tag on the operculum (1938—1939), the internal anchor tag (1938—1940), and the Petersen tag on the operculum (1938—1939—1940). The tags are illustrated and described by Rounsefell and Kask (1945). To eliminate any variables introduced by using different tags at different times, he rotated the tags so that when three types were being tested, every third fish was marked with the same type. On the basis of this experiment, he concluded that the Petersen tag gave the highest initial return but poorer returns later. The bachelor button tag yielded more long-term recaptures than the Petersen tag, but presented mechanical problems in its method of attachment. The internal anchor tag remained attached longer than the Petersen tag and possibly longer than the bachelor button tag, but because the dangler and chain were too easily lost the tag needed improvement before further use.

Encouraged by Rounsefell's success, we began a large-scale haddock tagging program in 1953 and 1954 in the offing of Chatham, Massachusetts, aboard a 38-foot line trawler. Nearly 2,000 haddock were tagged either with Petersen tags on the operculum or with modified internal anchor ("combination") tags (Fig. 1). Additional large-scale haddock tagging was conducted, with otter-trawl-caught fish, from the *Albatross III*, beginning in 1957 using Petersen tags and plastic "spaghetti" tags (Wilson, 1953).

This report discusses the relative merits of the tags used in the Chatham and *Albatross III* tagging studies. The studies were conducted as part of the haddock stock definition program, and as further field tests of the Petersen tags, combination tags, and spaghetti tags. Additional information was gained about the growth of haddock and the problems of tagging from otter trawlers.

In previous experiments, tagging haddock from otter trawlers had been notably unsuccessful. Such tagging by W. C. Herrington (and reported by Rounsefell, 1942) yielded no returns from 522 tagged fish. In 1950, more than 1,800 haddock were taken in an otter trawl by the *Albatross III* and tagged with Petersen tags. Less than 1 percent of these fish were recovered (Fish and Wildlife Service unpublished records).

Tagging Methods

Line trawl tagging. — Beginning in the autumn of 1953 and continuing through the summer of 1954, periodic trips were made aboard a line trawler out of Chatham, Massachusetts, to tag haddock. The vessel fished with commercial gear, in its usual manner, and we selected the liveliest-looking fish from those caught during the normal day's operation. The tagging area was a regularly-fished ground, 17 miles east-southeast of Pollock Rip light vessel in depths between 15 and 30 fathoms.

The fish were tagged with Petersen tags or combination tags that consisted of an internal anchor connected to a Lea hydrostatic capsule with a short length of Monel chain (Wise, 1958). The internal anchor was inserted through an incision in the flank of the fish. The Petersen tags were attached to the operculum with nickel pins in the manner described by Rounsefell (1942), in which the pin is threaded through the center of one disc and then pushed through the operculum from the inside. The second disc is then threaded on the projecting point of the pin. The surplus part of the pin is cut off and the remainder twisted into a loop and bent over with longnosed pliers. The fish were measured and then released.

The Petersen tags and combination tags were rotated in use except that two combination tags were used for each Petersen tag used. A total of 1,870 haddock were tagged; 1,253 with combination tags and 617 with Petersen tags.

Otter trawl tagging. — In March and April 1957, haddock were tagged on Georges and Browns Banks aboard the research vessel *Albatross III.* A Yankee 41 otter trawl with a fine-mesh cod end cover was towed for 20 to 60 minutes in depths from 24 to 56 fathoms. At the end of the tow, the net was hauled back and the contents of the cover emptied into circular wooden tanks supplied with running sea water. The cod end, which usually contained large numbers of anglers, skates, and miscellaneous species, was emptied on deck. The haddock that had escaped through the meshes of the cod end into the cover were usually in good condition, with little or no indication of abrasion or other injury. Presumably this was because they were not in contact with the rough fishes during the haulback. Sluggish haddock were removed from the tank. The lively ones were dipnetted individually and handed to the tagger who attached the tag, measured the fish, and immediately released it over the side of the vessel.

On Georges Bank, 297 fish were tagged with Petersen tags on the operculum, 179 with Petersen tags attached dorsally, and 221 with spaghetti tags attached dorsally. On Browns Bank, 640 haddock were tagged with Petersen tags on the operculum, 399 with Petersen tags attached dorsally, and 272 with spaghetti tags attached dorsally.

The Petersen tags on the operculum were attached in the same manner as for the line trawl tagging described previously, except that stainless steel pins were used instead of nickel pins. An aquarium study with tagged haddock (Jensen, 1958) had shown that the stainless steel pins were more resistant to sea water corrosion than the nickel pins. The dorsal Petersen tags were attached with stainless steel wire through the dorsum, immediately anterior to the first dorsal fin.

The spaghetti tag is a 350-mm length of 2.5-mm (outside diameter) yellow Vinyl plastic tubing with a serial number and return address imprinted with waterproof ink. The tubing is drawn through the dorsal muscles, between the first and second dorsal fins, and the free ends of the tube tied in a simple overhand knot.

The Petersen tags and spaghetti tags were used alternately on the Georges Bank haddock. On Browns Bank, two haddock were tagged with Petersen tags for each one tagged with the spaghetti type. However, the principle of alternation of tags was followed so that every third fish was tagged with the spaghetti tag.

Results

Line trawl. — Of the total of 1,870 haddock tagged off Chatham, 221 (11.8 percent) were returned as follows: 63 Petersen tags (10.2 percent) and 158 combination tags (12.4 percent) (Table 1). As shown in Figure 2 and Table 1, the Petersen tags gave a high initial return and then began to diminish after about 30 weeks. Fewer fish with combination tags were returned at first but the percentage of returns increased rapidly. At 60 weeks both tags yielded about the same percentage of returns. The initial fish mortality, from the effect of tagging, is probably higher with the combination tag but actual loss of tags is probably greater with the Petersen tag.

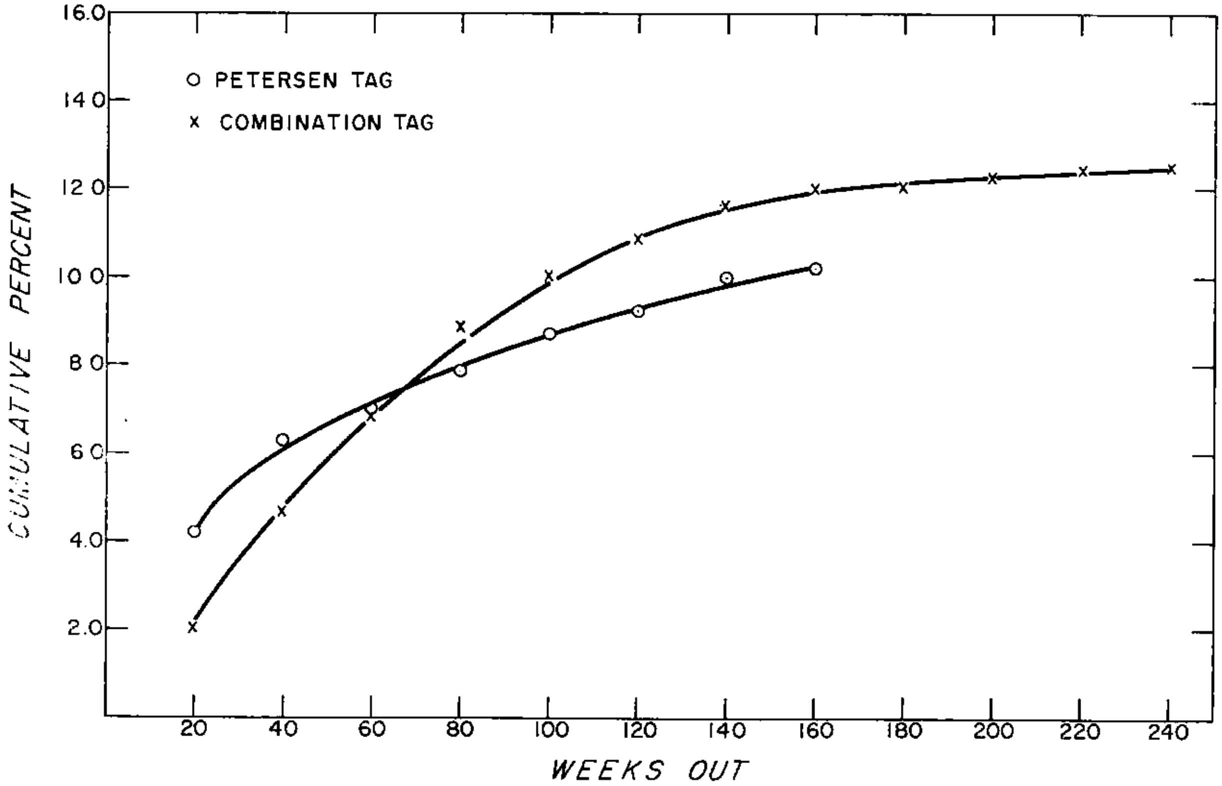


Figure 2. Graph comparing rate of return of Petersen tags and combination tags, Chatham, 1953—1954.

Aquarium studies (Jensen, 1958) have shown that the Petersen tag on haddock may be grown over and not seen, or may cause an opercular ulceration and be shed.

Table 1

Cumulative number and percentage returns, by 20-week intervals, of Petersen tags and combination tags used on haddock, Chatham, 1953—1954

(Cumulative numbers in parentheses)

Time at liberty	Petersen tags		Combination tags*	
(weeks)	(No.)	(%)	(No.)	(%)
0—20	26 (26)	4.2	26 (26)	2.1
21—40	13 (39)	6.3	33 (59)	4.7
41—60	4 (43)	7.0	27 (86)	6.9
61—80	6 (49)	7.9	25 (111)	8.9
81—100	5 (54)	8.7	14 (125)	10.0
101—120	3 (57)	9.2	10 (135)	10.8
121—140	5 (62)	10.0	10 (145)	11.6
141—160	1 (63)	10.2	5 (150)	12.0
161—180			1 (151)	12.0
181—200			3 (154)	12.3
201—220			1 (155)	12.4
221—240			1 (156)	12.4

* Two tags with recovery date lacking, not included.

At the 60-week level, both tags still yielded about the same percentage of returns; no Petersen tags were returned after 160 weeks. The combination tags, however, continued to be returned beyond 160 weeks, and one fish (possibly others not captured) retained the tag for nearly 5 years. The chain was worn thin on some of the combination tags out for long periods, and the nickel pins with Petersen tags showed some corrosion. In many cases, finders noted that operculum tissue under the Petersen tags was raw and eroded.

Although we have no measure of the loss, undoubtedly tags of both types were lost even though the fish were later recaptured. This was demonstrated when the skipper of the tagging boat later recaptured a haddock that had been tagged with a combination tag. The chain had broken close to the internal anchor leaving no external evidence of the tag. While gutting the fish, the skipper noticed a lump on the liver that proved to be the internal anchor portion overgrown with liver tissue. It might never have been seen had the fish been gutted by a less observant person.

Otter trawl. — The results of the tagging experiments aboard the *Albatross III* are reported separately for Georges and Browns Banks, for several reasons. The area on Georges in which we tagged haddock is fished year-round by United States vessels, whereas Browns Bank is fished only in the first few months of the year and is little fished by Canadian vessels. Thus, there is a greater likelihood for tagged fish

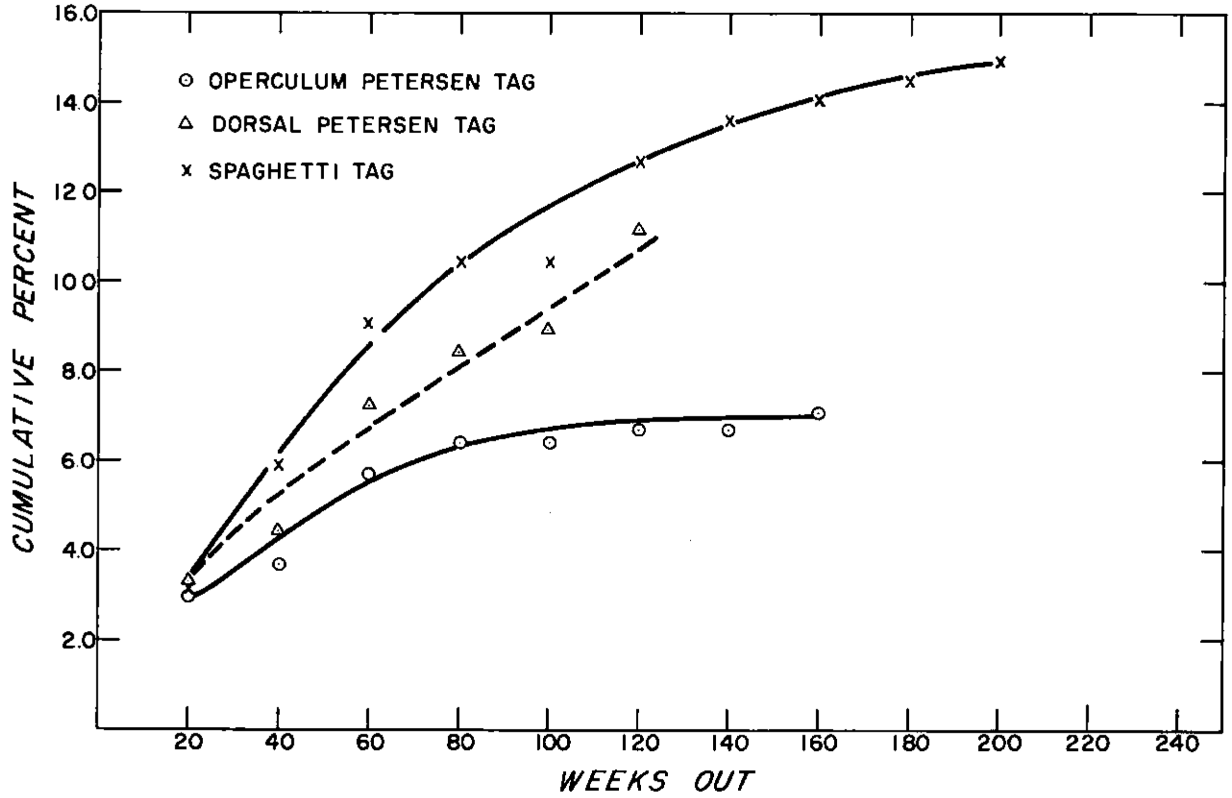


Figure 3. Graph comparing rate of return of operculum Petersen tags, dorsal Petersen tags, and spaghetti tags, Georges Bank, 1957.

Table 2

Cumulative number and percentage returns, by 20-week intervals, of Petersen tags on the operculum and on the dorsum, and spaghetti tags on the dorsum, Georges Bank, 1957

(Cumulative numbers in parentheses)

Time at liberty	Petersen tags				Spaghetti tags	
	Operculum		Dorsum			
(weeks)	(No.)	(%)	(No.)	(%)	(No.)	(%)
0—20	9 (9)	3.0	6 (6)	3.3	7 (7)	3.2
21—40	2 (11)	3.7	2 (8)	4.5	6 (13)	5.9
41—60	6 (17)	5.7	5 (13)	7.3	7 (20)	9.0
61—80	2 (19)	6.4	2 (15)	8.4	3 (23)	10.4
81—100	0 (19)	6.4	1 (16)	8.9	0 (23)	10.4
101—120	1 (20)	6.7	4 (20)	11.2	5 (28)	12.7
121—140	0 (20)	6.7			2 (30)	13.8
141—160	1 (21)	7.1			1 (31)	14.0
161—180					1 (32)	14.5
181—200					1 (33)	14.9

to be recaptured on Georges than there is on Browns. Scale studies have shown that Browns Bank haddock grow at a slower rate than Georges Bank haddock (Wise, 1957) and the two groups do not mingle to any great extent.

Tag returns from Georges Bank include 21 (7.1 percent) Petersen tags on the operculum, 20 (11.2 percent) Petersen tags on the dorsum, and 33 (14.9 percent) spaghetti tags (Table 2). The pattern of returns has been somewhat similar to that of the Chatham tagging study. The three kinds of tags yielded about the same percentage of returns through the first 20 weeks, but after 60 weeks the return rate for operculum Petersen tags began to decline. In contrast, the returns of dorsal Petersen tags and spaghetti tags continued to rise (Fig. 3).

Table 3

Cumulative number and percentage returns, by 20-week intervals, of operculum Petersen tags, dorsal Petersen tags, and spaghetti tags on the dorsum, Browns Bank, 1957

(Cumulative numbers in parentheses)

Time at liberty	Petersen tags				Spaghetti tags	
	Operculum		Dorsum			
(weeks)	(No.)	(%)	(No.)	(%)	(No.)	(%)
0—20	9 (9)	1.4	2 (2)	0.5	8 (8)	2.9
21—40	4 (13)	2.0	0 (2)	0.5	6 (14)	5.1
41—60	13 (26)	4.1	4 (6)	1.5	10 (24)	8.8
61—80	3 (29)	4.5	0 (6)	1.5	2 (26)	9.6
81—100	0 (29)	4.5	2 (8)	2.0	1 (27)	9.9
101—120	1 (30)	4.7	2 (10)	2.5	5 (32)	11.8
121—140	0 (30)	4.7			1 (33)	12.1
141—160	3 (33)	5.2			2 (35)	12.9
161—180	1 (34)	5.3				
181—200	0 (34)	5.3				
201—220	1 (35)	5.5				

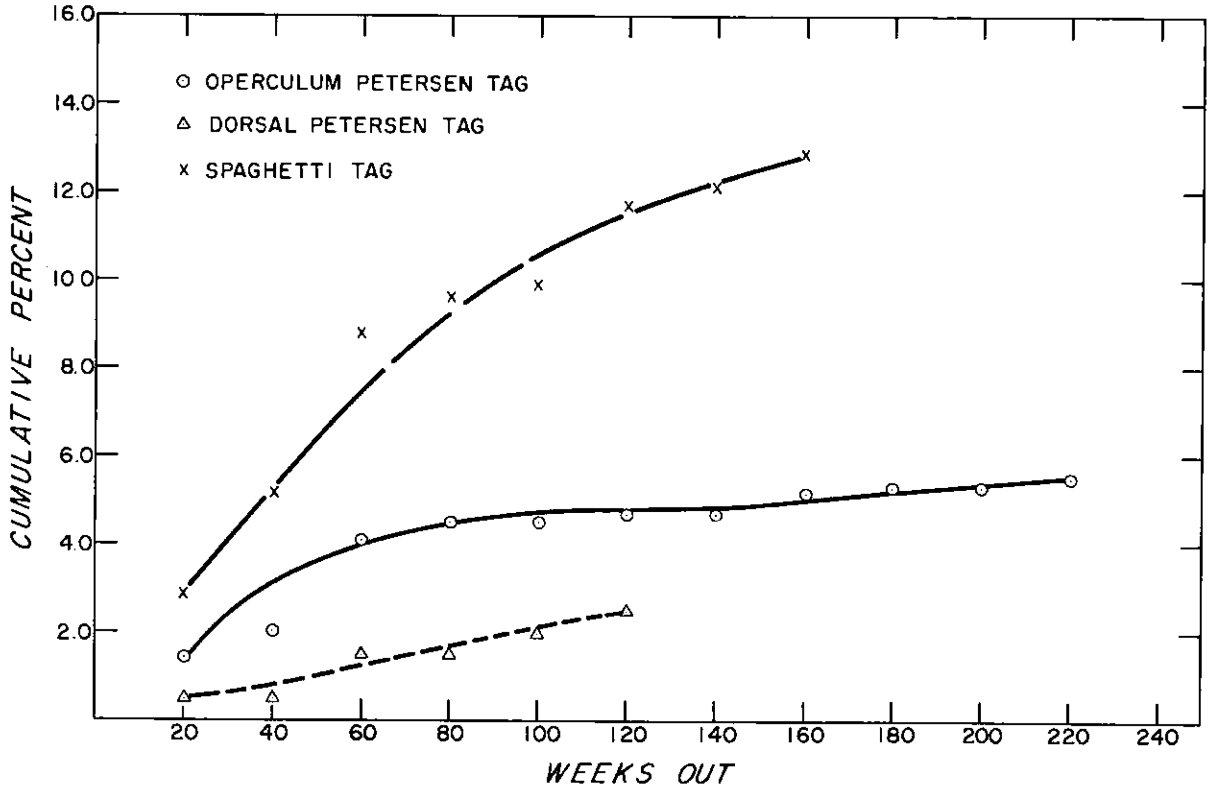


Figure 4. Graph comparing rate of return of operculum Petersen tags, dorsal Petersen tags, and spaghetti tags, Browns Bank, 1957.

In the haddock tagging on Browns Bank, despite the greater number used, the Petersen tags yielded a total of only 45 returns — 35 (5.5 percent) on the operculum and 10 (2.5 percent) on the dorsum — compared with the spaghetti tag that yielded 35 returns (12.9 percent) (Table 3). The pattern of returns has been quite different. The rate for Petersen tags (operculum and dorsal) was low at the beginning and leveled off at a low rate after 60 weeks. The spaghetti tags were returned at a good rate, though none were returned after 160 weeks (Fig. 4).

Growth of Tagged Fish

Tagging experiments offer one of the best methods for obtaining empirical growth data for fish, since the fish are measured when tagged and again when recaptured, and the time interval is precisely known. When tagged fish are recaptured, however, the finder often neglects to include an adequate length measurement, or reports the size of the fish as "$2^1/_2$ pounds," or "$19^1/_2$ inches long."

The most reliable length measurements we have of recaptured fish are those made by our technicians at the several ports. Because of the small sample involved, however, the data do not lend themselves to sophisticated statistical analysis and can give only the grossest indication of growth. Instead, we have simply determined a weighted mean weekly growth for fish tagged with each kind of tag.

Line trawl. — Haddock tagged with Petersen tags grew at a faster rate than those tagged with combination tags. It is interesting to note that the 5 fish tagged with Petersen tags in November 1953 grew an average of 1.4 mm per week over periods that ranged from 10 to 123 weeks, and the 10 fish tagged in April 1954 grew an average of 0.99 mm per week over periods that ranged from 14 to 105 weeks. The 7 fish tagged in August 1954 grew an average of 1.2 mm per week over periods of from 8 to 122 weeks (Table 4). It seems reasonable to combine the data and state an average growth of 1.1 mm per week for the fish tagged with Petersen tags.

For the returns from the November 1953 tagging, the average length growth per week (for periods from 13 to 141 weeks) was 0.9 mm for the 5 fish tagged with the combination tag; for the April 1954 tagging it was 0.8 mm for the 29 fish, for periods from 15 to 150 weeks. The 7 fish returned from the August 1954 tagging grew an average of 0.6 mm per week over periods of from 31 to 97 weeks (Table 5). Again combining these data, we may state 0.7 mm per week as an average growth for the haddock tagged with the combination tag.

Table 4
Growth of haddock tagged with Petersen tags on the operculum, Chatham, 1953–1954

Date Tagged	Date Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
Nov 1953	Feb 1954	10	510	537	27	2.7
	Apr 1955	74	480	577	97	1.3
	May 1955	78	540	640	100	1.3
	July 1955	86	570	650	80	0.9
	Mar 1956	123	510	625	115	0.9
					$\bar{x}$ =	1.4
Dec 1953	Apr 1956	120	460	525	65	0.5
Apr 1954	July 1954	14	537	555	18	1.3
	Aug 1954	14	638	645	7	0.5
	Feb 1955	44	578	632	54	1.2
	Mar 1955	48	506	586	80	1.7
	July 1955	63	529	562	33	0.5
	Oct 1955	77	486	544	58	0.7
	Oct 1955	78	539	584	45	0.6
	Dec 1955	85	348	521	173	2.0
	Feb 1956	94	507	620	113	1.2
	May 1956	105	541	565	24	0.2
					$\bar{x}$ =	0.99
July 1954	Sept 1955	61	579	628	49	0.8
Aug 1954	Sept 1954	8	418	420	2	0.2
	Dec 1954	16	643	686	43	2.7
	Jan 1955	25	630	649	19	0.8
	Mar 1955	31	565	571	6	0.2
	Mar 1955	32	518	551	33	1.0
	Sept 1955	56	528	700	172	3.1
	Dec 1956	122	530	572	42	0.3
					$\bar{x}$ =	1.2
					Grand average =	1.1

Otter trawl. — As was the case with the line trawl tagging experiments, the number of reliable length measurements obtained at the time of return from the otter trawl tagging experiments is small and the data are not suitable for statistical analysis. However, by again examining the average growth per week, we are afforded a rough approximation of the differences in growth between the fish tagged with Petersen tags and those tagged with spaghetti.

On Georges Bank the haddock tagged with spaghetti tags grew at a much faster rate than those with Petersen tags (Table 6). The 9 haddock tagged on the operculum with Petersen tags grew an average of 0.5 mm per week over periods of from 6 to 80 weeks at large. The 21 haddock tagged with spaghetti tags grew an average of 0.8 mm per week over periods of from 6 to 182 weeks. The 8 fish tagged dorsally with Petersen tags grew an average of 0.5 mm per week over a period of from 13 to 107 weeks.

The growth of tagged Browns Bank haddock (Table 7) was less than that for the tagged Georges Bank haddock, but this is to be expected since scale readings show that Browns Bank fish grow at a slower

Table 5

Growth of haddock tagged with combination tags, Chatham, 1953—1954

Date Tagged	Date Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
Nov 1953	Feb 1954	13	560	575	15	1.2
	Oct 1954	47	520	568	48	1.0
	Jan 1955	62	500	543	43	0.7
	Oct 1955	100	480	541	61	0.6
	Aug 1956	141	540	657	117	0.8
					$\bar{x}$ =	0.9
Dec 1953	Sept 1955	88	530	635	105	1.2
	Apr 1956	120	540	595	55	0.5
	Apr 1958	223	520	680	160	0.7
					$\bar{x}$ =	0.8
Apr 1954	Aug 1954	15	577	580	3	0.2
	Aug 1954	16	668	678	10	0.6
	Oct 1954	25	566	578	12	0.5
	Oct 1954	26	563	574	11	0.4
	Oct 1954	26	464	505	41	1.6
	Dec 1954	33	517	548	31	0.9
	Mar 1955	48	655	668	13	0.3
	Apr 1955	50	529	584	55	1.1
	May 1955	55	600	646	46	0.8
	June 1955	60	569	635	66	1.1
	June 1955	61	567	635	68	1.1
	July 1955	63	520	591	71	1.1
	July 1955	64	464	542	78	1.2
	July 1955	64	552	609	57	0.9
	July 1955	65	505	572	67	1.0
	July 1955	66	515	539	24	0.4
	Aug 1955	70	474	533	59	0.8
	Sept 1955	73	510	584	74	1.0
	Sept 1955	73	488	562	74	1.0
	Nov 1955	81	635	660	25	0.3
	Mar 1956	97	705	750	45	0.5
	Apr 1956	103	564	667	103	1.0
	May 1956	105	603	686	83	0.8
	May 1956	109	545	584	39	0.4
	June 1956	111	583	619	36	0.3
	Oct 1956	130	505	635	130	1.0
	Nov 1956	134	551	680	129	1.0
	Dec 1956	138	529	623	94	0.7
	Feb 1957	150	551	639	88	0.6
					$\bar{x}$ =	0.8
Aug 1954	Mar 1955	31	631	639	8	0.3
	Mar 1955	32	478	483	5	0.2
	June 1955	46	566	580	14	0.3
	Sept 1955	60	541	584	43	0.7
	Oct 1955	64	562	591	29	0.4
	Jan 1956	74	688	720	32	0.4
	June 1956	97	494	647	153	1.6
					$\bar{x}$ =	0.6
					Grand average =	0.7

rate. The 10 fish tagged on the operculum with Petersen tags and at large for from 35 to 210 weeks grew an average of 0.4 mm per week. The growth of the 10 spaghetti-tagged fish, at large for from 37 to 160 weeks, grew an average of 0.4 mm per week. The 3 fish tagged dorsally with Petersen tags grew an average of 0.5 mm per week over a period of 52 to 105 weeks.

It seems certain the physical presence of the tags inhibited the normal growth rate of the tagged haddock. Untagged haddock, with about the same size composition as the tagged haddock reported in this paper, grow at the following rates: Georges Bank, 1.0 mm per week (Jensen and Wise, 1962); Browns Bank, 0.6 mm per week (Wise, 1957).

Table 6

Growth of haddock tagged on Georges Bank, 1957

Date Tagged	Date Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
Petersen tags on the operculum						
Mar 1957	May 1957	6	584	590	6	1.0
	Sept 1957	23	484	501	17	0.7
	Sept 1957	24	482	490	8	0.3
	Mar 1958	49	585	597	12	0.2
	Mar 1958	52	423	470	47	0.9
	May 1958	58	477	500	23	0.4
	May 1958	58	579	590	11	0.2
	June 1958	63	497	515	18	0.3
	Oct 1958	80	517	569	52	0.6
					$\bar{x}$ =	0.5
Petersen tags on the dorsum						
Mar 1957	June 1957	13	434	440	6	0.5
	Mar 1958	51	552	558	6	0.1
	Mar 1958	52	583	588	5	0.1
	May 1958	60	584	616	32	0.5
	May 1958	61	451	484	33	0.5
	July 1958	69	501	565	64	0.9
	Mar 1959	105	658	760	102	1.0
	Apr 1959	107	483	526	43	0.4
					$\bar{x}$ =	0.5
Spaghetti tags						
Mar 1957	May 1957	6	608	610	2	0.3
	May 1957	7	462	473	11	1.6
	May 1957	8	565	577	12	1.5
	June 1957	11	588	619	31	2.8
	Aug 1957	22	467	475	8	0.4
	Oct 1957	31	532	564	32	1.0
	Feb 1958	45	572	590	18	0.4
	Apr 1958	56	480	554	74	1.3
	Apr 1958	57	568	582	14	0.2
	May 1958	61	540	577	37	0.6
	May 1958	62	454	495	41	0.7
	June 1958	62	342	426	84	1.4
	Feb 1959	102	485	512	27	0.3
	Mar 1959	102	548	567	19	0.2
	Apr 1959	109	483	542	59	0.5
	Apr 1959	109	493	603	110	1.0
	Aug 1959	126	474	587	113	0.9
	Nov 1959	137	475	532	57	0.4
	Feb 1960	151	532	585	53	0.3
	May 1960	162	556	640	84	0.5
	Sept 1960	182	355	570	215	1.2
					$\bar{x}$ =	0.8

Table 7
Growth of haddock tagged on Browns Bank, 1957

Date Tagged	Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
Petersen tags on the operculum						
Mar 1957	Dec 1957	35	548	559	11	0.3
	Mar 1958	53	549	570	21	0.4
	Apr 1958	55	482	490	8	0.1
	Apr 1958	56	512	544	32	0.6
	June 1958	63	497	518	21	0.3
	July 1958	69	486	527	41	0.6
	Mar 1960	152	472	575	103	0.7
	Apr 1960	160	512	551	39	0.2
	June 1960	166	472	550	78	0.5
	Apr 1961	210	472	511	39	0.2
					$\bar{x}$ =	0.4
Petersen tags on the dorsum						
Mar 1957	Mar 1958	52	550	575	25	0.5
	Feb 1959	98	524	610	86	0.9
	Apr 1959	105	592	609	17	0.2
					$\bar{x}$ =	0.5
Spaghetti tags						
Mar 1957	Dec 1957	37	514	539	25	0.7
	Feb 1958	48	545	578	33	0.7
	Mar 1958	52	548	587	39	0.7
	Mar 1958	53	535	545	10	0.2
	Jan 1959	96	570	580	10	0.1
	Mar 1959	105	471	500	29	0.3
	Apr 1959	106	513	544	31	0.3
	Aug 1959	126	576	623	47	0.4
	Feb 1960	151	458	506	48	0.3
	Apr 1960	160	551	576	25	0.2
					$\bar{x}$ =	0.4

Thus, for Georges Bank haddock, fish marked with Petersen tags (both methods of attachment) grew at 50 percent of the rate for untagged fish, while the fish marked with spaghetti tags grew at 80 percent of the rate for untagged fish. For the Browns Bank haddock, the fish marked with dorsal Petersen tags grew at 83 percent of the rate for untagged fish, while the fish marked with operculum Petersen tags, or with spaghetti tags, grew at 67 percent of the rate for untagged fish.

Unfortunately, the data for untagged fish are not obtainable to make a similar comparison for the Chatham experiment.

Factors Affecting Tag Returns

Tag visibility. — Much of the value of a tag recovery is lost if the tag is seen at such a late stage in the marketing chain that the fish cannot be traced back to the area and date of capture with a reasonable degree of certainty. In Table 8, I have listed the numbers and percentages of tagged fish and the places in which the tags were discovered.

In the Chatham tagging, the Petersen tags were discovered on the vessel 68 percent of the time, the combination tags were discovered thus 60 percent of the time. The small difference in percentage indicates that both tags were equally visible to the fishermen. The kind of fishery involved may have some bearing on the place of discovery, since nearly $^1/_4$ (23 percent) of all the returned Chatham tags were found aboard line trawlers. In this type of fishery the fish receive more or less individual attention, in contrast to the obscurity of individual fishes aboard an otter trawler when the cod end load is dumped into the checkers.

It is surprising to note that so many tags (nearly 10 percent of Petersen tags and 19 percent of combination tags) passed through numerous hands to be discovered in the retail market; and we received 3 tags from housewives who discovered them while cleaning fish for supper! Undoubtedly, the sheer mass of fish aboard ship and ashore, the need of the handler to hurry along with his tasks, and the mental attitude or preoccupation of the handler, all contribute to tags passing unnoticed.

It was our hope that the use of spaghetti tags in the offshore tagging would result in a higher recovery rate aboard the vessel. The bright yellow tag, placed like a bridle on the fish, seemed to be one of the most visible tags used so far. Unfortunately, such was not

Table 8
Comparison of points of discovery for haddock tags

Where found	Chatham				Offshore tagging					
	Petersen tags		Combination tags		Petersen tags				Spaghetti tags	
					Operculum		Dorsal			
	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
When caught	14	22.2	25	15.8	18	32.7	4	13.4	7	10.4
Handling on vessel	29	46.0	70	44.3	16	29.1	3	10.0	16	23.9
Unloading	1	1.6	7	4.4	4	7.3	1	3.3	6	9.0
Processing ashore	10	15.9	14	8.9	10	18.2	18	60.0	25	37.3
Retail store	6	9.5	30	19.0	—	—	1	3.3	4	6.0
Private home	1	1.6	2	1.3	—	—	—	—	—	—
Unknown	2	3.2	10*	6.3	7	12.7	3	10.0	9	13.4
Total	63	100.	158	100.	55	100.	30	100.	67	100.

* Includes 2 found on beach.

the case. Only 34 percent of the spaghetti tags were discovered aboard ship. More than 60 percent of the operculum Petersen tags and 23 percent of the dorsal Petersen tags were thus discovered.

Dorsally placed tags apparently are not readily noticed aboard ship. Possibly this is because the fishermen commonly grasp the fish by the head, with its belly up, when it is handled for ripping and gutting. Thus the dorsally placed tag is hidden. Workers in processing plants discovered 60 percent of the dorsal Petersen tags, 37 percent of the spaghetti tags, and less than 20 percent of the operculum Petersen tags. One dorsal Petersen tag and four spaghetti tags reached the retail market before they were seen and reported. Presumably these fish entered the dressed fish market, since it would be impossible to fillet them without seeing the tag. A few of the dorsal Petersen tags became imbedded in the dorsal musculature through subsequent growth of the fish and were not readily visible. None of the spaghetti tags returned to date were faded; the color was still as bright as when the tag was attached, thus there was no problem of decreased tag visibility. Human carelessness, or indifference, is undoubtedly a big factor contributing to reduced or tardy tag discovery.

Time of year. — During the analysis of the Chatham tagging data, an apparent relationship was seen between the time of year when the fish were tagged and the percentage of returns. The highest return rate (17.3 percent) was for fish tagged in the spring (April), the second highest (11.3 percent) was for fish tagged in the winter (November and December), while the lowest (6.5 percent) was for fish tagged in the summer (July and August) (Table 9).

Table 9

Tagging success and season of the year, Chatham, 1953—1954

Season	Tag	Number Fish tagged		Number Tags returned		Rate of return (%)	
Winter	Petersen	232	697	22	79	9.5	11.3
	Combination	465		57		12.3	
Spring	Petersen	200	608	26	105	13.0	17.3
	Combination	408		79		19.3	
Summer	Petersen	185	565	15	37	8.1	6.5
	Combination	380		22		5.8	
Total	Petersen	617		63		10.2	
	Combination	1253		158		12.6	

Two factors are considered to explain the differential returns: (1) the effect of the water temperature, and (2) the condition of the haddock in springtime. It is possible that the cool isothermal water column which prevails in the spring (and to some extent in the latter part of the winter) does not add a physiological shock to the physical shock that occurs when the fish is hauled from the bottom to the surface for tagging. Another possibility, suggested by Parker, Black, and Larkin (this symposium, No. 19), lies in the fact that haddock spawn in the spring. Parker and his group, working with salmon, reported that death due to fatigue may be avoided and the survival of marked fish enhanced if tagging is restricted to the spawning season.

The influence of time of year is further demonstrated by our successful springtime tagging with fish caught in an otter trawl in the experiment described in this paper, and the lack of success, under similar tagging conditions, of experiments conducted at other times of the year (Fish and Wildlife Service unpublished data). The failure of the haddock tagging conducted in September 1950 aboard the *Albatross III*, described in this paper, was probably due to the time of year when the experiment took place.

Ease of tag attachment. — Although we made no precise studies of the time needed to attach the different kinds of tags, it was evident that some were attached with greater ease than others. The time varied with the skill of the operator, too, but in most cases the spaghetti tag was attached in less time than the others. Thus, haddock tagged with spaghetti tags were out of water a shorter time, which may be one of the reasons for the success of this tag.

Conclusion

Petersen tags and combination tags. — The present tagging studies did not distinguish any one tag type as superior for marking haddock. For studies of less than 3 years, the Petersen tag on the operculum seems to yield the greatest number of returns. For longer studies the combination tag is better, although there is probably greater initial tagging mortality with this tag than with the Petersen tag. Neither tag shows any special advantage in studies where precise recovery locations are wanted, since both were found aboard ship at about the same rate; also, about the same percentage of both tags escape the fishermen's notice to be found in processing plants and markets. More combination tags were discovered in retail markets, thus greatly reducing the likelihood of tracing the tag back to the vessel and so learning the position at which the tagged fish was first captured.

Petersen tags and spaghetti tags. — The offshore tagging again showed the Petersen tag on the operculum to be better for short-term studies. The spaghetti tag yielded a high percentage of returns over a 3-year period and did not seem to cause the initial tagging mortality characteristic of the combination tag tested off Chatham.

There is little to recommend the Petersen tag attached through the dorsal musculature. Although it did yield a substantial percentage of returns from Georges Bank tagging, many of the tags were not discovered until the fish were in the shore processing plants.

Successful haddock tagging from an otter trawler requires that the tagging be done when the water is cold and isothermal. In the Georges Bank-Gulf of Maine region this occurs in the spring. The uniformly cold water apparently minimizes physiological damage to the fish and probably reduces the initial tagging mortality. Placing the fish for tagging in tanks with running sea water, and selecting only the liveliest individuals, further increases the chances for greater recaptures.

On the basis of the evidence presented here, the spaghetti tag is the most promising for future haddock tagging. It is easily attached to the fish and does not cause sores at the point of attachment. It cannot be overgrown with tissue as with the Petersen tag and, although we have no direct evidence, it probably is not easily shed.

Summary

1. Previous haddock tagging experiments in the Gulf of Maine area had been largely unsuccessful, with few or no returns. Tagging experiments with fish caught in otter trawls had been especially unsuccessful. Refinements in tag materials and tagging techniques, however, led to two large-scale tagging experiments.

2. In 1953 and 1954, haddock caught by line trawls in waters off Chatham, Massachusetts, were tagged as follows: 617 with Petersen tags on the operculum, and 1,253 with a combination internal anchor-hydrostatic capsule tag.

3. In the early spring of 1957, haddock caught in an otter trawl on Georges and Browns Banks were tagged as follows: Georges Bank; 297 with Petersen tags on the operculum, 179 with Petersen tags on the dorsum, and 221 with spaghetti tags on the dorsum: Browns Bank; 640 with Petersen tags on the operculum, 399 with Petersen tags on the dorsum, and 272 with spaghetti tags on the dorsum.

4. Returns from the Chatham experiment yielded 63 (10.2 percent) Petersen tags and 158 (12.6 percent) combination tags.

5. The spaghetti tags yielded a higher rate of return than the Petersen tags in the offshore haddock tagging experiments. On Georges Bank, 21 (7.1 percent) Petersen tags on the operculum, 20 (11.2 percent) Petersen tags on the dorsum, and 33 (14.9 percent) spaghetti tags were returned. On Browns Bank, 35 (5.5 percent) Petersen tags on the operculum, 10 (2.5 percent) Petersen tags on the dorsum, and 35 (12.9 percent) spaghetti tags were returned.

6. All of the tags tested on the offshore banks tended to inhibit the growth of the tagged fish.

7. The two kinds of tags used in the Chatham experiment were equally visible to the fishermen, since 68 percent of the Petersen tags and 60 percent of the combination tags were discovered aboard ship. The remainder were discovered ashore, at the dock, in the filleting plant, or in a retail market.

In the offshore tagging, 62 percent of the Petersen tags on the operculum, 23 percent of the Petersen tags on the dorsum, and 34 percent of the spaghetti tags were discovered aboard ship. Tags attached dorsally apparently are not easily seen by the fishermen.

8. The highest rate of tag returns came from fish tagged in the spring.

9. The experiments did not demonstrate that any one tag was vastly superior for haddock tagging. However, the spaghetti tag is recommended over the others because it is easily attached, does not irritate the tissues at the point of attachment, cannot be overgrown with tissue, is probably not easily shed, and remains on the fish at least 4 years.

Acknowledgements

The tagging experiments described herein were carried out under the leadership of John R. Clark. John P. Wise and Sterling L. Cogswell assisted with much of the field work.

References

JENSEN, ALBERT C. 1958. Corrosion resistance of fish tagging pins. *Spec. Sci. Rep. U. S. Fish and Wildl. Serv.*, 262, 6 p.

JENSEN, ALBERT C. and JOHN P. WISE 1962. Determining age of young haddock from their scales. *Fish. Bull., U. S.* **61** (195): 439—450.

PARKER, ROBERT R., EDGAR C. BLACK, and P. A. LARKIN. 1963 Some aspects of fish-marking mortality. *This symposium*, No. 19.

ROUNSEFELL, GEORGE A. 1942. Field experiments in selecting the most efficient tag for use in haddock studies. *Trans. Amer. Fish. Soc.*, **71**: 228—235.

ROUNSEFELL, GEORGE A., and JOHN LAWRENCE KASK (1945). How to mark fish. *Trans. Amer. Fish. Doc.*, **73**: 320—363.

SCHROEDER, WILLIAM C. 1930. Migrations and other phases in the life history of the cod off southern New England. *Bull. U. S. Bur. Fish.*, **46**: 1—136 (*Bur. Fish. Doc.* 1081).

SCHROEDER, WILLIAM C. 1942. Results of haddock tagging in the Gulf of Maine from 1923 to 1932. *J. Mar. Res.*, 5 (1): 1—19.

WILSON, ROBERT C. 1953. Tuna marking, a progress report. *Calif. Fish Game*, **39** (4): 429—442.

WISE, JOHN P. 1957. Growth rate of Browns Bank haddock. *Res. Rep., U. S. Fish Serv.*, 50, 13 p.

WISE, JOHN P. 1958. The world's southernmost indigenous cod. *J. Cons. int. Explor. Mer*, **23** (2): 208—212.

31.

Estimation of Population Size and Mortality Rates from Tagged Redfish, *Sebastes marinus* L., at Eastport, Maine

By

GEORGE F. KELLY and ALLAN M. BARKER*

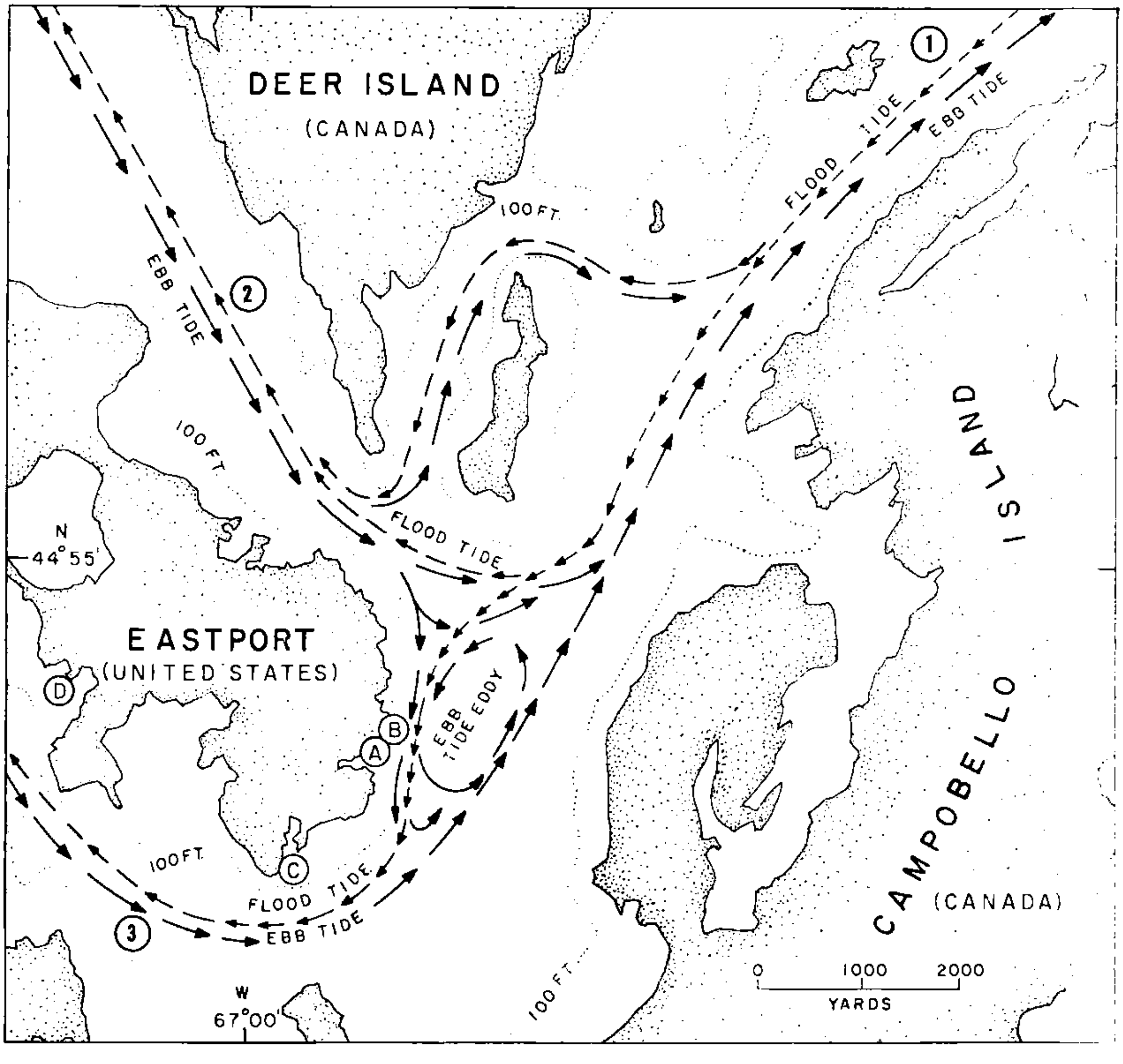


Figure 1. Chart of Eastport vicinity showing tidal current pattern and location of four tagging sites, A, B, C and D. (1) Head Harbor Passage; 2) Western Passage; and 3) Cobscook Bay).

Introduction

Since 1956 more than 6,000 redfish have been tagged from an apparently isolated population that inhabits the waters around Eastport, Maine, near the mouth of Passamaquoddy Bay. This normally deep-water species comes to the surface around the docks of the harbor and is caught readily on hook and line while feeding during ebb tide at night.

---

* U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Tagging was done at four locations in the area, mainly at two closely situated docks, points A and B in Figure 1. Fishing effort was sporadic during the five years, regular neither in season nor in amount. The time of fishing was usually confined to the portion of the monthly tidal cycle prior to the start of the spring tides. Large numbers of tagged fish were recaptured in the tagging area by the investigators; these were measured and returned to the water unharmed. Since there is neither a commercial fishery for redfish in that area, nor an active sport fishery for this species, the population is believed to have been virtually undisturbed during the study period except for the hook and line angling of the investigators.

Tag returns indicate that many of the fish remain in the area throughout the year (Kelly and Barker, 1961). There is no evidence of migration from the tagging area, since there were no returns from outside the immediate vicinity of tagging. Many of the fish displayed strong tendencies to remain in, or return to, particular territories, and a large number were repeatedly recaptured at the same location. The population is thought to be concentrated throughout the year in the comparatively deep waters of the rocky basin at the confluence of the tidal streams flooding through Head Harbor passage and ebbing from Cobscook Bay and Western Passage. Although there are no physical barriers to movement offshore, the population appears to be attracted here by a combination of optimal year-round hydrographic conditions, seasonally supplemented with an abundance of euphausiid shrimp that are concentrated in the region by the tidal currents, and are fed upon by the redfish. Many gravid females were caught in June and July. There appears to be little incentive for the fish to leave the area. The population appears to be in equilibrium, recruitment and other additive factors about equalling the annual depletive forces.

More than 2,400 tagged fish were recaptured from this physically unconfined, but isolated, population. Population estimates obtained from these data could be expected to be very precise, and to show a high degree of consistency, provided the proper assumptions were used as the basis for the estimates. It is the purpose of this paper to present the estimates obtained from different methods, and endeavor to determine some of the factors contributing to the variability of the results obtained at different times and by different methods.

For the purpose of these studies, the following conditions were assumed to exist in the population:

1. natural mortality was the same for tagged and untagged fish,
2. there was no loss of tags from the tagged fish,
3. tagged fish were as vulnerable to capture as untagged fish,
4. tagged and untagged fish were randomly mixed in the population, and
5. a single population was available, and recruitment to the population and emigration from the area were negligible.

Results

As more tagged fish were added over the years, the proportion of tagged fish in the samples increased, reaching a peak in 1958 and diminishing in 1959 and 1960 (Fig. 2). After the first year, daily samples regularly contained between 60 and 85 percent tagged fish.

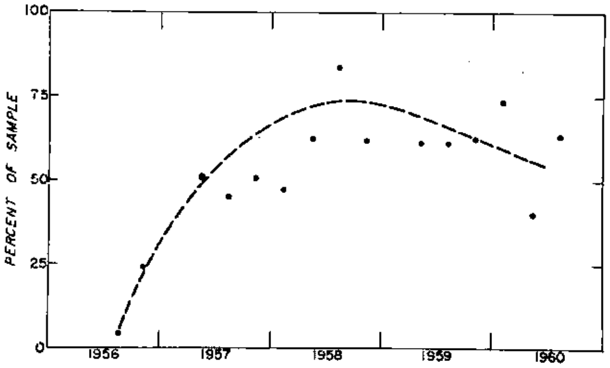


Figure 2. Changes in the proportion of tagged fish in samples, grouped in 3-month intervals, 1956 through 1960.

Estimates of population size were made using three accepted techniques; the Petersen, Schnabel and Schumacher-Eschmeyer methods. In each, all of the above assumptions must be satisfied to obtain an accurate population estimate. Each method gives an estimate of the total population size derived from the ratio of tagged to untagged fish in the samples. The equations for the methods are:

Petersen (1896)— $$P = \frac{AB}{C} \quad (1)$$

Schnabel (1938)— $$P = \frac{\Sigma(AB)}{\Sigma C} \quad (2)$$

Schumacher and Eschmeyer (1943)— $$P = \frac{\Sigma(AB^2)}{\Sigma BC} \quad (3)$$

When: P = total population estimate
A = total number of fish caught during a unit time interval
B = total number of tagged fish released prior to sampling
C = number of recaptures in the sample.

Of the three techniques, the Schumacher-Eschmeyer method probably is best suited to the conditions that prevailed in this study. This approximation is considered most reliable when the ratio B/P is greater than 0.25 during most of the experiment, whereas the Schnabel method gives a less accurate estimate when this occurs. In the Eastport study, the ratio was greater than 0.25 for most of the time.

Early estimates were relatively high for each method, but as the number of recaptures increased the estimates steadily reduced. The values determined from the three methods are shown in Table 1. The Schnabel and Schumacher-Eschmeyer estimates are rather close and each has the same year-to-year trend. The Petersen values are more variable than the other two.

A new method for population estimation was suggested by the repeated recapture of a great many

Table 1

Population estimates of Eastport redfish computed by (1) Petersen, (2) Schnabel, and (3) Schumacher and Eschmeyer methods

	Petersen estimate[1]				Schnabel estimate[2]			Schumacher and Eschmeyer est.[3]
Date	A Total no. fish caught	B No. tagged fish available	C No. tagged fish caught	P Estimated population	B	C	P	P
1956								
September	1296	2106*	155	17609	2106	155	17609	17609
November	102	2106	25	8592	3231	25	16994	16731
September—November	1398	2106	180	16357				
1957								
May	20	3257	12	5428	3257	12	16271	15741
June	98	3257	48	6650	3257	48	14347	13382
July	644	3256	274	7653	3307	276	10800	9970
August	891	3256	397	7308	3489	428	9197	8626
October	100	3244	58	5593	3648	65	8966	8406
November	336	3244	136	8015	3676	162	8780	8285
December	135	3243	49	8935	3784	57	8789	8321
May—December	2224	3243**	974	7405				
1958								
February	28	3241	9	10083	3862	10	8791	8329
March	58	3241	27	6962	3879	30	8760	8306
May	128	3241	44	9428	3907	61	8735	8300
June	166	3241	104	5173	3974	125	8438	7997
July	361	3241	249	4699	4014	306	7795	7349
August	795	3240	519	4963	4014	694	6892	6495
September	85	3233	47	5847	4047	63	6856	6466
October	226	3230	94	7766	4069	141	6838	6469
February—October	1847	3230	1093	5453				
1959								
June	122	3224	54	7284	4069	75	6832	6474
July	315	3222	126	8055	4087	199	6807	6474
October	44	3089	26	5228	4101	36	6786	6454
December	35	3089	13	8317	4119	17	6795	6467
June—December	516	3089	219	7278				
1960								
February	100	3089	56	5516	4125	80	6753	6429
March	76	3080	30	7803	4134	49	6747	6429
April	103	3065	9	35077	4134	22	6834	6529
May	93	3059	33	8621	4134	51	6847	6547
July	117	3049	45	7927	4134	73	6842	6548
August	108	3049	45	7318	4134	78	6816	6527
September	66	3049	28	7187	4134	39	6818	6535
February—September	642	3049	246	8217				

[1] Using only fish released in 1956.

[2] Using all fish released prior to month of estimate.

[3] Based on same data used in computing Schnabel estimate.

* Released in July—August 1956.

** Minimum number available throughout the year.

fish, an unusual aspect of the present study. For this method to be successful, it is necessary that all recaptured fish be returned to the water, and that all untagged fish be tagged and set free. As operations continued, the number of one-, two- and three-time recaptures reached substantial proportions, and some fish were recaptured as often as six and seven times. As these numbers increased, it became apparent that a consistent relationship existed between the groups. It was noted that, where n equals the number of times captured, the ratio $n/n + 1$ was approximately the same value between adjacent groups. A similar numerical relationship occurred between the two- and three-time captures as was shown between the four- and five-time captures. When the numbers of fish were converted to logarithms and plotted against the number of times captured, the result was very nearly a straight line (Fig. 3). If this semi-logarithmic, straight-line relationship exists so strongly between randomly selected groups of fish that were captured one, two, three or four times within a 1-year period, it is then logical to extrapolate the curve to the y-axis to obtain an estimate of the total population available. In Figure 3, a straight line fitted to the upper four points intersects the y-axis at about 18,000, which is a slight over-estimate of the value that would result from fitting the actual curve to all of the points.

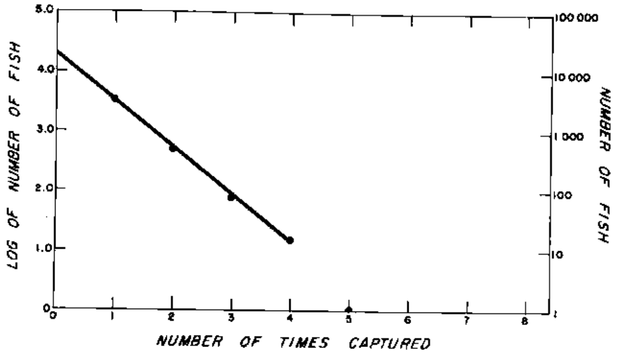


Figure 3. Semi-logarithmic relationship between groups of redfish arranged according to the number of times captured. Based on the numbers of fish tagged in 1956 and recaptured in 1957.

The repeated recapture method appears to be free of sampling bias since the probability of catching either an untagged fish, a first time recapture, or a multiple recapture fish, is proportional to the relative abundance of each group in the population. The tagged groups would be indistinguishable in the tagged population except for the number of times each had been captured previously. If the above listed assumptions are met, the population estimate obtained by this method should fall very close to the actual population number.

The broad range of population estimates resulting from the four methods suggests that perhaps some estimates are too high while others are too low, and that the true population size probably lies somewhere between 6,000 and 20,000 fish. However, there is no evidence to support, with confidence, any particular value in preference over any of the others.

The wide variation in estimates also suggests the possibility that one or more of the stated assumptions regarding the population has not been met. Although there are no specific data to support the opinion, daily and seasonal variations in the ratio of tagged and untagged fish lead us to believe that the number of redfish in the waters surrounding the tagging area might be considerably higher than the number shown hy the Schnabel and Schumacher-Eschmeyer estimates. Under the conditions of an open marine environment, it seems incredible that a mobile, apparently unrestricted population could be so limited in its distribution. It is suspected that some aspect of behavior, perhaps territorialism, accounts for the high incidence of recaptures and has resulted in population estimates that are too low.

Growth studies of the population indicate the probability that redfish tagged with the opercle tag suffer some malnutrition from reduced natural food supply, and, perhaps, are more likely to bite on a baited hook than untagged fish. If this is so, it would negate the third assumption of this study, and the improbable condition would prevail where tagged fish would be more vulnerable to capture than untagged fish. This would have opposite effects on the two types of population estimates used here. An increase in the rate of recapture would result in greater numbers of repeated recaptures. This would serve to raise the line fitted to the repeated-recapture data and would result in an over-estimate of the population size determined by this technique. On the other hand, for the standard methods, an increase in the recapture rate of tagged fish would result in an artificially high ratio of tagged to untagged fish, reducing the apparent number of untagged fish and resulting in an under-estimate of the population size.

There is insufficient evidence to question the applicability of the other assumptions used in the study. It is possible that other factors such as differential tagging mortality, or changes in the behavior of tagged fish, could alter the probability of recapture. If tagging mortality were a significant factor, it would tend to reduce the number of multiple recaptures, so causing an under-estimate of the population. If the fish became hook-shy, this would similarly reduce the probability of repeated recapture, with similar effect. The very fact that so many multiple recaptures have occurred suggests that this is not a major cause of error.

Mortality Estimates

Reduction in the percentage of 1956 tags present in the monthly samples of redfish was used to estimate the mortality rate of tagged redfish. More than 3,200 redfish were tagged during the period July through November 1956. Varying numbers of these were recaptured in the samples collected each year since that time. The monthly percentage incidence of this group of tagged fish is shown in Figure 4. Recaptures in 1956 were comparatively low, but the proportion reached as high as 69 percent in 1958 (Table 2). The trend has been decreasing since then. A regression line was fitted to the sample data for 1957—1960, giving equal weight to each of the monthly values of tag incidence. The slope of the line indicates a reduction from an average of 50.9 percent occurrence in mid-1957 to 40.2 percent in mid-1960. If this line were extrapolated to 1 December 1956, the time at which all of the 3,257 fish tagged in 1956 were first available for recapture, the value of the ratio would be 53.0 percent. When these values are equated to percentage of the initial number of tags, there is an annual reduction of 6.7 percent per year during the 4-year period.

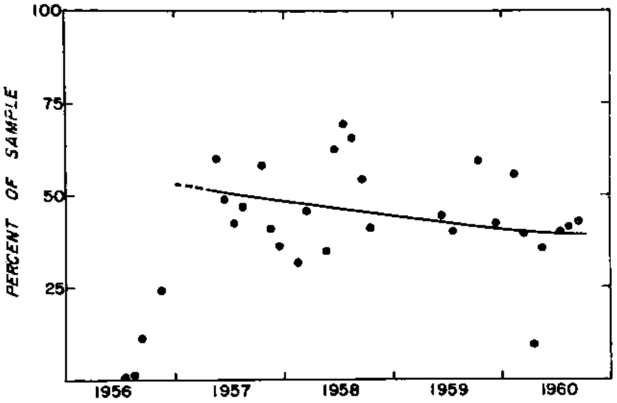


Figure 4. Changes in the monthly percentage incidence of fish tagged in 1956, recaptured during 1957 through 1960.

Table 2

Number and percent recaptured of redfish tagged at Eastport in 1956

	Total number caught	Number of 1956 tagging recaptured	Percent of sample tagged
1956 — July	126	0	0.0
August	1980	8	0.4
Sept.	1296	155	12.0
Nov.	102	25	24.5
1957 — May	20	12	60.0
June	98	48	49.0
July	644	274	42.5
August	891	397	44.6
Oct.	100	58	58.0
Nov.	336	136	40.9
Dec.	135	49	36.3
1958 — Feb.	28	9	32.2
Mar.	58	27	46.6
May	128	44	34.4
June	166	104	62.7
July	361	249	69.0
August	795	519	66.5
Sept.	85	47	54.1
Oct.	226	94	41.6
1959 — June	122	54	44.3
July	315	126	40.0
Oct.	44	26	59.1
Dec.	35	13	37.1
1960 — Feb.	100	56	56.0
Mar.	76	30	39.5
April	103	9	8.7
May	93	33	35.5
July	117	45	40.2
Aug.	108	45	41.7
Sept.	66	28	42.4

Aside from the previously mentioned behavioral factors that could influence the number of tagged fish recaptured, reduction in the percentage of tagged fish in the samples could be affected by the following factors: emigration of tagged fish, immigration of untagged fish, recruitment of young fish, differential fishing mortality of tagged and untagged fish, tagging mortality and natural mortality of tagged fish. The relatively high incidence of tagged fish throughout the 4-year period suggests that emigration and immigration were of comparatively low magnitude. Since there is no evidence of tagging mortality, it is assumed to be negligible. In this study there was no measurable fishing mortality, because virtually all of the recaptured fish were returned to the water unharmed. The remaining causes of tag reduction are recruitment of young fish and natural mortality.

Recruitment of a slow-growing species is difficult to measure, since it is spread over a longer time period than with faster-growing fish and does not appear as a seasonal influx of small fish that is readily discernible in size composition measurements. During this study there was no evidence of additions of small fish into the population, and recruitment is assumed to have been relatively low and of a gradual nature. Direct measurement of recruitment is therefore very difficult. However, if recruitment and immigration of untagged fish are equal to the natural mortality of untagged fish, then the change in the ratio of tagged: untagged fish is equal to the natural mortality.The comparatively low average reduction of 6.7 percent per year, a maximum value, suggests that natural mortality of tagged redfish is of low magnitude.

It is not suggested that this measurement of natural mortality should be considered as a prohahle mortality rate for the offshore redfish stocks. It is the value obtained from an atypical population existing under conditions that approximate to a modified aquarium experiment. Many factors could prevail to influence this value in either direction. However, this value of 6.7 percent per year is a first approximation of natural mortality available for *Sebastes* anywhere, and it may serve as a guide for population studies until more precise mortality estimates of exploited populations are available.

Summary

More than 2,400 redfish were recaptured from a total of 6,000 tagged since 1956 at Eastport, Maine. Population estimates using three accepted estimation methods indicate a population size between 6,500 and 9,000 fish. A new estimation technique based on the repeated recapture of large numbers of fish indicates a population of 18,000 fish. The difference in estimates is attributed to the unusual behavior of the Eastport redfish, resulting in unrealistically low population values using the standard estimation methods.

A mortality estimate based on the returns of fish released in 1956 indicates a natural mortality rate of 6.7 percent per year.

References

KELLY, GEORGE F., and ALLAN M. BARKER 1961. Observations on the behaviour, growth and migration of redfisb at Eastport, Maine. *Rapp. Cons. Explor. Mer*, **150**: 263—275.

RICKER, WILLIAM E. 1948. Methods of estimating vital statistics of fish populations. *Indiana Univ. Publ., Sci. Ser.*, No. 15, 101 p.

SCHNABEL, ZOE E. 1938. The estimation of the total fish population of a lake. *Amer. Math. Mon.* **45** (6): 348—352.

SCHUMACHER, F. X., and R. W. ESCHMEYER 1943. The estimate of fish population in lakes or ponds. *J. Tenn. Acad. Sci.*, **18**: 228—249.

32.

Effect of Tagging on Redfish Growth Rate at Eastport, Maine

By

GEORGE F. KELLY and ALLAN M. BARKER*

Introduction

The occurrence of an inshore stock of redfish (*Sebastes marinus* L.) in shallow water at Eastport, Maine, has, for the first time, permitted extensive tagging of this species for growth and migration studies. Tagging began in 1956 and has continued to the present time. Initial results of the studies were reported in an earlier paper (Kelly and Barker, 1961) which reviewed the factors contributing to the unusual occurrence in shallow water of this deep-water fish, and summarized the observations on behavior, growth and migration through 1958.

In brief review, the redfish are present at Eastport throughout the year. They come to the surface at night, and are readily caught on hook and line as they feed on concentrations of the euphausiid shrimp *Meganyctiphanes norvegica.* A large number of the tagged fish have been recaptured in the vicinity of the tagging site, and many appear to display defensive territorial behavior and preference for particular locations. There is no evidence that these fish move to offshore fishing grounds at any time of the year.

During the first 3 years of tagging, 5419 fish were tagged with Petersen discs (Cons. Perm. Int. pour l'Explor. de la Mer, 1953) on the operculum. During 1959 and 1960, an additional 586 fish were tagged with modified yellow plastic spaghetti dart tags (Everhart and Rupp, 1960) applied in the flesh of the dorsum. More than 2000 of the Petersen disc-tagged fish have been recaptured; most of these were measured and returned to the water unharmed. Many have been recaptured two or more times. This paper deals with the analysis of the recapture data from the Petersen disc tagging, the returns of dart tags being insufficient for analysis at the present time.

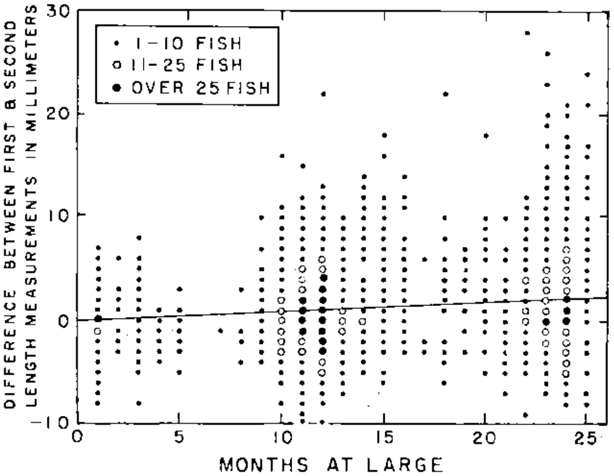


Figure 1. Measured growth of 2500 tagged redfish.

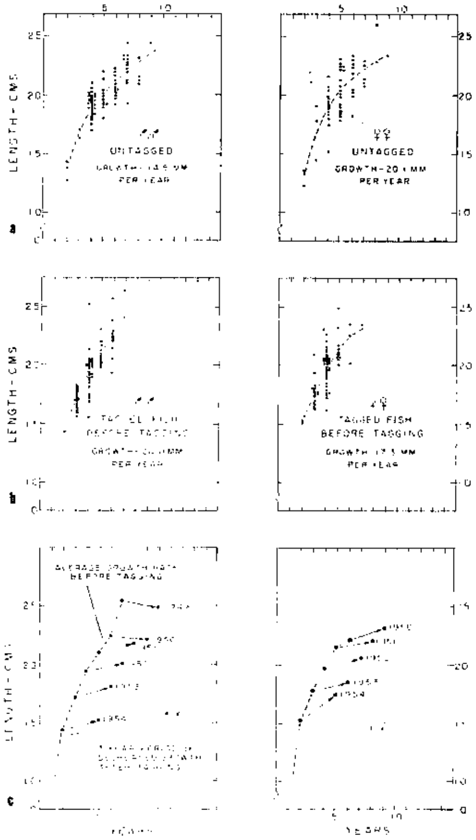


Figure 2. Comparison of growth rate of tagged and untagged redfish. a. Growth of untagged fish determined from otoliths. b. Growth of tagged fish prior to the time of tagging, determined from otoliths. c. Growth of tagged fish determined from length measurements.

Results

Measurements of recaptured fish obtained early in the study showed the growth of tagged fish to be much slower than that determined from previous studies of Gulf of Maine redfish otoliths (Kelly and Wolf, 1959). A regression line fitted to the growth

---

* U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Mass., U.S.A.

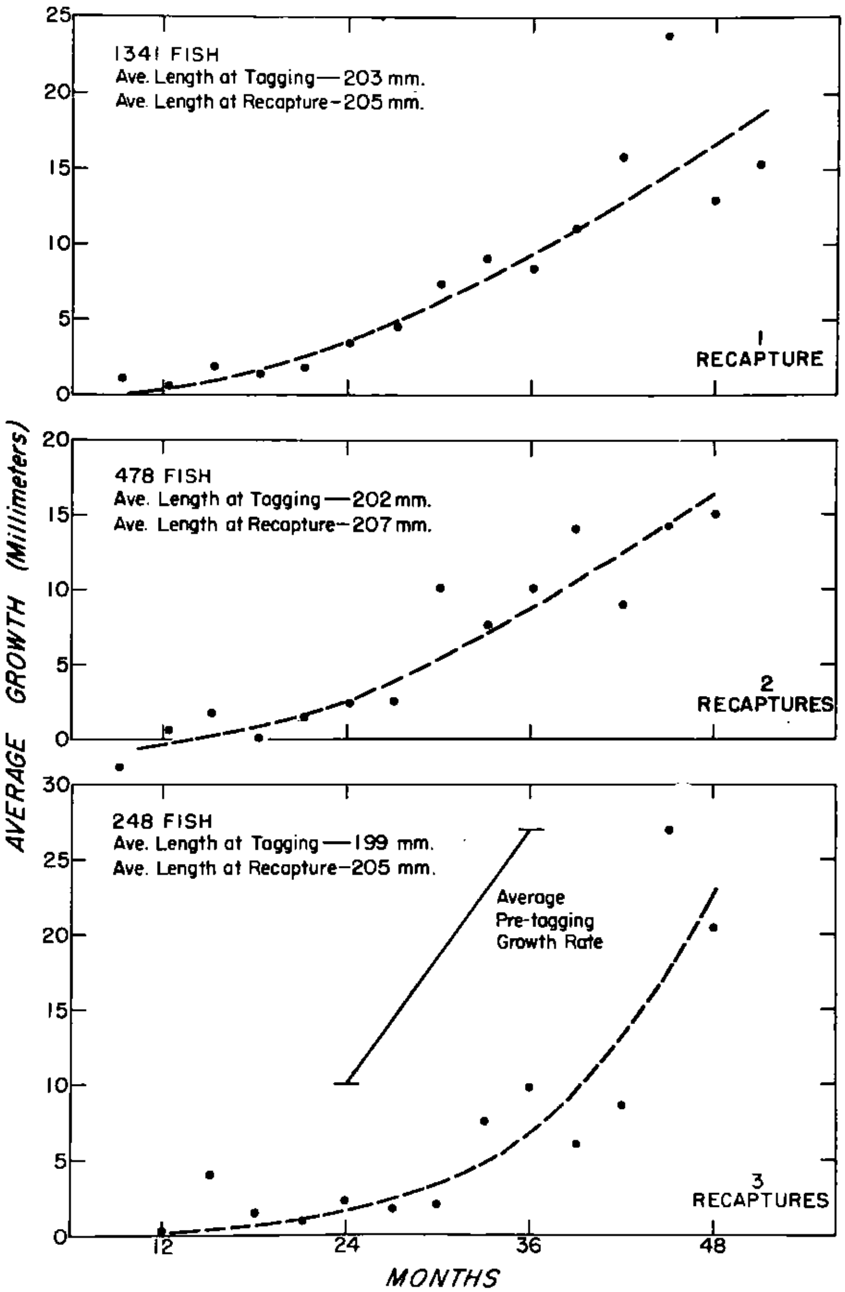


Figure 3. Comparison of changes in growth rate of tagged fish recaptured one, two and three times during a 4-year period.

increments of 2500 fish, measured over a 2-year period, showed an average increase of 1 mm per year (Figure 1).

Examination of otoliths of tagged and untagged fish disclosed a consistent difference in the pattern of zone formation between the two groups. Otoliths from untagged fish were similar to those of offshore Gulf of Maine redfish, the zone pattern consisting of a regular sequence of alternating opaque and hyaline zones. Otoliths of tagged fish contained a broad hyaline zone at the edge which was not present in the otoliths of untagged fish. The time of formation of the hyaline zone appeared to coincide with the time of tagging.

Growth rate determined from otoliths of untagged fish indicated an annual growth increment of 15 mm for males and 20 mm for females within the age range of 2 to 9 years, values close to those determined for offshore Gulf of Maine redfish (Figure 2).

Growth studies from otoliths of tagged redfish showed the growth rate prior to the time of tagging to be the same as the growth rate of untagged fish (Figure 3). Growth after tagging was very slow, the broad hyaline zone representing 2 or 3 years of diminished growth during which time the normal otolith pattern was disrupted (Figure 2).

While it was apparent that tagging influenced growth rate, it was impossible to state which aspect of the tagging operation was the primary cause. Since the tag did not physically interfere with the operation of the fish's mouth, and the tagged fish were readily caught on baited hooks, it appeared that they were behaving in a normal way. The decreased growth rate of apparently normal fish suggested that the psychological effect of tagging was a possible cause of diminished growth. A more probable cause, however, was judged to be the influence of the opercle tag in serving to startle live prey when the fish was feeding, frequently causing the prey to escape. The reduced intake of food resulting from this would, in turn, reduce the growth rate. Similarly, this would stimulate the hungry fish to bite readily on baited hooks, giving a false impression of normal behavior.

Additional recapture data have been collected since 1958, permitting further study of long-term influences of tagging on growth rate. The studies have had two aspects; first, the comparative effect of repeated recapture on the growth of fish recaptured once, twice and three times; and second, the duration of the slow growth period and the adjustment of the fish to the circumstances of tagging.

The average growth increments from measurements of fish recaptured one, two and three times during a 4-year period are summarized in Figure 3. In each group, growth was very slow for about $2^1/_2$ years. It then increased markedly in all groups, and, contrary to expectations, during the fourth year was greatest in the group that had been recaptured most frequently. While this may be an artifact caused by the relatively small number of three-time-recaptures, the growth rate of this group has very nearly equaled the rate of growth of untagged fish. It is clearly shown that the growth rate of each group increased during the third and fourth year after tagging, and each has approached the growth rate of the pre-tagging period. The comparison of otoliths of fish tagged for 1, 2, 3 and 4 years indicates that the hyaline zone at the otolith edge has persisted for this entire period, increasing gradually so that it is broadest in those at large for the longest time (Figure 4). In many otoliths of fish tagged for 3 or 4 years, thin traces of opaque material are visible within the hyaline zone, suggesting that a slow resumption of summer growth has occurred in later years.

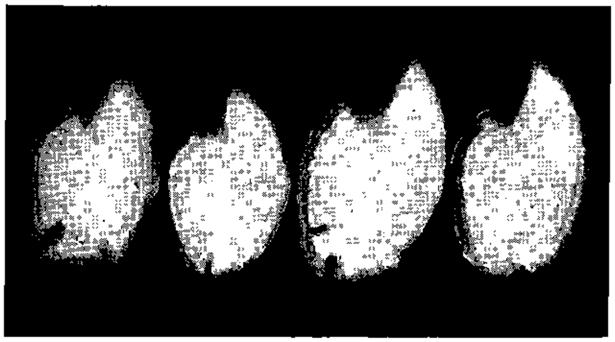


Figure 4. Comparison of otoliths of fish tagged 7 months, 2 years 3 years and 4 years

The comparison of otoliths of fish recaptured one, two or three times during periods of 3 or 4 years did not show any discernible differences that could be attributed to the effects of repeated recapture (Figure 5). Otoliths from fish that had been recaptured once during 4 years could not be separated objectively from those fish that were recaptured three times in 4 years.

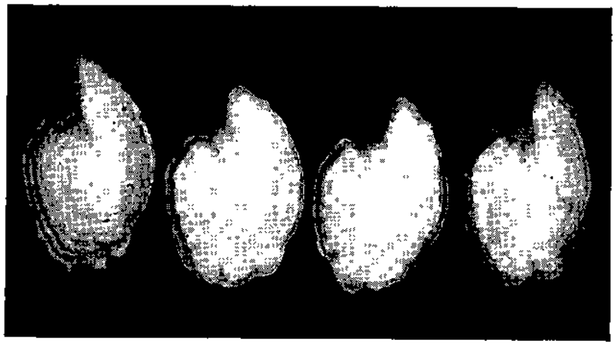


Figure 5. Comparison of otoliths of untagged fish and fish tagged for 4 years and recaptured one, two and three times.

Discussion and Conclusions

The obvious effect of tagging was to inhibit growth of the fish for about $2^1/_2$ years, after which time the growth rate slowly increased. Additional handling of the tagged fish during repeated recapture and release in subsequent years did not appear to influence the rate of resumption of growth. These facts made possible a more precise determination of the probable cause of the initial cessation of growth.

Recaptured fish were handled in an almost identical manner to those caught for the first time. Each was hooked, landed, held in a live car for several hours, measured and returned to the water. In addition, the new fish were tagged through the opercle, a rather minor operation since the pin was inserted through the thin membranous portion. The two operations are so alike that it is illogical to name the first as the cause of psychological shock without considering the second operation the same. Since the second operation did not affect growth, it is therefore considered unlikely that either operation was sufficiently damaging to cause the observed effect, and psychological shock is discounted as the primary cause of decreased growth rate of tagged fish.

Although the opercle tag does not physically hinder the fish, its role in diminishing the fish's food supply, by startling live prey and causing it to escape, remains as the most probable cause of diminished growth rate. Apparently this influence changes in time, as evidenced by the eventual resumption of growth. Of the several possible contributing factors, fouling with marine growth is the most obvious occurrence that could alter the effect of the tag. The fouled tag would be less visible, and therefore less effective in arousing the potential prey. Also, the fish may have adapted to new conditions and learned to feed despite the presence of the tag. Either, or both, of these factors could account for the sequence of changes in growth rate.

Tagging mortality cannot be entirely discounted as a possible explanation for the sequence of changes in growth rate. If tagging mortality removed the slower-growing fish, those surviving to be recaptured would display an ever-increasing growth rate as time passed and the number of recaptures mounted. However, there is little evidence of tagging mortality, since no sickly or injured fish were recaptured during field operations. All of the recaptured fish appeared to be normal and in healthy condition. Furthermore, the recapture of as much as 40 percent of the tagged population, and the comparatively large number of repeated recaptures, serves to minimize the probability of tagging mortality as a major factor influencing the apparent growth rate of the tagged fish.

Summary

An initial decrease in growth rate occurred when redfish were tagged with opercle tags. Otoliths of tagged fish showed a zone of hyaline material at the edge that was not present in the otoliths of untagged fish. After $2^1/_2$ years of diminished growth, the growth rate gradually increased toward the pre-tagging value. Fish that were caught and released three different times appeared to grow as fast as those recaptured only once. The sequence of growth changes might be explained as the effect of the opercle tag causing the escape of potential prey, thus reducing the food supply and decreasing the growth rate of the fish. The eventual resumption of growth is probably the result of increased food intake caused by a combination of two factors, the tag becoming less visible because of fouling with marine organisms, and the fish learning to feed in spite of the presence of the tag.

References

Conseil Permanent International pour l'Exploration de la Mer. (1953). A guide to fish marks used by members of the International Council for the Exploration of the Sea. *J. Cons. int. Explor. Mer*, **19** (2): 241—289.

EVERHART, W. HARRY and ROBERT S. RUPP. 1960. Barb-type plastic fish tag. *Trans. Amer. Fish. Soc.*, **89** (2): 241—242.

KELLY, GEORGE F. and ALLAN M. BARKER. 1961. Observations on the behavior, growth and migration of redfish at Eastport, Maine. *Rapp. Cons. Explor. Mer*, **150**: 263—275.

KELLY, GEORGE F. and ROBERT S. WOLF. 1959. Age and growth of the redfish (*Sebastes marinus*) in the Gulf of Maine. *Fish. Bull., U. S.*, **60** (156): 31 p.

33.

An Analysis of Silver Hake Tag Returns

By

RAYMOND L. FRITZ*

The success of a tagging or marking experiment depends on the use of healthy, undamaged fish marked with a durable tag that will be detected readily and returned with information about the tagged fish. To achieve the planned objectives of an experiment, precise information regarding the location and date of recapture of the fish, depth of water, and other pertinent data is necessary. Generally, this information is most accurate when the tag is recovered by the person recapturing the fish. Information received from other sources is generally incomplete. However, we must often depend upon recoveries made ashore after the fish are landed. When the fish are utilized in different ways, tags will be recovered from different kinds of processing plants. Some of these are more efficient than others in detecting and reporting tags.

The silver hake (*Merluccius bilinearis*) is an example of a Western Atlantic species which is utilized by several important United States fisheries. It is used largely for human food, but substantial quantities are also used for animal food and for industrial use (fish concentrates, fish meal, and oils). This paper compares the relative success of tag recovery from these three fisheries, and compares the number of tags returned in the various stages of the fish processing system.

During the spring and summer of 1957 and 1958, tagging experiments were conducted from trap nets, otter trawls, and hook and line along the coastal waters of Massachusetts and New Jersey and offshore on Georges Bank. The tag used (Fritz, 1959) consisted of an 8-inch piece of yellow Vinyl plastic tubing with an Atkins tag tied at one end with a figure eight knot, the other end inserted through the flesh of the dorsum of the hake and knotted (Fig. 1). This is a very conspicuous tag.

Reward posters were put up at almost every processing plant, regardless of type, to notify and remind plant employees and fishermen alike of the tagged silver hake and the appearance of the tag.

Table 1 compares the returns for each of the three kinds of fisheries. The human food fishery turned in the largest number of tags, with the animal food fishery next, and finally the industrial fishery, even though more trips were made and more silver hake landed by the industrial fishery than the animal food fishery. The number of tag returns from the human food fishery was significantly greater than the others, even though the vessels from the three fisheries often fished side by side on the same grounds.

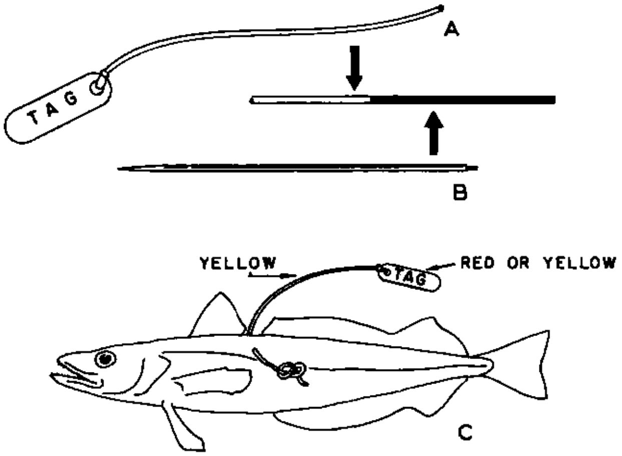


Figure 1. Tag used on silver hake.

Table 1
Comparison of returns from three kinds of fisheries

	Human food	Animal food	Industrial
Total pounds landed 1957—1958 combined	182 million	36 million	43 million
Relative pounds landed	5.0	1.0	1.2
Number of trips*	2019	750	1861
Number of tags returned	222	7	1
Percent returned	4.0	0.1	0.02

* Estimated

An analysis of the data was made to determine when the tagged fish were detected, using the following categories: when caught, while unloading, during processing, by consumer, and source unknown. The results are presented in Table 2.

Since only one tag was returned from the industrial fishery no conclusion can be drawn from returns from that source, except that neither the fishermen nor the processors detect many tags in this fishery. In the animal food fishery 5 of the 7 recoveries were made by the fishermen, 1 while unloading and 1 by the consumer, the consumer in this case being the animal farmer who handled the fish while feeding his animals (mink). In the human food industry the greatest percentage of returns came from processors, with an almost equal number from the fishermen.

---

* U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

Table 2
Comparison of returns, with time of detection

When detected	Human food	Animal food	Industrial use	Source unknown	Total number	Percent
When caught	85	5	1	2	93	38.9
While unloading	16	1	—	1	18	7.5
During processing	103	—	—	—	103	43.1
By consumer	12	1	—	—	13	5.4
Unknown	6	—	—	6	12	5.0
Total	222	7	1	9	239	100.0

Since the vessels in the three industries often fish the same stocks of fish at the same time, the difference in returns from the fishermen is probably not due to a different percentage of recaptures but to differences in detection in the different fisheries. The fishermen fishing for human food grade their catch on board and sometimes ice and box it on board. Thus, they handle the fish individually and have good opportunity to see the plastic tags, whereas the fishermen in the animal and industrial fisheries move the fish *en masse* and have much less opportunity to detect the tags.

In the human food industry the fish are individually handled after they are landed, both in packing and in preparation for eating. This explains the returns from the human food fishery at stages after unloading. It is interesting to note that the ratio of the number detected at unloading to the number detected at capture is the same for the animal food fishery as the human food fishery.

Total returns amounted to only 4.3 percent. Obviously, there is either a high mortality of tagged fish or a low recovery of tags. The tags are so conspicuous that it is difficult to understand how they could pass through a packer's hands. But this they do, as evidenced by the 12 tags recovered by the ultimate consumer in the human food fishery. The silver hake is not a large fish and it does not seem practical to extend the plastic tube. Future experiments may involve use of different colors and a change in the tag itself.

A higher rate of return in the industrial fishery could be effected by use of a different kind of tag which is recovered mechanically, but the expense of such machinery prohibits installation at this time.

Summary

Silver hake are landed in the U.S. for three different uses; human food, animal food, and industrial products. The fish landed for the three different purposes are handled and processed in three different ways. In 1957 and 1958, 5,495 fish were tagged. A little over 4 percent of the tags were returned, almost all from the human food fishery. This is explained by the fact that the fish in this fishery are given more individual attention on board ship and ashore than in the other fisheries.

Reference

FRITZ, RAYMOND L. 1959. A summary of hake tagging in Europe and the United States, 1931—1958. *J. Cons. int. Explor. Mer*, **24** (3): 480—485.

34.

Haddock Tag Returns in Relation to Fish Condition

By

JOHN P. McDERMOTT and ROBERT LIVINGSTONE, Jr.*

Introduction

During the past 10 years, more than 15,000 haddock have been tagged in a series of experiments as part of a migration study. Returns, which are now virtually complete, varied from 0.7 to 17.5 percent for individual experiments. A major factor contributing to this wide variability appears to be water temperature. Jensen (this Symposium, No. 30) found that the highest returns were obtained from fish tagged in the spring, at which time water temperature is minimum and the water column is isothermal. Type of tag is another important factor affecting returns, spaghetti tags yielding higher returns than Petersen disc tags (Jensen, contribution No. 30). Still another factor is the physical damage resulting from capture. In this study returns of haddock tagged on one spring cruise were examined in relation to physical condition of the fish at time of tagging.

Materials and Methods

A total of 1,979 haddock were tagged on Georges Bank and Browns Bank in the spring of 1957. The fish were caught with a standard No. 41 otter trawl towed from 20 to 60 minutes in depths from 25 to 60 fathoms. The cod end was opened on deck and the haddock placed in holding tanks of circulating sea water. Haddock that lost their equilibrium were not tagged. Only fish which actively swam in the normal horizontal position were selected for tagging; they were classified as undamaged if no scales were lost and if there was no damage to fins. Damaged fish were placed into one of three categories, corresponding to the following types of damage:

1. Bloody fins only
2. Bloody areas on the body and/or loss of up to 10 percent of scales. (Fish with more than about 10 percent scale loss were not tagged.)
3. Both fin and body damage (1 and 2).

Three tagging methods were used:

1. Petersen disc tags ($^{1}/_{2}$-inch diameter) attached with stainless steel pins through the operculum (Rounsefell and Kask, 1945)
2. Petersen disc tags pinned through the flesh of the dorsum
3. Spaghetti tags through the flesh of the dorsum (Wilson, 1953).

The spaghetti tag was a 350-mm length of 2.5 mm (O.D.) yellow, extruded Vinyl tubing with a message and serial number printed on the tubing. The tag was inserted with a needle (described by Fritz, 1959) through the dorsal musculature between the first and second dorsal fins, and the ends of the tubing were knotted together.

In each haul, method (1) was alternated with methods (2) and (3) so that approximately twice as many Petersen disc tags on the operculum (922) were used, as Petersen disc tags through the dorsum (572), or spaghetti tags (485). The length frequency of fish tagged with each method was approximately the same.

Results

For each tag type, the percentage of returns from undamaged haddock was higher than returns from any of the three categories of damaged fish. Spaghetti tag returns from damaged fish ranged from 2.4 to 9.7 percent as compared with 17.4 percent returns from undamaged fish (Table 1). Petersen disc tag (operculum) returns from the damaged categories ranged from 0 to 2.7 percent, as compared with 5.8 percent from undamaged fish. Corresponding figures for Petersen disc tag (dorsum) returns were 1.4 to 3.2 percent from damaged fish and 5.6 percent from undamaged fish.

Table 1

Tag returns of undamaged and damaged haddock tagged with spaghetti tags and Petersen discs

	Undamaged	Damaged			
		Fins	Body	Both fins and body	Total
	Petersen disc (operculum)				
No. tagged . . .	670	146	69	37	252
No. returned .	39	2	0	1	3
% returned . .	5.8	1.4	0	2.7	1.2
	Petersen disc (dorsum)				
No. tagged . . .	357	63	79	73	215
No. returned .	20	2	2	1	5
% returned . .	5.6	3.2	2.5	1.4	2.3
	Spaghetti tag				
No. tagged . . .	305	103	41	36	180
No. returned .	53	10	1	2	13
% returned . .	17.4	9.7	2.4	5.6	7.2

---

* U. S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Mass., U.S.A.

For each tagging method, returns from all three categories of damage were combined and compared with returns from undamaged fish. χ^2[*] values were 8.00 ($Pr = 0.005$), 2.71 ($Pr = 0.10$), and 9.08 ($Pr = < 0.005$) for tagging methods (1), (2), and (3), respectively. Combination of these values ($\chi^2 = 19.79$, 3 degrees of freedom, $Pr < 0.005$) leaves little doubt that injury associated with damage to fins and body significantly reduces survival of tagged haddock.

The consistently lower returns from fish with body damage only as compared with returns from fish with fin damage only suggest that injuries associated with loss of scales and lesions on the body may be more severe. However, the data are not conclusive on this point. Comparison of returns from fish with body damage only and fin damage only (using the same method described above) gave a χ^2 value of 2.32 which has a probability of about 0.15.

It may be noted that percentage tag returns were higher with spaghetti tags than with Petersen disc tags, which agrees with the result obtained by Jensen (No. 30).

Discussion

Beverton, Gulland, and Margetts (1959) found returns from tagged whiting with no loss of scales to be three times greater than returns from whiting with severe scale loss. Fin injury and scale loss reduced the percentage of tag returns for yellowtail flounder from 19.7 percent for uninjured fish to 3 percent for injured fish (Royce, Buller and Premetz, 1959). In the present study survival rates appeared to be reduced by about one third to one half, depending on type of damage.

Loss of scales or mucus and lesions in the skin may permit improper fluid exchange and invasion of pathogenic organisms, and thus contribute to tagging mortality. Fin injury and scale loss may also be associated with internal injuries.

Summary

Haddock tag returns were examined in relation to physical appearance of fish at time of tagging. Fish selected for tagging were classified either as undamaged or damaged and the latter group was further subdivided into three categories:

1. Bloody fins
2. Bloody areas on body and/or scale loss
3. Both body and fin damage.

Returns from damaged fish (all three categories combined) were significantly lower than returns from undamaged fish, thus indicating that injury associated with fin damage and body damage reduces survival of tagged haddock. Consistently lower returns from fish with body damage only as compared with fish with fin damage only suggest that injuries associated with loss of scales and lesions on the body may be more severe. However, returns from these two categories of damage did not differ significantly.

Spaghetti tags yielded approximately three times as many returns as Petersen disc tags on the operculum or dorsum.

References

BEVERTON, R. J. H., J. A. GULLAND, and A. R. MARGETTS. 1959. Whiting tagging: how the tag return rate is affected by the condition of fish when tagged. *J. Cons. int. Explor. Mer*, **25** (1): 53—57.

FRITZ, RAYMOND L. 1959. Hake tagging in Europe and the United States 1931—1958. *J. Cons. int. Explor. Mer*, **24** (3): 480—485.

JENSEN, ALBERT C. 1961. Further field experiments with tags for haddock. *This Symposium, Contrib.* No. 30.

ROUNSEFELL, GEORGE A., and JOHN L. KASK 1945. How to mark fish. *Trans. Amer. Fish. Soc.*, **73**: 320—363.

ROYCE, WILLIAM F., RAYMOND J. BULLER, and ERNEST D. PREMETZ 1959. Decline of the yellowtail flounder (*Limanda ferruginea*) off New England. *Fish Bull. U. S.*, **59** (146): 169—267.

WILSON, ROBERT C. 1953. Tuna marking, a progress report. *Calif. Fish Game*, **39** (4): 429—442.

---

[*] Test of homogeneity employing numbers returned and numbers not returned. Single degree of freedom comparisons, adjusted for continuity.

35.

The Estimation of Fishing Mortality from Tagging Experiments

by

J. A. GULLAND*

Introduction

Tagging experiments may be used to estimate fishing rates because at the instant of marking, the number of individuals in the marked population is known (assuming that there is no loss due to fish being killed by the tagging process). Returns are therefore a known and measurable fraction of the population. Because the numbers in the tagged population are steadily decreasing, partly at least through causes atypical of the natural population, the most reliable estimates of fishing rates relating to the most accurate estimates of numbers in the tagged populations are likely to be those made within as short a time as possible after tagging. Directly after tagging, however, the tagged fish will not be mixed with the natural population. If this mixing is quick, say nearly complete in a few days or weeks, then (with due correction for reduction in the tagged population in the mixing period), the fishing mortality can be estimated from returns in the period after mixing is effectively complete. For the North Sea plaice tagged fish are not completely mixed with the whole stock even after a period of years. They will therefore never have precisely the same fishing mortality as the stock as a whole, and the most useful estimate is not of fishing mortality rate on the tagged population, but the rate per unit fishing intensity. The present paper is concerned with making such estimates from various tagging experiments on the North Sea plaice, using various measures of fishing intensity.

Material

The data analysed here are from extensive experiments made in 1946, 1947 and 1948. Altogether some 30,000 plaice were tagged with the usual black ebonite Petersen discs, attached by silver wire. Most of the returns are direct from the fishermen and give positions that are generally accurate. Other fish are returned by workers on the fish market; these can usually be related to a known ship, and can then be ascribed, with varying degrees of confidence, to the ground where that ship has done most fishing during her trip.

The fishing intensity was determined from the records of British trawlers and seiners (these accounted for the majority of all returns) for which a record is made after each trip, giving details of catch, time at sea, time spent fishing, and fishing ground or grounds. For statistical purposes the North Sea has been divided into rectangles of 1° of latitude by 30′ of longitude (i.e. roughly 1,000 sq miles in area), and every trip is allocated, after interview, usually with the mate, to one or other of these rectangles, even though some fishing may have been done in other areas. From these records, two measures of fishing intensity were calculated. The number of hours fishing by vessels landing from each rectangle during each month could be tabulated directly from a computor. Because the average length of voyage was 8—10 days, these records in fact represent fishing between about the 25th of the previous month and the 25th of the named month of fishing. Secondly, for a limited number of rectangles, the number of boats actually fishing on each day was calculated; this was summarised in 10-day periods, reckoned from the day of marking. From these data of fishing activity, and the tag returns, the returns from any area in any time interval can be expressed as number per unit effort. Returns from fishing methods not represented in the effort statistics (e.g. foreign vessels and other types of gear) are omitted in the analysis.

The Catchability Coefficient

The returns per unit effort will be proportional t. the average number of tagged fish present in the areao The constant of proportionality will be q, the catchability coefficient. In the usual relation between fishing mortality and fishing intensity, $F = qf$, if, in the area considered, the tagged fish have the same distribution as the untagged fish. Thus, considering a small area round the marking position, for a time interval i we can write, in the obvious notation

$$n_i/f_i = q\,\bar{N}_i$$

If then the tags returned per unit effort are plotted against time the intercept at time 0, when $\bar{N}_i = N_o$, the number of fish tagged, can be used to give an estimate of q. An alternative form, and better for comparisons between experiments, is to plot the numbers returned per unit intensity as a proportion of the initial number tagged; then the intercept is itself q. This quantity, percentage recaptures per unit intensity, may be called the nominal catchability, equal to the actual catchability if all the fish tagged survive and are in the area considered. A minor error may be introduced because $\bar{N}_i$, the average

---

* Fisheries Laboratory, Lowestoft, England.

number present during a given time interval, is unlikely to be equal to the actual number present at the midpoint of the interval, so that $\bar{N}_i$ should be plotted at some time other than the midpoint. However, unless the change in abundance during the interval is very large the discrepancy will be small. Beverton and Holt (1957) show, in their Table 14.1, the precise changes (for the case of a constant exponential decline in tagged fish) for what is essentially this situation.

Data from more than one area can be taken together, and an estimate obtained for all, or part, of the area inhabited by the stock being investigated. Thus, using prefixes to denote values from a particular sub-division of the whole area,

$$q\,N_i = \sum_j q\,{}_j\bar{N}_i$$

or, expressing in terms of tags per unit fishing intensity, so that ${}_jf_i$ is in terms of, say, days fishing per statistical rectangle

$$q\,\bar{N}_i = \sum_j q\,{}_j\bar{N}_i = \sum_j \frac{{}_jn_i}{{}_jf_i}$$

or dividing by N_o, the number tagged,

$$q\,\frac{N_i}{N_o} = \Sigma\,\frac{{}_jn_i}{{}_jf_i\,N_o} \qquad (1)$$

i.e. the nominal catchability for the whole area is the sum of the nominal catchabilities for the sub-areas.

1946—7: Smith's Knoll releases

Most of the fish marked in 1946 and 1947 were released in the Southern Bight of the North Sea, mainly in the rectangle G4 (52° 30′N to 53°N, 1° to 2°E). In this rectangle the most important fishing ground is at Smith's Knoll — actually in the deeper water (20—25 fm) alongside the bank itself, which shoals to 3 to 8 fm. At the time of marking, this ground was one of the areas in the North Sea most intensely fished by English (and particularly Lowestoft) trawlers. In all, 12,576 marked plaice in separate batches were released in this rectangle, 8,394 of them actually at Smith's Knoll, during 1946 and 1947. The patterns of returns from different batches of releases were much the same, so that those in each year have been pooled. The effort was taken as the mean weighted by the number of fish released in each batch. In practice it was simplest to calculate

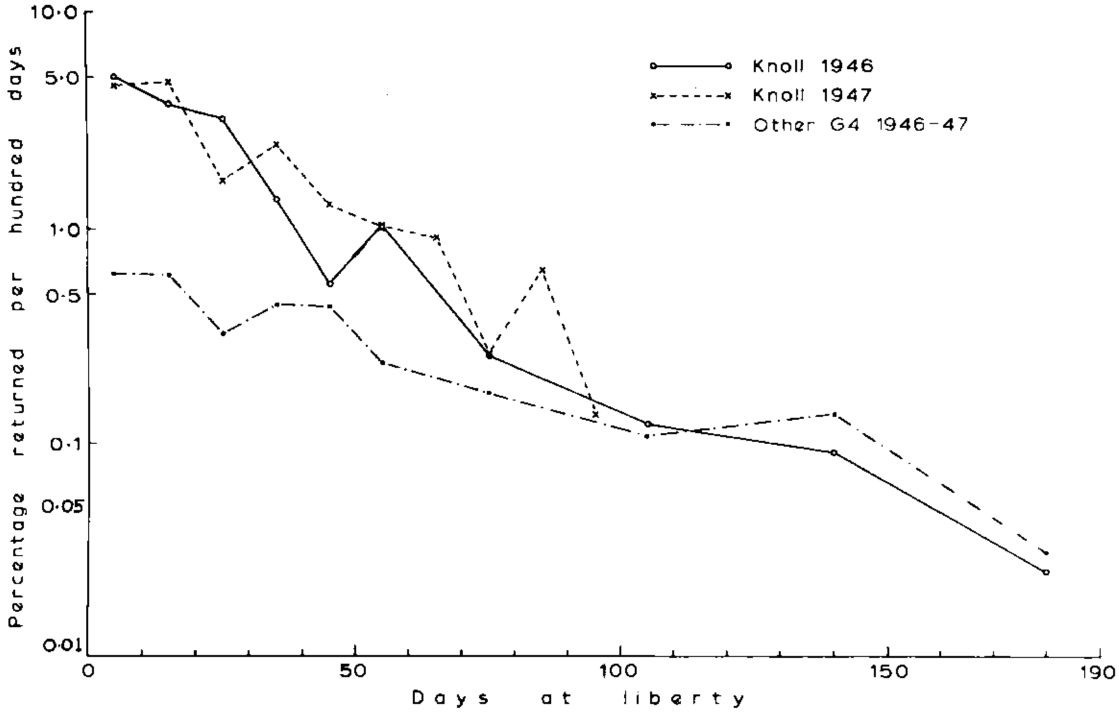


Figure 1. Decrease of nominal catchability coefficient (per cent of tags returned per unit fishing intensity) for three batches of plaice tagged in the Southern Bight of the North Sea.

directly the percentage returned per days' fishing (nominal catchability) in the form

$$\frac{\Sigma n_i}{\Sigma N_i f_i}$$

where, for the ith batch of fish,

N_i = number released

n_i = number recaptured } in the period considered, e.g. 10—19 days after marking

f_i = days' fishing

The nominal catchability was thus calculated for 10-day intervals up to 100 days from marking and (for the 1946 liberations) for further 30-day intervals up to 200 days. These are plotted against the mid-point of the interval, on a logarithmic scale, in Figure 1, the points for 1946 and 1947 being given separately, and showing remarkably close agreement. The fall-off (due to mortality, emigration and loss of tags) in the rate of return may not be described precisely by a straight line (i.e. an exponential decrease), but a curve may be readily drawn by eye to give an intercept at time 0 of 6% per 100 days.

Other 1946—7 releases

A further 4,182 tagged fish were released in rectangle G4, but away from Smith's Knoll. Recaptures from these were calculated for 10-day intervals up to 60 days, and for 30-day intervals up to 200 days; they have also been plotted in Fig. 1. Again the plot shows a fairly steady decline, but compared with the Smith's Knoll releases the initial level is much lower, 0.7% per 100 days absent, and the rate of decline is much slower. This difference may be reasonably explained by a different degree of concentration by the trawlers on the two sets of tagged fish. As time passes, the fish disperse from the tagging position and the two groups mix, so that eventually the return rates are the same. This mixing appears to be effectively complete after about 100 days. Fishing is concentrated near Smith's Knoll, so that the fishing rate on fish tagged there is higher than on the population of fish in the rectangle taken as a whole. Conversely, the fishing rate on those fish away from Smith's Knoll is lower than average. Though the fish tagged away from Smith's Knoll were not distributed evenly through the rest of the rectangle, the fishing rate on them is probably also lower than

Table 1

Nominal catchability coefficients (% returned per 100 days fishing) of plaice tagged in the Southern North Sea, according to rectangle of liberation and recapture, in 30-day periods. (Numbers of fish returned shown in brackets)

Recapture Rectangle	Release Rectangle					
	G3	H4	H5	Knoll (1946)	Knoll (1947)	Other G4
			0—29 days at liberty			
G3	0.49 (16)	0.52 (11)	0 .	0.09 (5)	No fishing	0.05 (2)
G4	0.33 (18)	0.42 (38)	0.15 (7)	4.07 (311)	3.88 (415)	0.53 (76)
G5	0.05 (1)	0.40 (7)	0.38 (9)	0.56 (20)	0.05 (7)	0.29 (10)
H4	0.31 (16)	0.16 (5)	0.07 (2)	0.04 (5)	No fishing	0.06 (4)
H5	0.07 (1)	0.08 (1)	1.31 (42)	0	0.03 (2)	0.14 (5)
Total	1.27	1.58	1.91	4.76	3.96 (4.09)	1.07
			30—59 days at liberty			
G3	0.07 (2)	0	0	0.06 (4)	No fishing	0.03 (2)
G4	0.25 (19)	0.28 (21)	0.20 (6)	0.97 (108)	1.65 (148)	0.37 (40)
G5	0.11 (2)	0.52 (5)	0.18 (4)	0.10 (4)	0.04 (4)	0.23 (7)
H4	0.10 (3)	0.36 (14)	0	0.02 (1)	No fishing	0.12 (9)
H5	0.15 (2)	0.22 (4)	0.62 (10)	0.08 (1)	0.03 (1)	0.25 (8)
Total	0.68	1.38	1.00	1.23	1.72 (1.84)	1.00
			60—89 days at liberty			
G3	0	0.03 (1)	0	0.02 (1)	No fishing	0.04 (3)
G4	0.15 (12)	0.17 (7)	0.12 (3)	0.26 (39)	0.65 (57)	0.21 (19)
G5	0.13 (1)	0.15 (2)	0.50 (1)	0.12 (4)	0.05 (3)	0.27 (11)
H4	0.20 (6)	0.27 (10)	0	0	No fishing	0.11 (8)
H5	0.21 (5)	0.06 (1)	0	0.08 (1)	0	0.53 (15)
Total	0.69	0.68	0.62	0.48	0.70 (0.82)	1.16
Numbers Tagged ...	2007	1637	1015	5192	3202	3459

the rate on the population of plaice in rectangle G4 taken as a whole. Thus the true catchability on this population by fishing in G4 lies between 0.7% and 6% per 100 days absent.

While the majority of both releases and recaptures in 1946 and 1947 took place in rectangle G4, both also occurred in the surrounding rectangles. Releases in these areas were too few to make the detailed analysis in 10-day periods of recaptures in the rectangle of release, but sufficient numbers were returned to enable nominal catchability coefficients to be calculated, in 30-day intervals, for each of the five statistical rectangles G3, 4, 5, H4 and 5, for the three groups of fish released in G4 and for those released in G3, H4 and H5. These are shown in Table 1, which also gives the numbers of tagged fish actually returned. A striking feature of this table is that the catchability coefficients in the rectangle of marking (underlined in the table) are much lower for the rectangles G3, H4 and H5 than for G4 — in fact, those for G3 and H4 are lower than the figure for fish tagged in G4 away from Smith's Knoll, which is believed to be abnormally low for the rectangle as a whole. The nominal catchability coefficient for the whole area of analysis (the sum of the coefficient for the individual rectangles) is, however, much more consistent, especially for the later periods. (For the 1947 Smith's Knoll releases, where there was little or no fishing in rectangles G3 and H4 an estimate of the total was obtained by using the values for the 1946 releases; this is given in brackets). This may be shown more clearly by taking a single average figure for rectangle G4. The average should be weighted according to the ratio of the numbers of fish at Smith's Knoll and elsewhere. This ratio cannot be determined with any precision, especially as the boundaries of the "Smith's Knoll" region are unknown, but a ratio of 1 : 4 has been used. The results are given in Table 2.

Table 2

Nominal catchability coefficients for the whole area of analysis

Release rectangle	Days at liberty		
	0—29	30—59	60—89
G3	1.27	0.68	0.69
H4	1.58	1.38	0.68
H5	1.91	1.00	0.62
G4	1.74	1.11	1.06
Mean	1.62	1.04	0.76
Loge	0.48	0.04	—0.27

The mean values decline at a rate which is nearly exponential, as is shown by the change in their natural logarithms. Fitting a straight line to the latter values gives an intercept at the time of tagging of 0.635, equivalent to a catchability coefficient of 1.89. (Extrapolating for the individual rectangles gives values of 1.3, 2.1, 2.4 and 1.7.)

This figure of 1.89 is therefore in some way the mean catchability coefficient for the whole area considered. It does not follow that the catchability coefficient for any individual rectangle is 1.89; in fact the figures in Table 1 suggest that the values for G3 and H4 are considerably less. The different figures for G4, away from, and at Smith's Knoll, show that fishing in this rectangle is very patchy; this is probably matched by a patchiness in the fish distribution, so that the aggregation, in the sense of Gulland (1955), may be high. Thus the catchability coefficient for G4 will be high. In theory this question might be solved by dividing the rectangle into, say, a dozen sub-areas, collecting statistics for each and computing fishing intensities, etc. In practice it would be difficult to assign statistics of commercial fishing operations to such small areas (less than 10 miles across, and of the same order of magnitude as the length of a single trawl haul), and in any reasonable time period there would be no data for possibly the majority of the sub-areas.

Because of somewhat similar practical difficulties it is difficult to test the significance of the differences in Table 1. Thus, the figure for G3 is obtained from four batches of tagged fish. Taken separately, these give the following figures: —

Cruise	Month	Number Tagged	Number Re-captured	% Re-captured	Fishing effort	Catcha-bility
IX/47	March	191	9	4.7	106	4.4
X/47	March	260	1	0.4	72	0.5
VI/46	May	739	2	0.3	92	0.3
XXIII/46	Oct.	817	4	0.5	269	0.2

The agreement is good for the three last cruises, but the first is wildly different. Finer analysis shows that all the nine tags concerned were returned within nine days of release (therefore none between ten and twenty-nine days), and five were returned by trawlers which were reported as having done most of their fishing for the trip outside G3 — so that their effort was not counted in calculating the catchability. These facts explain the existence of the differences, in qualitative terms, but make it difficult to give a definitive figure for the catchability for Cruise IX/47, from which the mean and confidence limits for the four cruises together can be calculated. This is, however, clearly less than that for Smith's Knoll alone (c.4 · 0), and very probably less than for G4 taken as a whole.

If the catchability coefficients are different for each rectangle, then the equation (1) must be re-written as:

$$\sum_j \frac{{}_jN_i}{{}_jf_iN_o} = \frac{1}{N_o} \sum {}_jN_i\ {}_jq$$

$$= \frac{N_i}{N_o} \sum \frac{{}_jN_i\ {}_jq}{{}_jN_i}$$

Thus the nominal catchability coefficient, as calculated above, is equal to the proportion of the tagged fish still alive in the area, multiplied by the weighted mean of the catchability coefficient, the weighting factor being the number of tagged fish in the area concerned.

In the same way, the usual expression for the effective overall fishing intensity (cf. Beverton and Holt, 1957, eqn. 10.30) must be re-written. As usually calculated:

$$(\tilde{f})\ \text{calc.} = \frac{Y}{\Sigma\ {}_jY/{}_jf} = \frac{Y}{\Sigma\ {}_jY/{}_jq\,{}_jF} = \frac{Y}{\Sigma\ {}_jq\ {}_jN} = \frac{Y}{\bar{q}\ N} = \frac{\tilde{F}}{\bar{q}}$$

if $\bar{q}$ is the weighted mean of the ${}_jq$'s, weighted by the number of fish in the subarea. These factors vary if the distribution of the population changes, so that the ratio of effective overall fishing intensity to fishing mortality is not constant. However, the ratio will be the same as the mean catchability coefficient as estimated above, provided the tagged fish are distributed in the same way as the untagged fish.

1948 releases

During 1948 tagging was concentrated in a small number of intensive cruises. Four of these — "Platessa" IX, X and XIV, and Sir "Lancelot" VI, were in approximately the same area, centred on 53°30'N, 3°E in March and April, during which 1179, 1410 and 5035 and 484 fish respectively were released. English fishing round the marking area was not very intense, and the most detailed practicable analysis was into 30-day periods. The results are given diagrammatically in Table 3, which shows, for each cruise, the nominal catchability coefficient in the four rectangles (G–H, 5–6) immediately surrounding the liberation positions, and the sum for the four rectangles together. There are some differences between cruises — the figures for "Sir Lancelot" VI being outstandingly high — but taking the mean of the cruises, weighted by the number of fish tagged in each cruise, gives values of 1.4, 0.7, and 0.6 (2.4, 1.3, and 0.9 unweighted) for successive 30-day periods. Extrapolation back to time zero gives an estimated catchability coefficient of 1.6% per 100 days absent per rectangle.

Another major cruise in 1948 was that in which 4,784 plaice were tagged in March on the Haddock Bank (53°20'N, 1°20'E). The returns from this experiment were analysed in two ways; first as numbers per 100 days in the rectangle of release (F 5), grouped in 10-day periods. These data are plotted in Figure 2, (broken line), for periods up to 100 days at liberty. The points are scattered about a moderately flat line, with an intercept at about 0.3% per 100 days.

Secondly the data of hours fishing in each rectangle for each month were used to give an estimate of the tags caught per 10,000 hours fishing in each rectangle in the south-eastern part of the North Sea. The results for June 1948 (about three months after release) are shown in Figure 3. In each rectangle the top figure gives the number of tags returned, the middle figure

Table 3

Nominal catchability coefficients in statistical rectangles G 5, G 6, H 5 and H 6 of fish released near the centre of this area in 1948

		(Per cent returned per 100 days' fishing)					
		0—29 Days		30—59 Days		60—89 Days	
		G	H	G	H	G	H
SIR LANCELOT VI/48, 484 fish	**6**	0	2.7	0	0.7	0.1	0.5
	5	0	2.0	0	0.9	0	0.6
Total		4.7		1.6		1.2	
PLATESSA IX/48, 1,179 fish	**6**	0.2	0.8	0.1	0.6	0.1	0.5
	5	0.3	1.2	1.0	0.8	0	0.3
Total		2.5		2.5		0.9	
PLATESSA X/48, 1,410 fish	**6**	0.3	0.2	0.1	0.3	0.1	0.5
	5	0.4	0.7	0	0.5	0.2	0.2
Total		1.6		0.9		1.0	
PLATESSA XIV/48, 5,035 fish	**6**	0.04	0.65	0.06	0.15	0.12	0
	5	0.01	0	0.02	—	0.02	0.25
Total		0.70		0.23		0.39	
Mean — all cruises		2.4		1.3		0.9	
Weighted mean		1.4		0.7		0.6	

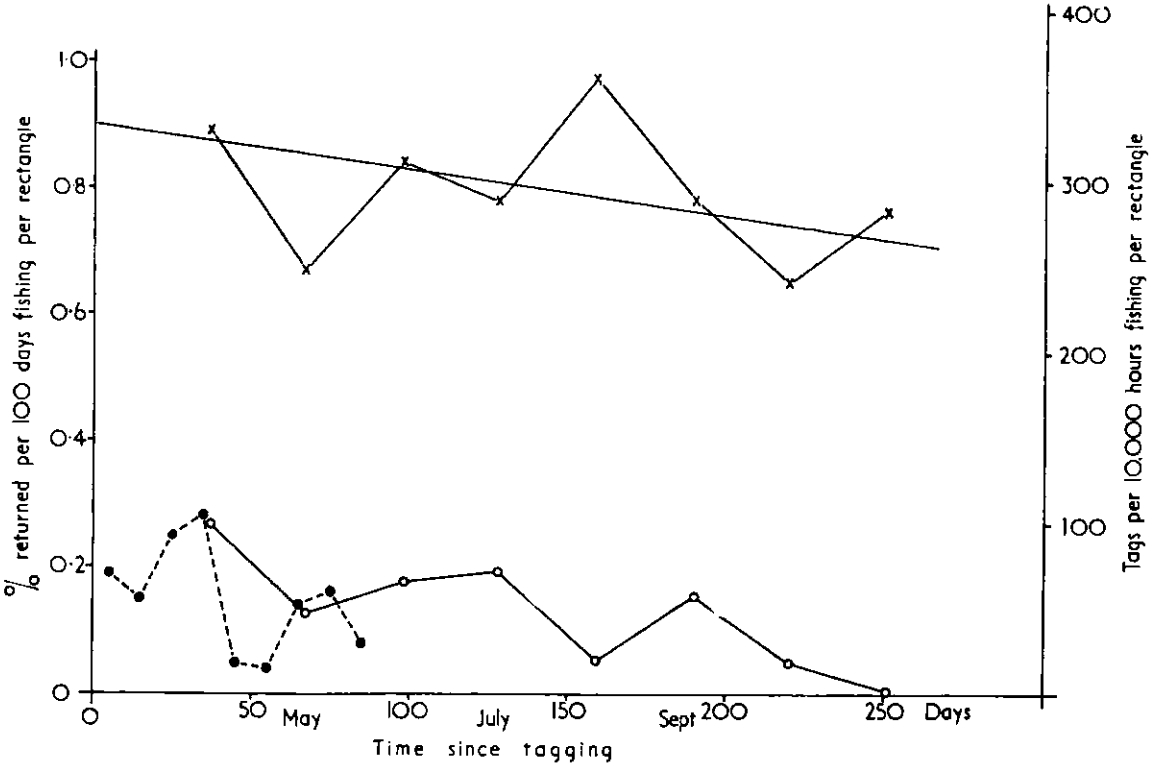


Figure 2. Nominal catchability coefficients of fish tagged on the Haddock Bank in March 1948 for fish recaptured within the area of release only (below), and in the whole North Sea (above). (Full line, data grouped in months; broken line, data grouped in 10-day intervals).

the number of hours fishing (in hundreds), and the bottom figure the number of tags returned per 10,000 hours fishing. These last give, of course, the pattern of dispersal of fish from the release position (subject to the unavoidable inaccuracies of the reported positions of fishing and recapture of tagged fish), and it appears that the main movements have been within a strip lying north-west to south-east, roughly parallel to the coast, there being little movement north-eastward towards the Dogger Bank. By summing the densities (tags per 10,000 hours fishing) of tagged fish in all rectangles, a nominal catchability coefficient can be obtained for each month (e. g. 316 for June). These values, for the months April—November 1948, are plotted in Figure 2 (upper full line); in contrast to the steep slope (very steep for the Smith's Knoll release) of the plots of nominal catchability coefficient within a single rectangle, or small group of rectangles, this plot has only a moderate slope, presumably because there is virtually no loss due to emigration (a very few plaice tagged in the North Sea have, in fact, been returned from the English Channel). A line fitted by eye, shown in Figure 2, has an intercept at time zero (mid-March) of 380 tags per 10,000 hours fishing, i. e. 7.95% per 10,000 hours; or, since about 12.8 hours fishing are done per day absent, 0.95% per 100 days absent.

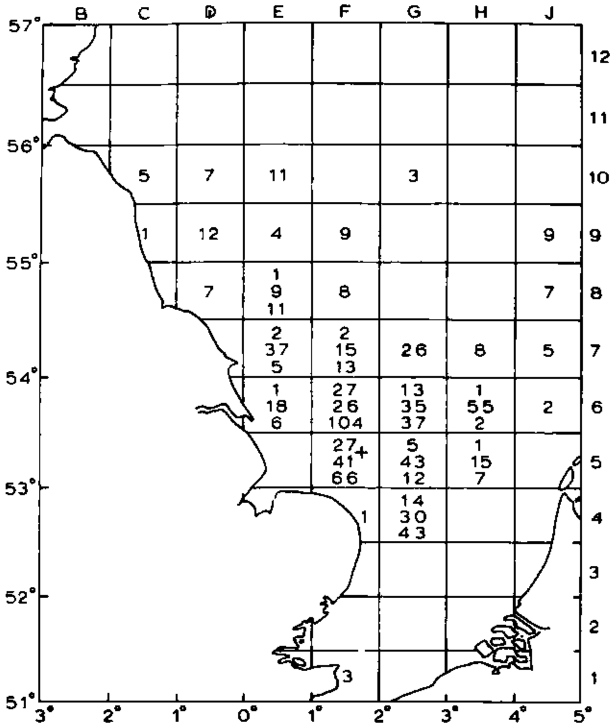


Figure 3. Distribution in June 1948 of tagged fish released on the Haddock Bank in March, 1948.

This is considerably higher than the value (0.3% per day) obtained from the returns per days fishing within the rectangle of release; the difference lies in the choice of area of analysis, rather than the unit of fishing effort, as may be seen by comparing the monthly returns per 10,000 hours fishing within the release rectangle (lower full line in Figure 2), which agrees closely with the returns per 100 days fishing in ten-day intervals and has approximately the same intercept. Probably these latter intercepts are underestimates of the true value in the same way as the returns from fish released in rectangle G4 but away from Smith's Knoll give underestimates; as in G4 much of the fishing in F5 was away from the release position. This also contributes to the rather flat slope of the lower lines of Figure 2 — the losses due to mortality and emigration out of the rectangle being partly compensated by movement into the more heavily fished areas within the rectangle.

Length and Sex

The percentage returned was not constant for fish of all sizes: the gross result, in terms of the percentage returned of each size of all plaice released in 1946—8 is shown in the upper part of Figure 4. Males (full line) and females (broken line) have been shown separately. There is a very marked increase in return rate with increasing length of fish, up to about 32 cm, when returns fall off. Between 30 and 40 cm appreciably more females than males are returned.

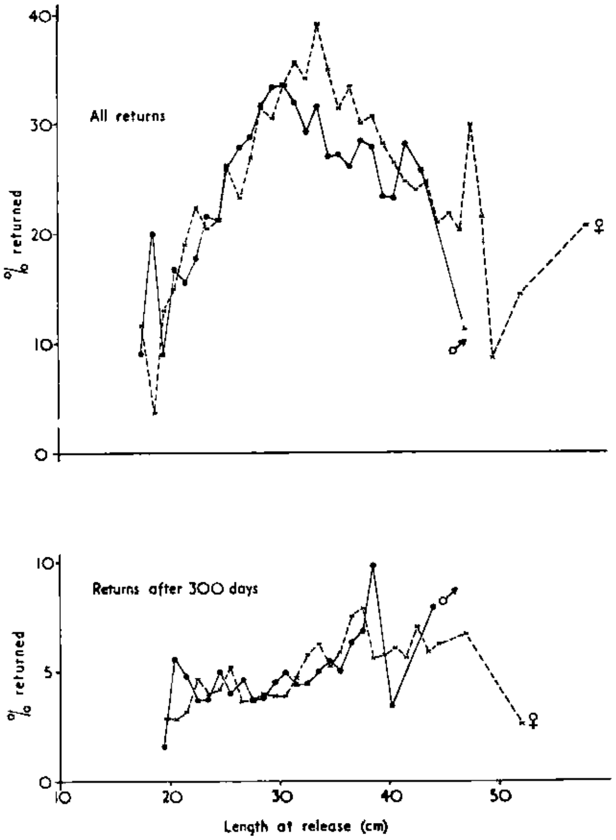


Figure 4. Relation between the size of plaice at release and the percentage returned.

A rather different picture is given if possible differences soon after liberation are eliminated, by considering only returns after 300 days. These are plotted in the lower part of Figure 4. Now the percentage returned shows no trend for fish less than 30 cm, but thereafter increases with increasing size, with no marked reduction for very big fish. These later returns should, of course, preferably have been expressed in terms of the tagged fish surviving and retaining their tags 300 days after release, but this number is difficult to estimate and requires some knowledge not only of those tagged fish caught, but also of the temporal pattern of other losses from the tagged population. Probably, however, any correction for differences in the proportion surviving to 300 days would not account entirely for the different trends shown by the two sets of data.

Similar differences in return rate also occur between batches of released fish, though it has not been possible to examine the trends for each separately. One cause could be different dispersal patterns or rates for different sized fish, so that they are exposed to different effective fishing intensities.

It might be expected that bigger fish move faster and further, and while the reported positions are not entirely accurate, they should show differences in movement. For fish released in 1946 outside rectangle G4, the rectangle of recapture of fish below 35 cm, and of fish 35 cm long and ever, was examined for all fish returned within 100 days of release. The results are summarized in the table below.

	< 35 cm		⩾ 35 cm	
	Number	%	Number	%
Number released ...	1,533		2,290	
Total returned	186	12.1	349	15.2
Total in release rectangle	23	1.50	33	1.44
Total north of 53°30′N	11	0.72	24	1.05

While fewer small fish were returned from all areas, taken together, the percentage returned from the release rectangle was greater than for the larger fish. Conversely, the proportion reported north of 53°30′N (some 50 miles or more from the release position) was markedly greater for the larger fish. Bigger fish do therefore seem to move more, and hence if released away from a centre of fishing effort, would move more quickly into a fished area, and have a higher rate of return, and vice versa if released in an area of high fishing effort. To test this, two

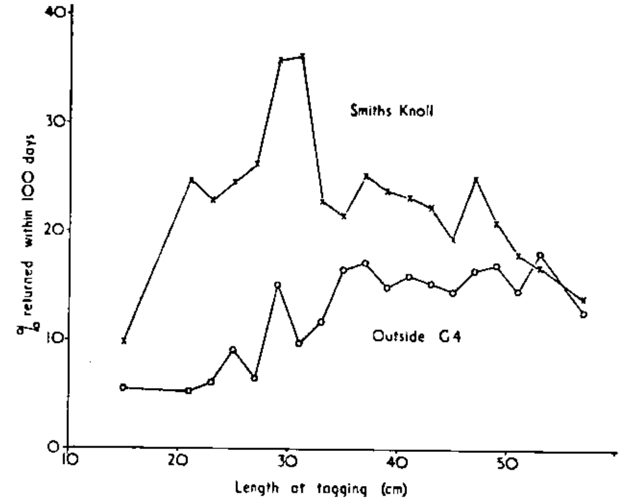


Figure 5. Relation between the size of plaice at release and the percentage returned within 100 days, for two batches of released fish.

batches of fish released in 1946 were examined — those released at Smith's Knoll in a centre of high fishing effort, and those released outside rectangle G4 away from any centre of high fishing effort. The percentages returned of each size of fish are plotted for each group in Figure 5. The first batch, released on a centre of high fishing intensity, has lower returns from the bigger fish, while in the second batch (released away from centres of fishing) the increase in return rate with size is very marked.

The difference in the pattern of returns is as expected, and it is reasonable to assume that the difference is due to the different rates of movement. However, while the first batch gave only slightly lower return rates for fish of 35 cm compared with those of 25 cm, in the other the difference in return rate is 5 or 6 to 1 in favour of the 35 cm fish. The two cannot be readily combined to determine the trend, if any, in return rate with size in an area of uniform fishing effort, but they do suggest that perhaps the return rate is higher for the larger fish. Further analysis of existing tagging data, and perhaps further special experiments, may show if this is true, and if so, whether it is due to a greater vulnerability of larger fish to the trawl, or to the geographical distribution of fishing giving a greater concentration on the larger fish.

These size differences could also occur if there were any size difference in tagging mortality, or chance of recovery. Certainly for very small fish (say, under 20 cm), the tag could be a considerable burden; also, the legal minimum landing size is 25 cm, so that returns of fish below c. 27 cm (at which all fish are marketable) might be low, due both to tagging mortality and to the fishermen not seeing recaptured fish. Above this size such losses seem unlikely; Beverton and Bedford (this Symposium, No. 18) analysed the effect of condition of plaice at release, and subsequent return rate, and found no relation. Some correction should be made for these losses of small fish. However, they made up only a small part of the total releases (c. 13% were under 25 cm), so that the correction would be small — an increase in the return rate of 100/87 = 1.15, if no fish under 25 cm were returned.

Male and female plaice differ in most of their vital parameters, females growing to a much bigger size and living longer (Beverton and Holt, 1959). The different survival has been believed to be due to a heavier fishing rate on the males, so that the higher return rate of females, particularly between 30 and 40 cm, is surprising. Males predominate in the landings to the greatest extent during the spawning season — a high proportion of males in the catches is a good indication of the spawning grounds (Wallace, 1909). If returns in the first quarter of the year — taken as a reasonable approximation to the spawning season — are considered separately, then returns of males are higher than those of females in the ratio of about 1.2:1. Most of the tagging experiments took place in the late spring and summer, so that, due to losses over the intervening months, relatively few fish were recaptured in the first quarter of the year. The observed return rate of tagged fish therefore probably underestimates the returns of males relative to females, but even so some slightly greater return rate for males would have been expected, rather than the significantly greater rate for females (c. 15% greater for all returns, c. 7% greater for returns after 300 days, for fish between 30 and 40 cm).

It appears, therefore, that there are some as yet unexplained differences in the return rate between fish of different sizes and sexes, so that the return rate, and its derivatives such as catchability coefficient, etc, refer to the tagged population, or any population with the same size and sex composition. This will be different, in general, from the composition of the true total population of North Sea plaice, but the difference is unlikely to be critical — the size composition of the tagged fish was similar to that of the commercial landings.

The Fishing Mortality on the North Sea Stock

The catchability coefficients, q, estimated above may be used to estimate the fishing mortality on the North Sea stock as a whole. This requires some measure of effective overall fishing intensity (cf. Beverton and Holt, 1957, eqn. 10.30) in the same effort units. While the centre of English fishing did not coincide with the centre of fishing by other countries, e.g. Denmark, English trawlers did range over nearly the whole of the North Sea. Of the 90 statistical rectangles in the central and southern North Sea (Regions IVb and IVc) — excluding certain incomplete rectangles on the coast — over 70 were fished at some time in each of the years 1946, 1947 and 1948. The catch per unit effort in some of the other rectangles could be estimated as the mean of two or more adjacent rectangles, leaving a maximum of six rectangles in any one year which could only be roughly estimated from the catch per unit in a single adjacent rectangle, and from catches in other years. Summing the estimated catch per 100 hours' fishing by British trawlers* in each of the ninety rectangles gives an index of abundance for the plaice in the southern and central North Sea. A few plaice inhabit the northern North Sea (IVa), but coverage by fishing here is less complete, and the stock was estimated as 5% of that in the southern and central part. The resulting index of abundance for the whole North Sea may be divided into the total North Sea catch to gave an effective overall fishing intensity in units of one hundred British steam trawler hours. The computations are shown in Table 4.

Table 4
Calculation of effective fishing intensity on North Sea plaice

	1946	1947	1948
Total North Sea landings of plaice (m tons)			
England	29,330	25,209	24,029
Denmark	37,960	31,939	35,637
Holland	15,871	11,862	13,530
Others	15,768	13,448	10,860
Total	98,929	82,458	84,056
Total catch ('000 cwt)	1,947	1,623	1,655
Rectangles fished by British trawlers	71	77	79
Abundance (Σ cwt/100 hrs)	5,200	3,620	3,280
Intensity (100 hrs/rect)	374.5	448.3	504.4

The total mortality in 1946—8 may be estimated directly from the age composition, and the estimates are shown in Table 5. Also shown are the total North Sea plaice catch in thousand tons and the estimated total effort in units of million English steam trawl hours. For comparison, the figures for 1932—8, and 1949—55 are also shown. The mortalities are obtained from the ratio of catches per hour in successive 'biological years' (April 1 — March 31). Thus the figure for 1948—49 uses data from 1 April 1948 to 31 March 1950; they are the mean values of Z for the ages 5/6 to 9/10 (1932—8 data from Beverton and Holt, 1957; 1946—55 from Annales Biologiques).

Table 5
Total catches and effort and estimated mortality of North Sea plaice

Year	Total catch ('000 tons)	Catch per unit effort (cwt/100 hrs)	Total effort ('000,000 hrs)	Z
1932	51	18	5.63	1.22
1933	54	18	5.97	0.58
1934	52	18	5.75	0.74
1935	47	18	5.22	0.45
1936	47	18.7	5.00	0.98
1937	47	19.2	4.93	0.66
1938	46	18.4	5.00	
1946	99	76.5	2.59	1.32
1947	82	54.1	3.05	1.04
1948	84	44.3	3.79	1.07
1949	81	35.0	4.64	0.45
1950	67	31.8	4.24	0.40
1951	67	31.2	4.26	0.55
1952	71	32.8	4.32	0.29
1953	79	35.9	4.39	0.62
1954	67	35.8	3.74	0.44
1955	63	39.2	3.23	

In this table there is a reasonable agreement between the periods 1932—38 and 1950—5, both effort and mortality being lower in the latter period — suggesting incidentally that fishing accounts for a major part of the total mortality. However, the mortality for 1947, and to a lesser extent for 1948 and 1949, is much greater than would be expected from the amount of fishing. At this time the wartime accumulation of fish, as shown by the high catch per unit effort, was still present. Studies now in progress at Lowestoft suggest that just after the war, when fishing started again, the catch per hour gave an overestimate of the stock abundance (perhaps because trawlers could concentrate on local accumulations of fish which in a more heavily fished stock would be reduced to more nearly the average density). Certainly during 1945 and 1946 the catch per hour of the main year-classes declined more rapidly than seems consistent either with the fishing effort or the quantity of fish removed from the stock. Formally this suggests a change in the mean catchability coefficient, $\overline{q}$; if this is high in, say, 1946, then not only is the true fishing mortality higher than usual, but the estimated mortality from 1946 to 1947 will be increased by a term log ($\overline{q}$ 1946/$\overline{q}$ 1947). The comparison of the 1946 and 1947 taggings at Smith's Knoll suggests no difference in the local catchability coefficient. The weighting factors used to obtain $\overline{q}$ could, however, be different in the two years. For instance, heavy fishing could keep down density at the favourite heavily fished area around Smith's Knoll to close to the average for the rectangle, but after a period of little fishing the density there could increase perhaps to considerably more than the rectangle average. In such a case the catch per hour of the trawlers, fishing

---

* The figures for 1946 refer only to English trawlers; few Scottish trawlers fish in the area concerned, and those that do have roughly the same fishing power as English trawlers.

mainly around Smith's Knoll, would be a considerable overestimate of the density in the rectangle as a whole. These are, however, only suppositions; for the present purpose it is sufficient to note that the true Z for 1947 is probably less than 1.32, and a more reasonable figure would be the mean Z for the post-war period (0.69) or perhaps even less.

The estimates of intensity in Table 4 can now be combined with the estimates of q, catchability coefficient, to give estimates of fishing mortality. The estimates of q obtained earlier were as follows:—

	Area (rectangle)	q
1946—7	G3	1.3
	H4	2.1
	H5	2.4
	G4	1.7
All 1946—7, mean .		1.89
1948	GH, 5, 6	1.6
	Haddock Bank	0.95

The overall mean, unweighted, is 1.67. If some allowance is made for losses among the small (under 25 cm) fish, a corrected value of, say, 1.8% per 100 days is obtained. For vessels fishing in this area one day's absence was equivalent to 12.8 hours fishing, so q = 0.141% per 100 hours fishing/rectangle. Multiplying this by the intensity figures in Table 4 (bottom line) gives estimates of F of 0.53, 0.63, and 0.71 for the years 1946, 1947 and 1948 respectively.

The data used in obtaining the estimate of q = 1.81 covered the same experiments as those used by Beverton and Holt (1957) in their example of tagging theory; however, they did not take account of variations in catchability either within or between rectangles, so they obtained a mean value approximately weighted by the number of fish released. As relatively more fish were tagged at Smith's Knoll with a high catchability, their estimate (effectively of q) was higher than the present one, and gave a value of F in 1946 for the English fishery alone of 0.5 to 0.6 (i.e. a total F = 1.5).

Discussion

The pattern of returns from marking experiments varies greatly between different release positions. Much of this difference still remains when the return rate is related to the fishing intensity in the rather gross sub-divisions of the North Sea, though these latter are probably the smallest practicable units for analyzing commercial statistics. Reasonable assumptions concerning the distribution of fishing within the sub-divisions used allowed the differences to be explained. This suggests that in tagging experiments the tagged fish should be distributed fairly widely over the fished area, and that in the analysis each batch should be considered separately. With the assumptions made, a figure for the fishing mortality, F, for the stock as a whole can be obtained which i close to the estimated total mortality Z. If the value of Z is 0.69 in each year, then estimates of natural mortality are 0.16, 0.06 and —0.02 for the years 1946, 1947 and 1948 respectively. The variance in the estimates of both Z and F is too great to attach any great confidence to any of these estimates of M. For instance, not unreasonably wide confidence limits for q are ± 20%, i.e. 1.30—1.94 (cf. Table 2). These give values of F in 1947 of 0.53 and 0.79, corresponding to M of 0.16 and — 0.10. It may also be noted that a comparison of total effort before and after the war suggests a pre-war F of over 1.0, bigger than the fairly accurate estimate of Z. The estimates do suggest that M is small — though not inconsistent with an M as high as 0.25. This agrees with other rough estimates of M, and it confirms that the estimate of F obtained is reasonable.

Summary

Data of returns from some 30,000 plaice tagged and released in the Southern North Sea are analysed. The returns were related to the fishing intensity — days absent from port, or hours fishing — in the area of release, and the percentage returned per unit fishing intensity calculated for short time intervals after release. Extrapolation back to time zero, when all tagged fish were presumably alive and in the tagging area, gives estimates of q, the catchability coefficient.

Differences in return rate were found between fish of different sizes and sexes. Some of the difference could be related to different rates of movement between areas of high and low fishing intensity.

The estimates of q obtained from the tagging data were combined with the overall fishing intensity to give estimates of F, the fishing mortality for the three years 1946—8; these ranged from 0.53 to 0.71, slightly below the probable values of Z in those years, and hence gave estimates of M around 0.1—0.2, agreeing reasonably with other estimates.

References

BEVERTON, R. J. H. & HOLT, S. J. 1957. On the dynamics of exploited fish populations. *Fish. Invest., Lond.*, Ser. 2, 19.

BEVERTON, R. J. H. & HOLT, S. J. 1959. A review of the lifespans and mortality rates of fish in nature and their relation to growth and other physiological characteristics; in *Ciba Foundation Colloquia on Ageing* Vol. 5 — *The Lifespan of Animals*, edited by G. E. W. Wolstenholme & M. O'Connor, 142—80, J. & A. Churchill Ltd, Lond.

BEVERTON, R. J. H. & BEDFORD, B. C. 1963. The influence on the recapture rate of condition of fish when tagged. (*This Symposium*, No. 18).

GULLAND, J. A. 1955. The estimation of growth and mortality in exploited fish populations. *Fish Invest. Lond., Ser.* 2, **18** (9).

WALLACE, W. 1909. Report on the size and age of plaice at maturity in the North Sea and English Channel. *Rep. Mar. biol. Ass. U.K., No.* 2, (*Southern Area*), 1904—5, Pt. 2.

36.

On the Analysis of Double-tagging Experiments

by

J. A. GULLAND*

A measure of the extent to which tags are lost from the fish can be given by attaching two separate tags, of the same or different types, and observing when only one of these is returned. The critical factor is the ratio at any time of fish still having two tags to those having only one (ideally we would also like to observe the proportion of fish which have lost both tags). If mortality rates, migrations, etc., apply equally to all tagged fish, irrespective of how many tags remain attached, this ratio is unaltered by mortality. The probability of a tag having come off hy time t will be a function of time, say p_t, and hence the probability of the tag being on is $(1 - p_t)$. If the probability is the same for all individual tags, regardless of how many other tags the fish carries, then we can write

${}_2N$ = number of fish with two tags $= (1 - p_t)^2$

${}_0N$ = number of fish with no tags $= p_t^2$

${}_1N$ = number of fish with one tag $= 2p_t(1 - p_t)$

Hence $$ {}_1N/{}_2N = \frac{2p_t}{1 - p_t} $$

or $$ \frac{{}_1N}{{}_1N + {}_2N} = \frac{2p_t}{1 + p_t} . $$

If the probabilities of detachment of the two tags, A and B, are different, then provided the probabilities are still independent, we can write, with the obvious notations

$$ {}_2N = (1 - {}_AP_t)(1 - {}_BP_t) $$
$$ {}_0N = {}_Ap_t\,{}_Bp_t $$
$$ {}_1N_A = {}_Bp_t\,(1 - {}_Ap_t) $$
$$ {}_1N_B = {}_Ap_t\,(1 - {}_Bp_t) $$

and $$ \frac{{}_1N_A}{{}_2N} = \frac{{}_Bp_t}{1 - {}_Ap_t} ; \quad \frac{{}_1N_B}{{}_2N} = \frac{{}_Ap_t}{1 - {}_Bp_t} . $$

Clearly p_t must increase with time, starting at zero, and probably tending to 1 eventually, so that ${}_1N/{}_2N$ will also increase from zero and become very large.

In Figure 1 the values of ${}_1N/{}_2N$ from the double-marking experiments on plaice carried out in 1947 (see Beverton and Holt, 1957) and 1959 have been plotted. These fish were marked with two pairs of ebonite Petersen discs attached by silver wire (1947) (516 fish) or stainless steel wire (1959) (603 fish). As Beverton and Holt found, there was no significant difference between the numbers of one-tag fish returned bearing the front tag (13) or the rear tag (12). (Since their analysis five more single-tag fish have been returned). The difference between A and B tags can therefore be ignored. To avoid difficulties in the choice of time-interval for grouping the returns when these are scarce, returns for the 1947 experiments after 100 days at liberty are taken in groups of 20 fish, in the order in which they were returned, and plotted at the average time of liberty. The 1959 experiments were grouped in six-monthly periods, up to 24 months at liberty.** The plots follow the general increasing pattern expected, but there is a very big difference between the two types of wire; the values after one year, as read from straight lines drawn through points were

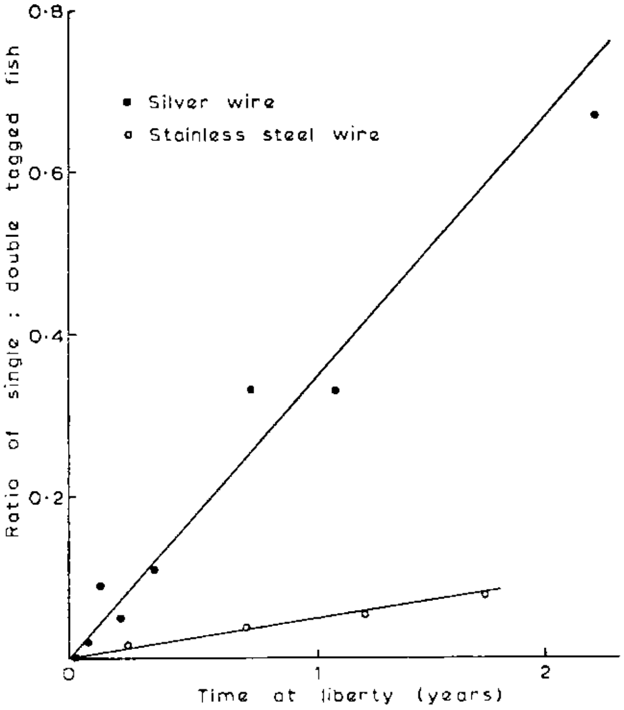


Figure 1. The ratio of the numbers of plaice, originally tagged with two pairs of Petersen discs, returned carrying only one tag to the numbers returned with both tags, plotted against the time since tagging.

	N_1/N_2	p
Silver	0.35	0.15
Stainless steel	0.05	0.025

---

* Fisheries Laboratory, Lowestoft, England.

** Since this paper was prepared further returns have been received, as follows: — 24—30 months at liberty, 18 fish with both tags, 2 with one tag; over 30 months at liberty, 19 fish with both tags and 2 with only one tag.

i.e. after 1 year 15% of the buttons attached by silver wire were lost, but only 2.5% of those attached by stainless steel.

Returns of single-marked fish have been too few (25 and 7 from the 1947 and 1959 experiments respectively) to enable the form of p_t to be determined empirically. Beverton and Holt made some reasonable hypotheses, assuming that the rate of detachment is constant in time. Thus if the tags on the same fish come off independently, then $p_t = 1 - e^{-Lt}$, and ${}_1N/{}_2N = 2\ (e^{Lt} - 1)$ (cf. their equations 14.29, 14.32). This should give an exponential curve, increasing rapidly at large values of t; though the observed curve for 1947 does not appear to curve upwards, the discrepancy is not great. A value of $P_t = 0.15$ after 1 year corresponds to a value of L of 0.162; using this value, and the observed values of ${}_2N$, 'expected' values of ${}_1N$ can be computed for any interval; these give

Time interval (days)	0—19	20—39	40—69	70—100	100—189	160—350	350—475	475+
Observed single tags	0	1	3	1	2	5	5	8
Expected single tags	0.2	1.2	2.0	1.6	1.9	3.9	5.9	10.3

The rate of detachment may however change with time, The buttons are normally attached rather loosely, to allow the fish room to grow; the rate of detachment may well increase at first with increasing wear, but then drop (say after a year) when the fish has become thicker and the buttons have become firmly attached (or even in extreme cases embedded). These effects are in the direction of the differences in the table above — smaller numbers of one-tag fish than expected, for very early and very late recaptures.

Beverton and Holt also considered the possibility of tags not acting independently. Thus certain events may remove at one time all tags on a fish regardless of how many it carries; as such losses will affect one- and two-tag fish equally they will not alter their ratio, and hence cannot be detected from the numbers of one-tag fish (cf. Beverton and Holt, para. 14.1.2.3.2.) In contrast one tag may protect the other, so that only one is vulnerable. The relative numbers of one- and two-tag fish cannot be expressed so simply in this case, but assuming that the rate of detachment of the vulnerable tag is constant with time, then from Beverton and Holt's equations 14.46 and 14.47 we have:

$$N_1/N_2 = Lt$$

If one tag is protected the initial number of vulnerable tags is half that on the assumption of independence, so that the initial rate of build-up of one-tag fish is halved. Thus when (as here) the proportion of one-tag fish is not large, the rate of detachment of single tags, as estimated from the observed number of one-tag fish, will, for the 'protection' hypothesis, be double that on the assumption of independence (cf. Beverton and Holt, Table 14.7).

Reference

BEVERTON, R. J. H. & HOLT, S. J. 1957. On the dynamics of exploited fish populations. *Fish Invest., Lond.* Ser. 2, 19.

37.

Exponential Rates of Decline and Type (1) Losses for Populations of Tagged Pink Salmon

By

GERALD J. PAULIK*

Introduction

The tail-end of the survival curve for salmon is one of the most intensely studied stages of any animal's life. The two to seven year-old adults are harvested during the last few weeks or months of their lives as they pass through the coastal fisheries during their spawning migration. Tagging is one of the basic methods of determining what proportion of these migrants are removed by the fishery. However, the measure of exploitation commonly used, the percent of tags recovered during the season, contains time as an implicit variable and provides neither a direct means of extrapolating for purposes of prediction nor a flexible theoretical tool to study dynamics of the system. For example, knowledge of a forty percent recovery during a three week season does not provide an estimate of the percent recovery expected during a four week season.

One immediate extension of the customary analysis is to represent the decline of the population during the fishing season by a simple exponential model. Although this is still a highly superficial treatment of the true complexities of the fishery, such a model contains time as an explicit variable and may thus be of aid in predicting the effect of alterations of fishing time on catch and escapement. It should be noted that limiting the fishing time is the primary means of regulating the salmon fisherics on the Pacific Coast. Restrictions concerning the type of gear employed are also imposed, but since entry into the fishery is unlimited, decreasing the efficiency of the individual units of gear is an ineffective means of regulating the rate of exploitation in the present economic setting. The parameters of an exponential model with constant rates are readily estimated from the temporal distribution of the returns from tagging experiments. An example demonstrating the fitting of a simple exponential curve to returns of tagged pink salmon (*Oncorhynchus gorbuscha*) will be given here. Bevan (1959) has used a similar approach for sockeye salmon, and considerably more sophisticated models are routinely applied in marine demersal fisheries (Beverton and Holt, 1957; Ricker, 1958; Jones, 1959).

Interpretation of salmon tagging experiments is complicated by the possibility of what Beverton and Holt (1957) call type (1) losses. They use this term to include all losses which have the same effect as reducing the initial numbers of fish tagged. If type (1) losses are present, the apparent rate of exploitation calculated from the tag returns will be too low. Ricker (1958) has called this sort of bias Type A error. The primary sources of type (1) losses in salmon tagging are immediate tagging mortality and incomplete tag reporting.

A number of workers have reported the deaths of salmonoids and other fishes following capture by trolling gear, transportation, strenuous swimming activity, or prolonged or vigorous struggling of the sort that might be induced by the handling employed in certain experimental procedures, or by electrical stimulation (Huntsman, 1938; Miller, 1954; Horton, 1956; Black, 1956, 1958a, b; Milne and Ball, 1956, 1958; Bates and Vinsonhaler, 1957; Milne, 1957; Verhoeven, Hoard and Nakatani, 1957; Parker and Black, 1959; Parker, Black and Larkin, 1959; Paulik, 1959; MacFarland, 1960; and Brown, 1961). The magnitude of immediate mortalities is critically dependent upon the type and intensity of fatigue the fish experience, their state of maturity, and the chemo-physical environment. For example, Parker et al. (1959) observed a 44 percent mortality for troll-caught sub-mature feeding silver salmon in salt water but when they repeated the experiment with adult silvers in fresh water no deaths occured. Deaths of apparently uninjured salmon after their capture on trolling gear in salt water (Fry and Hughes, 1951; Milne and Ball, 1956, 1958; Parker and Black, 1959; Parker et al., 1959) and the ability of salmon to withstand severe fatigue and handling at certain stages during their upstream migration (Paulik, DeLacy and Stacy, 1957; Paulik and DeLacy, 1958; Paulik, 1959) are both well documented phenomena. Present evidence appears to indicate that the likelihood of mortality following hyperactivity is greatest for feeding fish in salt water.

The exact stress to which a fish is subjected during a tagging operation varies with the circumstances of its capture and its response to the handling and confinement associated with tag application. The method of capture, type of tag and manner of attachment, the length of time the fish is out of water,

---

* University of Washington, U.S.A. This research was sponsored by the National Science Foundation under grant No. G—10365.

experience of the tagging crew, and a host of other factors affect the condition of the tagged fish at release. Even when the salmon is not dangerously fatigued during the tagging operation its increased susceptibility to predation during the recuperation period may result in sizeable type (1) losses. The prolonged post-exercise decline in blood lactate (Black, 1958a) and the long recuperation period before the fish's normal capabilities are restored (Paulik et al., 1957) increase the likelihood of predation.

The foregoing considerations indicate that type (1) losses for tagged salmon might be higher than previously suspected. A notable example of a high type (1) loss was the 71 percent mortality suffered by apparently uninjured troll-caught chinook salmon held in live boxes for observation after capture by Parker and Black (1959).

This paper re-examines the results of a major salt-water tagging experiment involving pink salmon that was conducted in Southeastern Alaska during 1950. This particular experiment was selected because the pattern of releases permitted estimation of the type (1) losses, and the tagging operation was typical of tagging experiments carried out in Alaska during the last two decades. The salmon were captured for tagging in a floating fish trap and were tagged with Petersen-disk-type tags beneath the dorsal fin. The pre-tagging feeding history of the fish is not known. Somewhat limited published studies that are relevant (Chamberlain, 1907; Vedenskii, 1954) indicate that the majority of the pink salmon had probably begun their spawning fast at the time they were tagged.

Experimental Methods and Results

Elling and Macy (1955) present a complete description of the details of the 1950 tagging experiments, the fishery, and the fishing area in Southeastern Alaska. A brief résumé of the methodology and experimental circumstances is given below.

The tagging traps were located on opposite sides of Icy Strait, the northernmost entrance from the sea to the complex of channels and inland waterways that constitute the Alexander Archipelago. Spawning occurs in thousands of streams scattered throughout the islands and along the mainland shore. An intensive fishery is centered in the inland waterways.

Traps were the dominant gear in 1950 and accounted for 88 percent of the tag returns. Purse seines took 8.5 percent of the tags; gill nets, 2 percent; and troll gear, 0.5 percent; one percent came from unknown sources.

Daily releases of tagged pinks were made for 12 consecutive days immediately preceding the opening of the commercial fishery at 6 a.m. on August 15. A few earlier releases and some later releases made near the close of the fishing season were not included in the analysis presented here. The 1950 commercial season was originally set to extend from August 15 through September 2, but was reopened on September 7 for a three-day extended season. During the regular commercial season 36 hour week-end closures were observed.

Since Elling and Macy's report does not include a breakdown by week of the reported recaptures from each release this information is given in Table 1. Minor discrepancies between the total numbers of reported recaptures given by Elling and Macy, and those shown in Table 1 are due to the exclusion from the table of reports made before August 15 or during the three-day extended season, and also because of an adjustment of the reports listed in Table 1 for the fewer days the fishery operated during the third week of the regular commercial season (4.5 days of fishing during the third week as opposed to 5.5 days during each of the first two weeks). The adjustment consisted of multiplying the actual number of reports taken in the third week by 5.5/4.5 and rounding the product to the nearest integer.

Theory

It is assumed that the recapture times of any of the 12 groups of tagged pinks followed a simple exponential law, i.e.,

Pr (a tag from the ith release is recaptured by the fisheries research agency between times t and t + dt)

$$= \begin{cases} 0 & t \leq 0 \\ pFe^{-Xp_i-(F+X)t}\,dt & t > 0 \quad i = 1, 2, \ldots, I. \end{cases} \qquad (1)$$

Table 1

Reported recaptures of tagged pink salmon by week in the commercial fishery for twelve pre-season releases

Release date, Aug.	3	4	5	6	7	8	9	10	11	12	13	14	Totals
Total number of tags released	784	574	862	1097	1146	1195	351	1509	1003	1938	1661	1083	13,203
Rep. Recaptures:													
First week	96	88	137	219	305	304	93	475	352	705	783	566	4,123
Second week	5	15	29	33	51	63	19	96	81	155	117	86	750
Third week	2	5	6	6	17	12	5	24	20	30	34	26	187
Recapture Time unknown	13	6	12	11	17	20	6	22	16	36	24	10	193
Total number	116	114	184	269	390	399	123	617	469	926	958	688	5,253

where the parameters are defined as follows:

F = exponential rate of fishing mortality.

X = exponential rate of removal of tags from the fishing area by all causes other than fishing. The X factor includes loss of fish due to escapement into the streams, emigration into closed areas, continuing tag loss, continuing mortality induced by the effects of tagging, and natural mortality.

p = product of the fraction of fish that survive tagging multiplied by the proportion of the total number of tags caught that are subsequently reported to the research agency.

ρ_i = the number of time units between the ith release and the start of the season; $i = 1, 2, \ldots, I$; where $I = 12$.

The following notation will also be used below:

N_i = the total number of tagged fish liberated at the ith release.

n_{ij} = the number of tagged fish reported during the jth recapture period from the ith release.
The j index designates the recapture period; $j = 1, \ldots, J$; where $J = 3$, the number of weekly recapture periods.

The basic unit of time is 5.5 days or 132 hours. All rates will be expressed in terms of this unit, e.g., $\rho_1 = 11/5.5 = 2$ for the first release made on August 3rd; this group of fish was exposed to the X rate of decline for 11 days or 2 time units before the onset of fishing. In equation (1), t is measured from the start of the fishing season.

The expected number of reported recaptures from the ith release during the jth recapture period can be easily shown to be

$$E(n_{ij}) = \frac{N_i\, pF}{F+X}\, e^{-X\rho_i}\, (1-e^{-(F+X)})\, e^{-(F+X)(j-1)} \qquad (2)$$

Dividing by N_i and taking logarithms we can write the linear form

$$\ln\left\{E\left(\frac{n_{ij}}{N_i}\right)\right\} = \ln\left\{\frac{pF}{F+X}\,(1-e^{-(F+X)})\right\} + \\ + (F+X) - X\rho_i - (F+X)\,j \qquad (3)$$

A random variable $Z_{ij} = \ln(n_{ij}/N_i)$ can be defined and its approximate moments can be found by Taylor series expansions; see Chapman (1956). Using these approximate moments, weighted regression estimates of $\ln\left\{\frac{pF}{F+X}\,(1-e^{-(F+X)})\right\}$, X, and F can be found. A detailed exposition of the derivation of these estimates will be published elsewhere. A recent comprehensive account of the general problem of estimating mortality rates from tagging data is given by Chapman (1960).

Assumptions

The applicability of the theoretical model outlined above is dependent on the reasonableness of the following assumptions:

1) The fishing mortality rate was constant during the entire three week season for all groups of tagged pinks.

2) The "other-loss" rate, X, was constant during the entire interval between the release of the tagged group and the end of the three week fishing season. All groups of tagged pinks are assumed to bave been exposed to the same other-loss rate.

3) All fish in the twelve releases had the same probability of surviving the tagging operation. It is assumed further that immediate mortality was complete within a short time after tagging.

4) The probability that a recaptured tag was reported remained constant during the entire season for all types of recapture gear.

If inferences concerning the untagged population are made from the analysis of the tag recaptures it is necessary to assume that the tagged fish were representative of the untagged population and, except for the presence of the tag, differed in no way from the untagged fish.

Assumption 1 was predicated upon the assumed joint effect of the migratory behaviour of pink salmon and the distribution of the traps in the fishing area. Verhoeven (1952) stated that the dominant characteristic of the migration of pinks in Southeastern Alaska is a directionless or random "to-and-fro" movement. Other investigators who conducted tagging experiments in the area (Rich, 1926; Rich and Suomela, 1927; Rich and Morton, 1929; Elling and Macy, 1955) considered the movement pattern to correspond more closely to a classic spawning migration, i.e., a well-defined oriented migration of the fish from the sea to the spawning grounds. I would favor a model in which a random component of secondary importance was superimposed upon a basic directed movement. The well known "milling" behaviour of pink salmon (Pritchard, 1936; Davidson et al., 1943; Ward, 1959) obscures the exact mechanism operating. A point of agreement in all of the previous tagging studies is that a large number of racial strains would be represented in any group of pinks tagged in the main channel of one of the major inlets. As this group traveled along its migratory route it would be continually diminished as the different races dropped out in the vicinities of their respective spawning streams. Drop-outs could either ascend a stream immediately or mill in the vicinity of the stream mouth for some time. The range of milling movements and the length of time milling persists are unknown.

The spatial distribution of the fish traps also affects the temporal consistency of the rate of exploitation. Although the distribution of the 73 traps that operated in the northern part of Southeastern Alaska was not perfectly uniform, traps were located throughout the area and were not densely concentrated in any single locality. A minimum distance between traps of one mile or one mile and a half, depending upon the locality, was maintained by law (Anonymous, 1950). The preceding argument is offered as support of the assumption that the combined distributions of traps and fish generated an approximately uniform fishing mortality rate.

The second assumption (of a constant "other-loss" rate) is more difficult to accept. The extensive intermingling of various racial components in the fishing area and the large number of spawning streams would appear to produce a fairly constant trickling or diffusion of pinks from the fishing area. Stream recoveries made by Elling and Macy suggested that all of the major geographical groups of races were available in Icy Strait at the same time. However, there was some evidence that groups of fish tagged during early August contained a higher proportion of pinks destined for Stephans Passage and Tenakee Inlet than those tagged in mid-August. Ignoring the racial factor, there is still the possibility of a change in the rate of escapement, during the season, with fluctuations in stream flow conditions or with maturation of the fish. The assumption of a constant X factor is suggested only as a useful first approximation.

In the absence of drastic changes in the ability of the tagging crews or in the weather (Elling and Macy made no mention of such changes) assumption 3 appears reasonable. The brevity of the commercial season is a strong argument for assumption 4.

Analysis of the Results

Estimates of $\ln \left\{ \frac{pF}{F+X} \left(1 - e^{-(F+X)}\right) \right\}$, X, and F were computed from the data listed in Table 1. Reported recaptures not accompanied by "days-out" information were excluded from this analysis. Weekend closures were ignored. The reported recaptures were treated as originating from three consecutive recapture periods, each 5.5 days in length. The vector of estimates was found to be:

$$\left\{ \begin{matrix} \ln \frac{pF}{F+X} \left(1 - e^{-(F+X)}\right) \\ X \\ F \end{matrix} \right\} = \left\{ \begin{matrix} -0.6868 \\ 0.6410 \\ 0.9661 \end{matrix} \right\}$$

with the variance-covariance matrix shown below:

$$\begin{bmatrix} 0.0002330 & 0.0004815 & -0.0000944 \\ * & 0.0009272 & -0.0009333 \\ * & * & 0.0027065 \end{bmatrix}$$

* Symmetric

Assuming normality the ninety-five percent confidence limits are:

$(-0.7167, -0.6570)$ for $\ln \left\{ \frac{pF}{F+X} \left(1 - e^{-(F+X)}\right) \right\}$

$(0.5814, 0.7007)$ for X

$(0.8641, 1.0681)$ for F.

It should be noted that the three estimates are not independent and care should be exercised when interpreting confidence intervals.

Solving for p, we obtain the surprisingly large value of 1.047. The regression procedure does not provide a direct estimate of the variance of p but an approximate variance is easily computed by the delta method (Deming, 1943). This variance gives 95-percent confidence limits for p (0.957, 1.137) that include the value $p = 1$. No sense can be ascribed to values of p greater than one since they indicate either a tagging survival over 100 percent or a reported ratio greater than one.

The agreement between expected recaptures (for $p = 1$, the terms "recaptures", "recoveries", and "reports" are synonymous) calculated from the theoretical population model and the actual reports is shown in Figures 1 and 2. Even though the usual goodness-of-fit test yielded a significant χ^2 value ($p < 0.01$), the agreement between the actual and the theoretical numbers of recaptures does not seem unreasonable for data of this sort. When such large numbers are involved a small percentage error gives rise to a large χ^2 value. Furthermore, spurious replication may be introduced by counting each fish of a schooling species such as pink salmon as an independent observation.

A number of useful quantities can be computed immediately from the three estimates given above. The weekly (5.5 days) exploitation rate was 50.32 percent; the seasonal (three weeks) rate was 62.42 percent. The percent remaining in the fishing area after a week's exposure to fishing and other losses was 20.04. The seasonal "survival" in the fishing area was only 0.80 percent. During the three weeks 99.20 percent had either been taken in the fishery, emigrated from the fishing area or succumbed naturally. Less than 37.58 percent of the fish present in the fishing area when the season opens would be expected to ascend the spawning streams. The coefficient of catchability, q, is equal to 0.88 F/f or 0.01165, where f is 73, the number of traps that fished in the northern part of Southeastern Alaska in 1950.

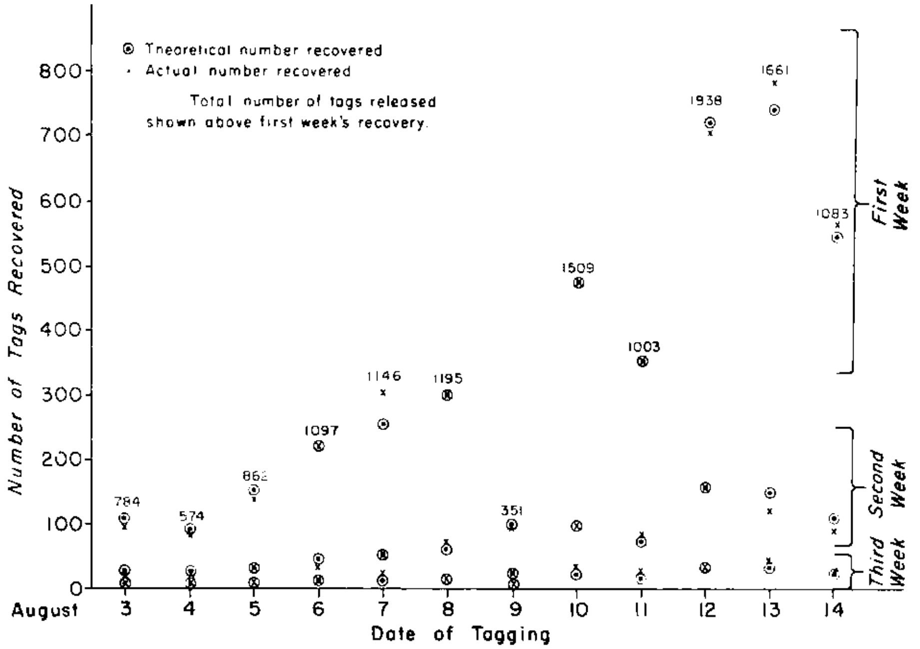


Figure 1. Theoretical and actual numbers of tagged pink salmon recovered by week from pre-season releases in Southeastern Alaska during 1950.

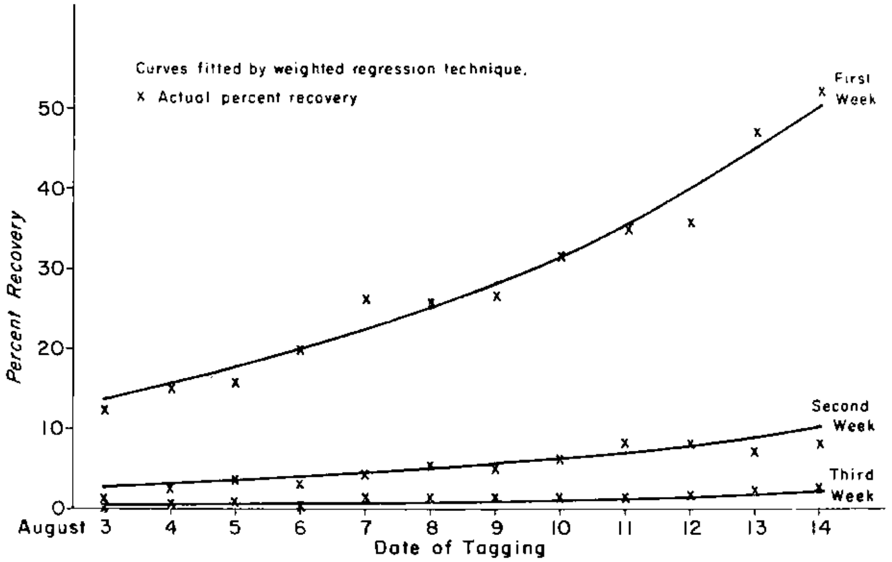


Figure 2. Theoretical and actual percent recovery of tagged pink salmon from pre-season releases in Southeastern Alaska during 1950.

Discussion

The apparent absence of type (1) losses, indicated by the estimated p-value of unity implies that, for the pink salmon fishery, tagging is a reliable method of assaying the effect of the amount of gear fished. Any possible bias introduced in the estimate of p by ignoring weekend closures and the tags of unknown recapture time had the effect of causing the estimated p to be less than the true p. The arbitrary assignment of the unknown-time-recaptures to the regular commercial season raises the actual percent recovered during the season from 38.32 to 39.78. A theoretical model including the week-end closures can be obtained easily from equation (3). Setting θ equal to the length of the closure ($\theta = 1.5/5.5$ for the case at hand) we obtain

$$\ln\left\{E\left(\frac{n_{ij}}{N_i}\right)\right\} = \ln\left\{\frac{pF}{F+X}(1-e^{-(F+X)})\right\} + \\ + F + (1+\theta)X - X_{\rho i} - [F + X(1+\theta)]\,j. \quad (4)$$

Since p has already attained its upper bound these corrections bring to light an interesting contradiction of the second assumption. This can be seen easily by recalling that the total quantity $(F + X)$ is estimated from the decrease in the relative numbers of recaptures during the three consecutive recovery periods. This total rate of decline is invariant, regardless of how it is interpreted. If the quantity estimated is assumed to represent $F + X(1 + \theta)$, to solve for F we must now subtract $(1 + \theta) X^*$, where X^* is estimated from the pre-season releases when only the X rate was operating. Subtracting $(1 + \theta) X^*$ depresses the estimate of F, and this in turn raises the estimate of p. But, rather than increase p, a more logical approach may be to interpret the X rate that operated during the season as $X_s = X^*/1 + \theta$, where X^* is the other-loss operating before the fishing season. Correcting in this manner for the omission of week-end closures in the original analysis changes the estimate of the value of X in effect during the season from 0.6410 to 0.5036. The implication that the physical presence of operating gear somehow alters the normal behaviour of the pink salmon raises a host of questions, only a few of which will be mentioned here. Does the removal of part of a school of pinks break up the school; do the survivors continue to mill in the proximity of the entrapped part of the school; are certain members of a school more liable to capture and does removal of some members cause temporary confusion until a new order is established; do the fish adopt an evasive behaviour, e.g. are frequent reversals of direction evoked by contact with or the sight of submerged webbing, that would hamper their migration?

The effect of the week-end closures upon the rate of escapement is of importance to management. The recaptures listed in Table 1 could have arisen from many different distributions of the other-loss rate within a week. For example, the rate of escapement might be almost negligible during the part of the week the gear operates, and then jump several orders of magnitude during the 36 hour closure. The intra-week distribution of recoveries for the 1950 experiments is, unfortunately, largely a function of the trap lift schedule and contains little information concerning the daily rate of escapement.

The apparent lack of immediate tagging mortality recommends both the method of capture and the tagging technique employed by Elling and Macy. Their handling during tag application appears routine; anaesthetics were not used and the fish were subjected to the overt trauma of removal from water and insertion of the tag pin through the dorsal musculature. Elling and Macy's use of a trap to capture the pinks differed sharply from the trolling method used by Parker et al. (1959) to capture chinook salmon for their mortality studies. In the former method, the pink salmon were guided by an extended net lead and an intricate system of successive enclosures into the heart of the trap, where they were brailed for tagging. All pinks were tagged on the same day they were trapped.

Although tagging from a trap appears to minimize struggling and the likelihood of severe fatigue, the 1950 experiments provide no basis for determining whether any other method of capture would have caused mortalities. Either observations on type (1) losses for pink salmon captured by other types of gear or information on the effect of maturity and feeding stage on the likelihood of mortality following hyperactivity are needed before the relative merits of traps for tagging can be evaluated. Further investigations on this point are needed, since recent regulations (1959) have outlawed the commercial use of traps in Alaska. If traps are a superior method of capturing fish for tagging it may be advisable for research agencies to maintain a number of traps solely for experimental work.

A study of the type (1) losses suffered by tagged salmon captured by various types of gear may help to pinpoint the particular phase of the capture-tagging sequence that is responsible for immediate mortalities. Another object of research in this area would be to develop a rapid method of diagnosing the fatigue condition of a tagged salmon when it is released.

A series of tagging experiments distributed over the geographical area and over a number of years would be required to provide an adequate test for a mathematical model of the present mobile-gear fishery. If a model similar to the exponential model given here is applicable, such a program would provide yearly estimates of F and X. The past history of the fishery indicates that a wide variability in the amount of gear fished from year to year may be expected. A plot of F vs. f (f is fishing intensity or simply the number of units of gear if the number remains constant during each season and the fishing area does not change from season to season) over a wide range of f values should define the relation between fishing intensity and fishing mortality. Such knowledge would further understanding of the history of the fishery. For example, if a simple linear relationship between F and f is assumed the rate of exploitation that occurred in some of the earlier years when gear intensity was higher may be readily computed. Using the coefficient of catchability found for the 1950 experiments ($q = 0.01165$) and taking X equal to 0.50, a weekly rate of exploitation of 57.06 percent for traps alone was estimated for the 1938 fishery when 101 traps operated in the northern part of Southeastern Alaska. A study of the relation between X and stream flow conditions or other environmental factors should also be fruitful.

Once these basic relations are established regulatory agencies could apply them to determine from yearly license applications, stream flow predictions and run size predictions, the optimum length of the fishing season.

Many of the ideas and suggestions mentioned only briefly here are developed more fully by Nakatani, Paulik and Van Cleve (1961). Nakatani et al. analyzed both the daily catch records of traps and the tag returns from tagging experiments in a study of the pink salmon fisheries in the northern part of Southeastern Alaska for the years 1938 to 1945.

The exponential model is a crude first approximation to an adequate mathematical model of a salmon fishery. Clearly the movements of the salmon should be explicitly represented in the model. The model used by Jones (1959) for analyzing the movements of tagged haddock appears to be a promising starting point for the development of a general model for a salmon fishery.

Summary

Recent physiological studies and field observations have demonstrated that hyperactivity may be lethal to salmonoids. These findings indicate that type (1) losses for tagging may be higher than previously suspected.

The data of a tagging experiment involving 13,203 pink salmon (*Oncorhynchus gorbuscha*) conducted in Southeastern Alaska in 1950 were re-examined and an estimate of the type (1) losses was made from the temporal distribution of the recoveries. The salmon were captured for tagging in a floating fish trap and were tagged with Petersen-disk-type tags.

It is assumed that the decline of the tagged populations could be represented by a simple exponential model containing the three parameters: 1) F, the exponential rate of fishing mortality; 2) X, the exponential rate of other-losses; 3) p, the type (1) loss correction factor.

This exponential model provided a reasonable representation of the weekly recaptures of tagged pink salmon from each of 12 pre-season releases made on consecutive days immediately preceding a three-week fishing season. The estimate of p was 1.047 with 95-percent confidence limits of 0.957 and 1.137. The estimate of F was 0.9661; that of X, which may be regarded as an upper limit of the rate of escapement, was 0.6410. The weekly exploitation rate was 50.32 percent; the seasonal rate, 62.42 percent. Less than 37.58 percent of the salmon would be expected to have reached the spawning streams. The coefficient of catchability, q, for traps was 0.01165. Applying this q to other years with high fishing intensities indicated that in some years as high as 57.06 percent of the population was caught in a week.

There was some evidence that the presence of the operating gear affected the behaviour of the salmon in a manner that lowered the rate of escapement into the streams.

Traps appear to be a satisfactory method of capturing pink salmon for tagging experiments in coastal waters.

Acknowledgements

I would like to thank Dr. Richard Van Cleve, Dean of the College of Fisheries at the University of Washington, for his willingness to discuss at length the general problem of studying salmon fisheries by means of tagging experiments; and Dr. D. G. Chapman of the Department of Mathematics at the University of Washington for his many critical comments and suggestions during the preparation of the manuscript.

References

ANON. 1950. Laws and regulations for protection of the commercial fisheries of Alaska 1950. *U.S. Fish Wildl. Serv. Reg. Ann.* 28.

BATES, D. W. and RUSSELL VINSONHALER. 1957. Use of louvers for guiding fish. *Trans. Amer. Fish. Soc.*, **86** (1956): 38—57.

BEVAN, DONALD E. 1959. Tagging experiments in the Kodiak Island area with reference to the estimation of salmon (*Oncorhynchus*) populations. Thesis (Pb. D.) Univ. Wasb. Coll. Fish.; 176 p.

BEVERTON, R. J. H. and S. J. HOLT. 1957. On the dynamics of exploited fish populations. *Fish. Invest.*, Lond., Ser. **II. 19.**

BLACK, EDGAR C. 1956. Appearance of lactic acid in the blood of Kamloops and lake trout following transportation. *Canad. Fish. Cult.* No. 18: 20—27.

BLACK, EDGAR C. 1958a. Energy stores and metabolism in relation to muscular activity of fishes. In *The investigation of fish-power problems* (ed. by P. A. Larkin), Canada: 51—67.

BLACK, EDGAR C. 1958b. Hyperactivity as a lethal factor in fish. *J. Fish. Res. Bd Canada,* **15** (4): 573—586.

BROWN, BRADFORD E. 1961. Differential sex mortality associated with handling landlocked alewifes. *Trans. Amer. Fish. Soc.* **90** (1): 80—81.

CHAMBERLAIN, F. M. 1907. Some observations on salmon and trout in Alaska. *Rep. Comm. Fish.* 1906 (Bur. Fisb. Doc. 627): 5—112.

CHAPMAN, DOUGLAS G. 1956. Estimating the parameters of a truncated Gamma distribution. *Ann. Math. Stat.* **27** (2): 498—506.

CHAPMAN, DOUGLAS G. 1960. Statistical problems in the dynamics of exploited fish populations. Paper presented at the *Fourth Berkeley Symposium on Probability and Statistics*, July, 22: 1—29.

DAVIDSON, F. A., E. VAUGHAN, S. J. HUTCHINSON and A. L. PRITCHARD. 1943. Factors influencing the upstream migration of pink salmon (*Oncorhynchus gorbuscha*). *Ecology* **24** (2): 149—168.

DEMING, W. E. 1943. *Statistical adjustment of data.* John Wiley and Sons. 261 p.

ELLING, C. H. and P. T. MACY. 1955. Pink salmon tagging experiments in Icy Strait and Upper Chatham Strait 1950. *Fish. Bull.* U.S., **56** (100): 331—371.

FRY, D. H. and E. P. HUGHES. 1951. The California salmon troll fishery. *Pac. Mar. Fish. Comm. Bull.* No. 2: 7—42.

HORTON, H. F. 1956. An evaluation of some physical and mechanical factors important in reducing delayed mortality of hatchery-reared rainbow trout. *Prog. Fish-Cult.* **18** (1): 3—14.

HUNTSMAN, A. G. 1938. Overexertion as a cause of death of captured fish. *Science,* **87** (2269): 577—578.

JONES, R. 1959. A method of analysis of some tagged haddock returns. *J. Cons. int. Explor. Mer,* **25** (1): 59—72.

McFARLAND, WILLIAM N. 1960. The use of anaesthetics for the handling and the transport of fishes. *Calif. Fish Game,* **46** (4): 407—431.

MILLER, RICHARD B. 1954. Comparative survival of wild and hatchery-reared cutthroat trout in a stream. *Trans. Amer. Fish. Soc.,* **83** (1953): 120—130.

MILNE, D. J. 1957. Recent British Columbia spring and coho salmon tagging experiments, and a comparison with those conducted from 1925 to 1930. *Bull. Fish. Res. Bd Can.,* No. 113: 1—56.

MILNE, D. J. and E. A. R. BALL. 1956. The mortality of small salmon when caught by trolling and tagged or released untagged. *Fish. Res. Bd Can. Progr. Rep. Pacif. Cst. Stas.* No. 106: 10—13.

MILNE, D. J. and E. A. R. BALL. 1958. The tagging of spring and coho salmon in the Strait of Georgia in 1956. *Ibid.* No. 111: 14—18.

NAKATANI, R. E., G. J. PAULIK and R. VAN CLEVE. 1961. Analysis of past Alaskan pink salmon tagging experiments, 1938—1945. (submitted to U.S. Bureau of Commercial Fisheries for publication in Special Scientific Report Series).

PARKER, R. R. and E. C. BLACK. 1959. Muscular fatigue and mortality in troll-caught chinook salmon (*Oncorhynchus tshawytscha*). *J. Fish. Res. Bd Canada,* **16** (1): 95—106.

PARKER, R. R., E. C. BLACK and P. A. LARKIN. 1959. Fatigue and mortality in troll-caught Pacific salmon (*Oncorhynchus*). *Ibid.,* **16** (4): 429—448.

PAULIK, GERALD J. 1959. The locomotive performance of salmonoids during upstream migration. Thesis (Ph. D.) Univ. Wash. Coll. Fish.: 1—216.

PAULIK, G. J. and A. C. DeLACY. 1958. Changes in the swimming ability of Columbia River sockeye salmon during upstream migration. *Univ. Wash. Coll. Fish. Techn. Rep.* 46: 1—67.

PAULIK, G. J., A. C. DeLACY and E. F. STACY. 1957. The effect of rest on the swimming performance of fatigued adult silver salmon. *Ibid.* 31: 1—24.

PRITCHARD, A. L. 1936. Factors influencing the upstream spawning migration of pink salmon, *Oncorhynchus gorbuscha* (Walbaum). *J. Fish. Res. Bd* Canada, **2** (4): 379—382.

RICH, WILLIS H. 1926. Salmon-tagging experiments in Alaska, 1924 and 1925. *U.S. Bur. Fish. Bull.* **42.** (Doc. 1005): 109—146.

RICH, W. H. and A. J. SUOMELA. 1927. Salmon-tagging experiments in Alaska, 1926. *Ibid.* **43,** Pt. 2 (Doc. 1022): 71—104.

RICH, W. H. and F. G. MORTON. 1929. Salmon-tagging experiments in Alaska, 1927 and 1928. *Ibid.* **45** (Doc. 1057): 1—23.

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Fish. Res. Bd Can. Bull.* No. 119: 1—300.

VEDENSKII, A. P. 1954. Age of pink salmon and the pattern of their fluctuations in abundance. (Translation available from Off. Techn. Ser., U.S. Dept. Comm.) *Izvestiya tikhookeanskogo nauchno-issledovalil 'skogo instituta ryknogo khozyaistvai okeanografii.* **41**: 111—195.

VERHOEVEN, L. A. 1952. A report to the salmon fishing industry of Alaska on the results of the 1947 tagging experiments. *Fish. Res. Inst. Univ. Wash.*: 1—21 (Processed).

VERHOEVEN, L. A., HOARD, G. L., and NAKATANI, R. E. 1957. Injurious and lethal effects of electricity on young salmon. *Univ. Wash. Sch. Fish. Tech. Rep.* 16: 1—21.

WARD, F. J. 1959. Character of the migration of pink salmon to the Fraser River spawning grounds in 1957. *Int. Pac. Salmon Fish. Comm. Bull.* 10: 1—70.

38.

Detection of Incomplete Reporting of Tags

by
GERALD J. PAULIK*

Introduction

When the primary objective of a tagging or marking experiment is to estimate the rate of exploitation of a population supporting a fishery, it almost invariably follows that the actual recovery of the bulk of the tagged or marked fish is out of the hands of the investigators conducting the experiment. A major part of the responsibility of detecting and reporting recaptures of tagged fish must be entrusted to the commercial, sport or native fishermen who harvest the population.

Attempts to enlist the cooperation of the fishermen and to increase their effectiveness in recovering tags have ranged from educational programs to various reward schemes.Measures aimed at overcoming possible disinterest on the part of the fishermen and increasing their incentive to search for and to turn in tags have been particularly imaginative. For example, for returning a tag to the Inter-American Tropical Tuna Commission, the fisherman receives one dollar and a chance in an annual three hundred dollar drawing (Schaefer, 1958). The Fisheries Research Institute at the University of Washington has approached the motivation problem in a forthright manner by proffering a reward of twenty-five dollars for the return of both fish and attached tag for recoveries of tagged salmon released in the North Pacific (Hartt, personal communication).

It is noteworthy that for the Fisheries Research Institute's high seas tagging studies the increase in the size of the reward was accompanied by two-fold increase in the percentage of tags returned (Hartt, ibid.). To attribute this increment solely to the change in the value of the reward is an oversimplification of a highly complex problem, but the magnitude of the increment does lead to interesting speculation.

Recovery programs that depend on voluntary tag reporting by sport fishermen appear to be subject to particularly high levels of non-response error. Angler response also appears to be highly sensitive to a variety of factors and is apt to fluctuate markedly, depending on the accompanying circumstances, e.g., in one of two studies conducted in Massachusetts, Mullan (1959) found a 60 percent non-response for mandible tags on trout and in the other, Stroud and Bitzer (1955) estimated a 25 percent non-response for strap and cheek tags on warm-water species. A recent article by McCammon and LaFaunce (1961) should be consulted for a more complete discussion of the incomplete reporting problem for fresh-water sport fisheries.

While rewards and other such measures decrease the possibility of non-reporting of tags, each tagging experiment should be so designed as to contain some provisions for testing the assumption that all of the recaptured tags are reported. The most direct method of testing this assumption is to have trained observers examine a portion of the catch. A sampling program of this sort may be objectionable because of the manpower requirements and because of the cost involved but it would seem to be unavoidable except in special circumstances.

The purpose of this paper is to provide the biologist planning a tagging experiment with a preliminary guide to help him decide how many tags should be put out and how much of the catch should be inspected to be reasonably sure of discovering non-reporting of a certain magnitude. When the total outlay for the tagging experiment is fixed, the table furnished here should also be an aid in the optimum allocation of personnel and resources between the tagging and recovery phases of the experiment. There may be a temptation to sample the catch for marks in a perfunctory manner and to conclude that incomplete reporting is not a serious problem unless a sizeable difference between the tagged to untagged ratios for the inspected and uninspected portions of the catch shows up. It is shown in Table 1 that if only "token" catch sampling is carried on, there is a rather large chance that a significant amount of incomplete reporting will not be detected. Or, to view the problem in a slightly different perspective, if we wish to maintain the same assurance of detecting incomplete reporting, a substantial increase in the numbers of fish tagged may be required to offset a decrease in the proportion of the catch inspected.

Theory and Methods

If incomplete reporting is extensive, the apparent rate of exploitation or the apparent size of the population as calculated from the tag returns may be seriously biased. The true rate of exploitation is equal to the apparent rate divided by the fraction

---

* University of Washington, U.S.A. This research was sponsored by the National Science Foundation under grant No. G-10365. Reprinted with alterations from the J. Fish. Res. Bd Canada, 18 (5), 1961.

of tags that are reported (Ricker, 1958). A convenient term for this fraction is the "reported ratio" which has been defined as (to paraphrase Atwood and Geis, 1960): the proportion of the total number of tagged or marked fish caught that are subsequently reported to the research agency.

In the development that follows it is assumed that the reported ratio remains constant during the duration of the experiment and over the entire area in which the recoveries are made. If these conditions are not met, it may be possible to subdivide the recoveries into groups so that the reported ratio for each sub-division is constant.

The need for such stratification should obviously be explored if the recaptures are made by nationals of several countries in an internationally fished area (Beverton and Holt, 1957, p. 200) or if the publicity given to the experiment is unevenly distributed over the exploited area. A time stratification might be called for if there is reason to suspect that a tag may be retained by the fishermen as a talisman when it is first introduced (Idyll, 1952; Rounsefell and Everhart, 1953). A number of specific examples of areal and temporal variations in the reported ratios for banded waterfowl are presented by Atwood and Geis (1960).

A natural formulation of the problem of detecting incomplete reporting is as a test of the hypothesis that the reported ratio is equal to one against the alternative that the reported ratio is less than one. The probability of detecting a reported ratio that is less than one with such a test (this probability is generally referred to as the "power" of the test) will be examined using the following notation:

ρ = reported ratio
f_i = number of standardized units of gear in the ith class ($i = 1,2$)
C_i = catch in numbers in the ith class,
r_i = number of tags recovered in the ith class ($r = r_1 + r_2$),
s_i = number of tags reported in the ith class ($s = s_1 + s_2$),
t = number of tags liberated,
N = number of fish in population at time of tagging,
Z = standardized normal variate, $\Pr(Z \geq z_{1-\alpha}) = \alpha$,
α = level of significance of the test, or the probability of concluding that $\rho < 1$ when in fact $\rho = 1$,
β = probability of failing to detect a reported ratio that is less than one. ($\beta = 1 -$ power of the test).

More adequate definitions of the statistical terms may be found in any standard text on statistics, e.g., see Chapter 7 of Dixon and Massey (1957).

The procedure outlined below presupposes the feasibility of classifying either the catch or fishing effort into two categories, one of which has a known reported ratio of unity or nearly so, while the other has an unknown reported ratio that is to be estimated from the tag recoveries. In practice the former category would be defined as the fraction of the catch or the effort inspected by special observers or, possibly, as the units of gear operated by fishermen who, by virtue of special training, long experience, or a keen interest in the experiment, could be relied upon to turn in all of the tags that appear in their catches. The sampling for tags might easily be coordinated with the collection of other biological data. For example, the International Pacific Halibut Commission at present assigns a biologist to each of a number of the vessels in the halibut fleet. One of the biologist's routine duties is to inspect the catch as it is brought aboard (Myhre, pers. comm).

Catch sampling

A simple probability model may be formulated in terms of catch inspection. For most commercial fisheries large catches (C_i's) and low tag ratios (t/N's) would be expected. If it is assumed that the same tag ratio applies to both inspected and uninspected classes and that the tag ratio within each class remains constant for the duration of the experiment, the number recaptured in each class should be approximately distributed according to a Poisson law (e.g., see Chapman, 1954), i.e.,

$$\Pr(r_i) = \left(\frac{C_i t}{N}\right)^{r_i} \frac{e^{-C_i t/N}}{r_i!} \quad i = 1,2 \qquad (1)$$

Now by hypothesis, $s_1 = r_1$ and it is reasonable to assume further that given r_2, s_2 is binomial (r_2, ρ), i.e.,

$$\Pr(s_2 \mid r_2) = \binom{r_2}{s_2} \rho^{s_2} (1 - \rho)^{r_2 - s_2}. \qquad (2)$$

By a well known result (e.g., see Feller, 1957, p. 269), s_2 is Poisson $\left(C_2 \frac{t}{N} \rho\right)$. It then follows that, given that a tag has been reported, the probability it was reported from the first class,

$$\Pr(s_1 \mid s) = \binom{s}{s_1} \left(\frac{C_1}{C_1 + \rho C_2}\right)^{s_1} \left(\frac{\rho C_2}{C_1 + \rho C_2}\right)^{s_2}. \qquad (3)$$

If the assumption that the tag ratio remains constant during the entire season is permissible, the catch inspection scheme is highly flexible, e.g., all of the fish landed during the first part of the season may be inspected and none of those during the latter part of the season or vice versa. It will be shown below that this assumption may be weakened somewhat provided that catch sampling is carried on in a specified manner. If we assume that the season can be divided into J intervals so that the tag ratio ($= t_j/N_j$ for $j = 1,2, \ldots, J$) remains constant within each interval, then

$$\Pr\,(r_{ij} \mid t_{ij}, N_j) = \frac{e^{-(C_{ij} t_j/N_j)}\,(C_{ij}\,t_j/N_j)^{r_{ij}}}{r_{ij}\,!} \qquad (4)$$

for $i = 1,2$ and $j = 1,2, \ldots, J$

Under these conditions it is necessary to sample the same fraction of the catch in each of the J intervals. Denoting the constant fraction of the catch inspected by λ it can be easily shown (as above) that

$\Pr\,(s_{1.} \mid s_{..}) =$

$$\binom{s_{..}}{s_{1.}} \left(\frac{\lambda}{\lambda + \rho\,(1 - \lambda)}\right)^{s_1} \left(\frac{\rho\,(1 - \lambda)}{\lambda + \rho\,(1 - \lambda)}\right)^{s_{2.}} \qquad (5)$$

where the dot notation is used to indicate summation over a subscript, i.e., $s_1 = \sum_{j-1}^{J} s_{1j}$.

Although the Poisson distribution probably applies to most fisheries situations, cases may arise (e.g. when t/N is not small) in which the probability of r_i recoveries may be more adequately approximated by a binomial law, i.e.

$$\Pr\,(r_i) = \binom{C_i}{r_i} \left(\frac{t}{N}\right)^{r_i} (1 - t/N)^{C_i - r_i} \qquad (6)$$

Equation (6) is equivalent to assuming that two independent random samples of sizes C_1 and C_2 respectively, are drawn from an infinite population for which probability of recovering a tag is t/N. Assuming as before that $s_1 = r_1$ and s_2, given r_2, is binomial (r_2, ρ), we have

$$\Pr\,(s_i) = \binom{C_i}{s_i} \left(\rho_i \frac{t}{N}\right)^{s_i} \left(1 - \rho_i \frac{t}{N}\right)^{C_i - s_i} \quad i = 1,2 \qquad (7)$$

where $\rho_1 = 1$ and $\rho_2 = \rho$. When the samples taken at all stages are chosen randomly, the exact probability distribution of the reports (recaptures reported by the fishermen) could be constructed from the observation that the probability of a total of r recoveries when a sample of size C is taken, is hypergeometric (Chapman, 1951); given r, C and C_2, the conditional probability of r_2 is again hypergeometric, and the conditional distribution of s_2 given r_2 is binomial (r_2, ρ). Unfortunately, this construction leads to equations that are difficult to manage algebraically.

If the observations are arranged in the usual two by two table, the chi-square statistic can be used to test the hypothesis $H\colon \rho = 1$. Since the alternative $(\bar{H}\colon \rho = \rho_a < 1)$ is one-sided, we would modify the usual test slightly by only rejecting H when $s_1/C_1 > s_2/C_2$ and the chi-square statistic exceeds $\chi^2_{1-2\alpha}$ instead of the usual $\chi^2_{1-\alpha}$. The limiting power of the chi-square test has been studied by Mitra (1958) and he gives the formulae needed for the power computations and examples of their use. For small numbers of recoveries and small catch sizes the hypothesis that a tag is equally likely to be returned from the uninspected as from the inspected portions of the catch could be tested by Fisher's exact test (Fisher, 1954). Tables and charts of the exact power of this test have been prepared by Bennet and Hsu (1960). Hsu (1960) gives a normal approximation that can be used for power computations when large sample sizes are involved. Another avenue of attack when larger samples are available would be to use the fact that $y_i = 2\arcsin \sqrt{s_i/C_i}$ measured in radians has an approximate normal $(2 \arcsin \sqrt{\rho_i\, t/N},\ 1/C_i)$ distribution. A detailed exposition of the power computations for the angular transformation and an arcsin table are available in Brownlee (1960).

The present discussion will be restricted to the case where the conditional distribution of the recoveries in a given class can be represented by equation (3). It may be asked what would happen if the Poisson distribution was erroneously assumed when in fact the binomial distribution given in equation (6) did apply. The required sample size as computed from Table 1 would then be conservative and the true power of the test would exceed the nominal power. A heuristic proof of this statement would be that under the null hypothesis the binomial probability given in equation (3) is replaced by the hypergeometric, i.e., $\Pr\,(s_1 \mid s) = \binom{C_1}{s_1} \binom{C_2}{s_2} \Big/ \binom{C}{s}$, which has a smaller variance. Since the use of this technique in practice will involve a number of approximations, it is doubtful whether it would be worth the trouble to go through the more exact and more laborious power calculations.

Effort sampling

For many fisheries the units of gear are the natural sampling units and effort-sampling may actually involve less effort on the part of the research agency than catch-sampling. There also may be some advantage in trading the assumptions concerning relations between the tagged and untagged portions of the population which are needed for the catch inspection method for parallel assumptions about the relationship between the tagged population and the fishing effort. Assume that the f_1 units of gear, which have a reported ratio of one, differ in no other way from the other units of gear. Assume further that the fishery is continuous with respect to the tagged populations (see Beverton and Holt, 1957) and that

$$\Pr\begin{pmatrix}\text{tag is recaptured by the}\\ \text{research agency between}\\ \text{times t and t} + \text{dt}\end{pmatrix} =$$

$$= q\,(f_1 + \rho f_2)\,e^{-[q\,(f_1 + f_2) + X]\,t}\,dt \qquad (8)$$

where X is an instantaneous rate which represents all factors other than the fishery which act to reduce the tagged population and q = ratio of the instantaneous rate of fishing mortality to the fishing intensity. For ρ, f_1, f_2, and X constant, by time $t = T$, a given tag will either have been reported from the f_1 units of gear, the f_2 units of gear or will not have been reported. The probabilities of the three possibilities are equal to

$$\frac{qf_1}{F+X}\left(1 - e^{-(F+X)T}\right),\ \frac{q\rho f_2}{F+X}\left(1 - e^{-(F+X)T}\right)$$

$$\text{and } 1 - \frac{q\,(f_1 + \rho f_2)}{F+X}\left(1 - e^{-(F+X)T}\right)$$

respectively, where $F = q\,(f_1 + f_2)$. Given that a tag has been reported, the probability that it was taken by fishermen in the first class is then binomial, i.e.,

$$\Pr\,(s_1 \mid s) = \binom{s}{s_1}\left(\frac{f_1}{f_1 + \rho f_2}\right)^{s_1}\left(\frac{\rho f_2}{f_1 + \rho f_2}\right)^{s_2} \qquad (9)$$

which is completely analogous to the corresponding results for catch sampling, cf. equation (3).

The parameter q measures "catchability" which in actuality may vary considerably during a long season or over several seasons. If the time scale is divided into J intervals and $q\,(t) = q_j$ for $t_{j-1} \leq t \leq t_j$, $j = 1,2\ \ldots,\ J$, it can be easily shown (following Chapman, 1960) that for a given tag the expected probability of recovery by the research agency by time $t = T_J$ is:

$$\Pr\,(\text{recapture by fisheries agency}) =$$

$$\sum_{j=i}^{J} \frac{q_j\,(f_1 + \rho f_2)}{X + q_j F}\left(1 - e^{-(X + q_j F)\,\Delta_j}\right)$$

$$e^{-\left(X\,t_{j-1} + F\sum\limits_{i=0}^{j-1} q_i\,\Delta_i\right)} \qquad (10)$$

where $\Delta_j = t_j - t_{j-1}$. By simply deleting ρf_2 in equation (10) we obtain an expression for the probability that the recapture was made by the fishermen in the first class. Thus the conditional probability of s_1 given s is again given by equation (9) showing that so long as the same fraction of the effort is inspected during each of the J intervals, variations in catchability can be ignored. Of course, the same statement also applies to variations in the number of units of gear since the fluctuations in the levels of fishing intensity could be incorporated in the parameter q.

Computation of Sample Size

The null hypothesis, $H_0 : \rho = 1$, would be doubted if the proportion of tags recovered from the inspected class is too high in relation to the proportion of the catch or the amount of gear in this class. Using the normal approximation of the binomial distribution, the well known most powerful one-sided test would be to reject H_0 if $s_1 \geq s_R$ where s_R is equal to

$$z_{1-\alpha}\sqrt{sp_0\,q_0} + {}^1/_2 + sp_0,$$

$$p_0 = \frac{f_1}{f_1 + f_2} \text{ or } = \frac{C_1}{C_1 + C_2},\ q_0 = 1 - p_0 \qquad (11)$$

if this expression happens to be an integer. If it is not, s_R is taken to be the nearest integer which is larger. The power of the test against a specific alternative would be the probability of rejecting H_0 when $\rho = \rho_a < 1$. Again, approximating the binomial distribution by the normal, the number of reported tags needed to test H_0 at pre-set values of α and β for different ρ's can be expressed as

$$s = \frac{z_{1-\beta}\sqrt{p_1\,q_1} + z_{1-\alpha}\sqrt{p_0\,q_0})^2}{(p_1 - p_0)^2} \qquad (12)$$

where $p_1 = \dfrac{f_1}{f_1 + \rho f_2}$ or $= \dfrac{C_1}{C_1 + \rho C_2}$ and $q_1 = 1 - p_1$.

Values of s as a function of the reported ratio and the fraction of the total catch $\left(\dfrac{C_1}{C_1 + C_2}\right)$ inspected or of the total effort $\left(\dfrac{f_1}{f_1 + f_2}\right)$ for which the reporting is known to be complete, are given in Table 1. The tabled values have low accuracy for small values of s where the normal approximation to the binomial distribution is not too close. These errors are of little importance for larger s's.

The following four examples will illustrate the use of Table 1.

Example 1. A biologist wants to be 99 percent sure of detecting non-reporting of 20 percent or more of the tags recovered by a commercial fishery. From past experience he knows that at least 30 percent of the tags released will be recovered. Twenty-five percent of the fishermen agree to attend a special course of instructions and cooperate fully in this experiment. If α is taken as 0.10, how many tags should be liberated?

Solution: In Table I, for $\rho = 0.80$, $f_1/f_1 + f_2 = 0.25$, $\alpha = 0.10$ and $1 - \beta = 0.99$, s is found to be 1340. To solve for t, the number of tags that must be put out when the 30 percent recovery estimate refers to

Table 1

Numbers of recoveries needed for prescribed probabilities of detecting incomplete reporting with various levels of catch inspection

ρ	1 — β	$\alpha = 0.10$									
		$C_1/C_1 + C_2$ or $f_1/f_1 + f_2$									
		0.05	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.70	0.90
0.25	0.50	6	4	4	3	3	4	4	5	9	28
	0.80	24	14	11	10	10	9	10	11	17	51
	0.90	39	23	18	15	14	14	14	15	23	66
	0.95	54	31	24	20	19	18	18	19	28	80
	0.99	88	50	37.	32	29	27	26	28	40	109
0.50	0.50	39	23	18	15	14	14	14	15	23	66
	0.80	136	76	56	47	42	39	38	39	55	147
	0.90	210	116	85	71	63	58	55	56	76	201
	0.95	284	156	114	94	83	76	71	73	97	252
	0.99	453	246	178	146	128	117	108	109	143	365
0.60	0.50	84	47	36	30	27	26	25	27	38	106
	0.80	276	151	110	91	80	74	69	71	95	247
	0.90	421	229	166	136	120	110	101	102	134	344
	0.95	564	305	221	180	158	144	132	133	172	436
	0.99	888	478	344	280	243	221	201	200	256	639
0.70	0.50	197	109	80	66	59	55	52	53	72	191
	0.80	615	332	240	196	171	156	143	143	186	469
	0.90	925	498	359	291	253	230	209	208	266	662
	0.95	1230	660	474	384	333	302	273	271	342	847
	0.99	1917	1026	734	593	513	464	416	410	513	1256
0.75	0.50	322	176	128	106	93	86	80	81	108	278
	0.80	981	527	380	308	268	244	221	220	280	696
	0.90	1468	787	564	456	395	358	323	319	402	990
	0.95	1943	1040	744	601	519	470	422	415	519	1272
	0.99	3016	1609	1148	925	797	720	643	630	781	1895
0.80	0.50	568	307	222	182	159	145	133	134	173	439
	0.80	1688	904	647	523	453	410	369	364	457	1121
	0.90	2512	1341	958	772	667	602	539	529	658	1603
	0.95	3314	1767	1260	1015	875	789	704	689	853	2065
	0.99	5120	2725	1939	1558	1340	1207	1073	1046	1285	3093
0.85	0.50	1130	607	436	354	307	279	252	250	317	787
	0.80	3290	1754	1251	1007	868	783	699	684	847	2052
	0.90	4866	2590	1844	1482	1275	1148	1021	997	1225	2950
	0.95	6401	3403	2420	1943	1670	1502	1333	1298	1590	3814
	0.99	9845	5227	3712	2975	2554	2294	2031	1972	2402	5733
0.90	0.50	2832	1512	1079	869	750	677	605	593	736	1789
	0.80	8074	4289	3048	2444	2100	1887	1672	1626	1985	4748
	0.90	11881	6305	4475	3585	3076	2761	2442	2369	2880	6859
	0.95	15579	8261	5859	4691	4022	3608	3186	3086	3743	8894
	0.99	23864	12643	8959	7166	6138	5501	4850	4691	5669	13423
0.95	0.50	12548	6658	4724	3785	3246	2914	2576	2499	3036	7227
	0.80	35080	18573	13151	10513	8999	8060	7097	6855	8262	19515
	0.90	51367	27181	19237	15369	13149	11770	10352	9989	12013	28320
	0.95	67153	35522	25132	20072	17167	15362	13503	13020	15641	36822
	0.99	102459	54175	38312	30586	26148	23389	20540	19791	23732	55778

Table 1 (continued)

ρ	1 — β	$\alpha = 0.05$									
		$C_1/C_1 + C_2$ or $f_1/f_1 + f_2$									
		0.05	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.70	0.90
0.25	0.50	9	6	5	5	5	6	7	8	14	46
	0.80	30	19	15	13	13	13	14	15	25	75
	0.90	47	28	22	19	18	18	18	20	32	93
	0.95	63	37	29	25	23	22	23	25	38	109
	0.99	101	57	44	37	34	33	32	35	51	143
0.50	0.50	63	37	29	25	23	22	23	25	38	109
	0.80	180	100	75	63	57	53	51	54	76	207
	0.90	264	146	108	90	80	75	71	74	102	271
	0.95	346	191	140	116	103	95	90	92	125	331
	0.99	530	289	211	174	153	141	131	133	177	458
0.60	0.50	137	77	58	49	45	42	41	44	63	174
	0.80	368	202	148	123	109	101	95	97	132	346
	0.90	533	291	212	175	154	142	131	134	178	460
	0.95	693	376	273	224	197	180	166	168	221	566
	0.99	1048	566	409	334	291	266	243	244	315	794
0.70	0.50	324	178	131	109	97	90	85	87	119	315
	0.80	827	448	325	266	233	213	196	197	257	653
	0.90	1183	638	461	375	327	298	272	272	350	879
	0.95	1524	820	590	479	417	379	344	343	437	1091
	0.99	2281	1223	877	710	615	558	503	498	628	1549
0.75	0.50	530	289	211	174	153	141	131	133	177	458
	0.80	1325	714	515	419	364	332	302	301	386	968
	0.90	1883	1011	726	589	511	464	420	416	528	1310
	0.95	2417	1296	929	751	651	590	532	525	662	1631
	0.99	3600	1924	1375	1110	959	867	777	764	953	2328
0.80	0.50	935	506	366	299	261	239	219	220	285	722
	0.80	2289	1227	880	712	617	560	505	499	630	1554
	0.90	3234	1730	1237	999	864	781	701	690	863	2114
	0.95	4137	2209	1578	1272	1098	992	888	872	1084	2641
	0.99	6132	3268	2329	1874	1614	1455	1297	1269	1567	3788
0.85	0.50	1862	1000	718	582	506	459	415	412	523	1297
	0.80	4473	2388	1705	1374	1185	1070	957	939	1166	2836
	0.90	6287	3350	2387	1920	1654	1491	1329	1299	1604	3877
	0.95	8016	4267	3037	2441	2100	1891	1682	1641	2018	4859
	0.99	11827	6286	4468	3585	3080	2769	2456	2390	2922	7000
0.90	0.50	4666	2490	1777	1432	1235	1115	997	977	1213	2947
	0.80	11012	5854	4162	3340	2871	2582	2291	2230	2730	6544
	0.90	15398	8176	5807	4655	3997	3590	3179	3088	3764	8989
	0.95	19572	10386	7371	5905	5066	4548	4022	3902	4743	11299
	0.99	28752	15243	10808	8651	7415	6649	5870	5684	6886	16345
0.95	0.50	20671	10967	7782	6234	5348	4799	4243	4116	5000	11902
	0.80	47983	25412	18000	14393	12324	11041	9727	9402	11345	26832
	0.90	66770	35343	25021	19997	17114	15324	13487	13022	15682	27015
	0.95	84619	44776	31689	25317	21660	19389	17053	16456	19791	46650
	0.99	123797	65478	46319	36989	31632	28303	24871	23978	28788	67741

Table 1 (continued)

ρ	1 — β	α = 0.01									
		$C_1/C_1 + C_2$ or $f_1/f_1 + f_2$									
		0.05	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.70	0.90
0.25	0.50	17	12	10	10	10	11	13	16	28	92
	0.80	45	28	23	21	20	20	22	25	42	131
	0.90	65	39	31	28	27	26	28	32	51	155
	0.95	84	50	39	35	33	32	33	37	59	175
	0.99	126	73	57	49	46	44	45	49	75	218
0.50	0.50	126	73	57	49	46	44	45	49	75	218
	0.80	278	157	118	100	90	85	83	88	127	350
	0.90	382	213	158	133	119	112	108	113	159	432
	0.95	479	266	197	164	147	137	130	136	188	506
	0.99	692	381	280	232	205	190	179	184	250	661
0.60	0.50	274	154	116	98	89	84	82	87	125	347
	0.80	578	319	235	195	174	162	153	158	217	579
	0.90	781	428	314	259	230	212	199	204	276	723
	0.95	971	531	387	319	281	259	242	246	329	855
	0.99	1385	753	546	448	393	360	332	336	441	1131
0.70	0.50	648	357	262	218	193	179	169	174	238	629
	0.80	1312	713	518	425	373	342	316	320	422	1083
	0.90	1751	948	686	561	490	449	412	414	539	1368
	0.95	2162	1167	843	687	599	547	500	500	645	1629
	0.99	3048	1640	1180	959	834	758	688	685	874	2181
0.75	0.50	1060	578	422	347	305	281	261	266	353	914
	0.80	2110	1140	823	671	586	535	489	490	633	1597
	0.90	2802	1509	1087	883	769	700	636	634	811	2029
	0.95	3446	1852	1331	1080	938	852	772	767	975	2424
	0.99	4835	2591	1857	1503	1302	1180	1063	1050	1323	3261
0.80	0.50	1869	1011	732	597	522	477	437	439	570	1444
	0.80	3661	1966	1413	1145	994	903	817	811	1029	2555
	0.90	4834	2591	1857	1502	1301	1179	1063	1050	1323	3261
	0.95	5927	3172	2270	1834	1586	1435	1290	1271	1593	3909
	0.99	8775	4419	3156	2544	2196	1984	1775	1743	2169	5282
0.85	0.50	3724	2000	1437	1165	1011	918	830	824	1045	2593
	0.80	7184	3840	2744	2214	1913	1729	1550	1524	1902	4647
	0.90	9441	5038	3595	2896	2498	2255	2015	1976	2452	5957
	0.95	11537	6150	4383	3528	3040	2741	2445	2393	2958	7161
	0.99	16035	8534	6074	4882	4201	3782	3364	3283	4036	9719
0.90	0.50	9332	4980	3554	2863	2470	2229	1993	1954	2424	5894
	0.80	17752	9444	6720	5398	4643	4178	3714	3621	4445	10689
	0.90	23221	12342	8773	7040	6049	5438	4824	4695	5742	13759
	0.95	28291	15027	10674	8560	7351	6604	5851	5687	6938	16586
	0.99	39150	20774	14743	11812	10134	9096	8044	7804	9488	22601
0.95	0.50	41348	21937	15566	12469	10696	9600	8487	8232	10002	23813
	0.80	77628	41128	29142	23312	19969	17897	15779	15263	18444	43682
	0.90	101102	53539	37919	30318	25958	23254	20483	19795	23878	56448
	0.95	122823	65021	46037	36797	31496	28206	24830	23981	28893	68223
	0.99	169262	89565	63386	50642	43326	38784	34111	32916	39588	93317

recaptured but not necessarily reported tags, note that r, the number of tags we would expect to be recaptured, can be written: $r = ut$, where u is the rate of exploitation (see Ricker, 1958, p. 20). Then s, the number of tags turned in, should be:

$$s = u\,[f_1/(f_1 + f_2) + \rho f_2/(f_1 + f_2)]\,t.$$

Substituting the values given above:

$$1340 = 0.30\left[\frac{1}{4} + \left(0.80\right)\frac{3}{4}\right] t, \text{ or } t = \frac{4\,(1340)}{(0.30)(3.40)} = \\ = 5{,}255.$$

However, the 30 percent recovery estimate could have been based on the percent of tags reported in the past. In this case $\rho u = 0.30$ or $u = \dfrac{0.30}{0.80}$. We now expect the number of tags reported to be:

$$s = \left(\frac{0.30}{0.80}\right)\left[\frac{1}{4} + \left(0.80\right)\frac{3}{4}\right] t.$$

Solving for t we find

$$t = \frac{4\,(0.80)\,(1340)}{(0.30)\,(3.40)} = 4{,}204.$$

The point of this example is that the tagging program should be designed to report at least 1340 tags to the research agency.

The second example illustrates a situation where there may be a differential between the costs of catch sampling and effort sampling.

Example 2. A biologist wants to estimate the percent of marks detected and reported by sportsmen and would like to be 90 percent sure of discovering a reported ratio of 80 percent or lower. Two thousand marked trout have been released in a large lake shortly before the opening of the fishing season and an unknown portion of them would be expected to survive until opening day.

Assume:

(i) the unmarked and marked members of the population are equally vulnerable to capture,

(ii) a reliable estimate of the total effort and the total catch for each week of the season is available,

(iii) the "catchability" of the trout is constant within a week but may vary from week to week,

(iv) no immigration or reproduction occurs during the season and thus the size of the population in the lake declines steadily as the catch mounts.

The biologist must decide whether to sample the catch or the effort to estimate the reported ratio. We will consider sampling to be largely a problem of providing coverage for the areas of access to the lake and that the cost would be roughly proportional to the percent of the total effort interviewed on a given day regardless of the numbers of fishermen involved. In such a situation it may be relatively inexpensive to sample ten or twenty percent of the fishermen using the lake on a given day, but the costs would be expected to increase rapidly as the percentage of fishermen included in the sampling was increased.

The total number of fish recovered from sampling a fixed percentage of the fishermen would, of course, tend to drop in the latter part of the season because of the drop in the numbers of fish in the lake and the concomitant decrease in the numbers of fishermen. For example, the total catch during a five week season may be 100000 but the majority of these fish, say 63000, may be taken during the first week of the season. Sampling one-half of the effort expended during the first week (which represents a smaller portion, say 20 percent, of the total season's effort; e.g., if a total of 25000 units of effort were expended

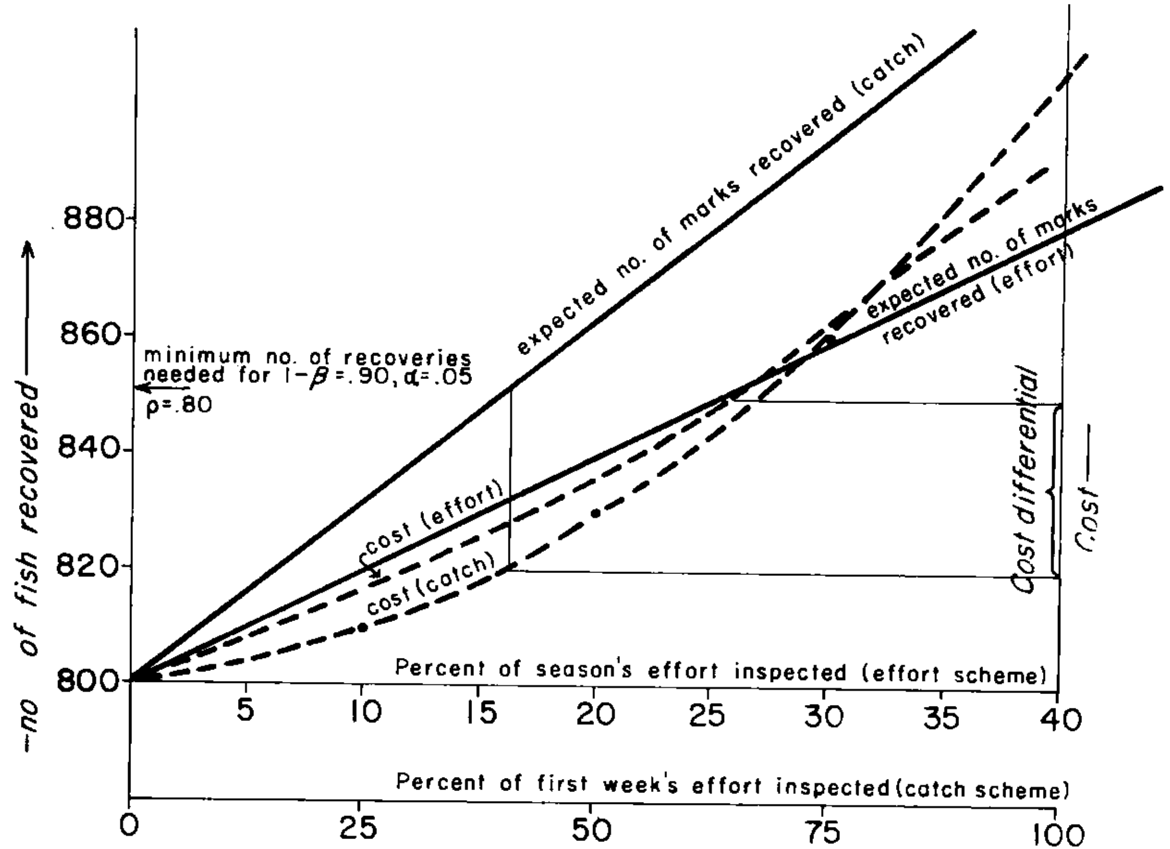


Figure 1. Comparison of the costs of catch and effort-sampling for a sport fishery.

during the entire season, 10000 or 40 percent of these fished during the first week) would then provide $31\,{}^1/_2$ percent of the total catch. On the other hand, inspection of a straight 20 percent of the effort expended each week would be expected to yield only 20 percent of the catch. As the marked ratio remains constant the catch can be inspected anytime during the season. Clearly the optimum time to inspect the catch is during the first part of the season when both the intensity and catch per unit of effort are highest; we will assume that the entire catch sample will be taken during the first week.

However, effort sampling is not so flexible. Because catchability and population size vary, a constant percent of each week's effort must be sampled. Effort sampling does not require assumption (i) since only the relationship between the effort and the marked population is involved. However, (i) is replaced by the assumption that the percent recovery is directly proportional to the fishing intensity in any interval.

The relevant factors that must be considered when evaluating the two sampling schemes are illustrated in Figure 1. An arbitrary number (taken to be 1000 here) must be assigned to the expected total number of marked fish recovered to plot the two "expected number-of-recoveries" lines. The required number of recoveries was taken from Table 1, using $\alpha = 0.05$, $\beta = 0.10$, $\rho = 0.80$ for the optimum $f_1/f_1 + f_2$ and $C_1/C_1 + C_2$ ratios. For the cost curves shown, catch sampling is most economical. A different choice of cost curves might reverse the verdict.

The next two examples will illustrate the use of Table 1 in other areas of fisheries research.

Example 3. Suppose the experiment described in Example 2 was carried out and a reported ratio of unity was found. The following year the hatchery conducts an experiment to determine the advisability of early pre-season stocking as opposed to plants made just before the onset of fishing. Assume that if the trout can be released two months before the opening of the season, the capacity of the hatchery (and the number of fish stocked) can be increased by ten percent. Thus if the survival rate of the early pre-season releases is greater than 0.909 an increase in the catch should result from early planting (ignoring possible differences between the growth rates of early and late plants).

To estimate this survival rate ($= q$), N_E fish are released in the early plant and N_C fish in the late plant. Assume that the survival of the late plant is one* and that the hypothesis of interest is, $H\colon q = 1$, vs. the alternative $\overline{H}\colon q = q_1 < 1$. The probability of rejecting H should be high when $q_1 \leq 0.90$. Taking $\beta = 0.01$ and $\alpha = 0.05$, how many recoveries are needed and what is the approximate optimum ratio of $N_C/N_C + N_E$? The exact optimum ratio will usually lie between two of the ratios given in Table 1. However, since in the neighborhood of the optimum ratio, the required sample sizes change slowly, the tabulated values will suffice for most practical purposes.

Solution: In Table 1 for $\rho\ (= q) = 0.90$, $\alpha = 0.05$ and $\beta = 0.01$ the minimum number of recoveries is found to be 5684 when $N_C/N_E + N_C = 0.5$. If the expected recovery is at least 60 percent, $N_C + q_1N_E = \frac{5684}{0.6}$, or setting $N_E = N_C$, $N_C = \frac{5684}{(0.6)(1+q_1)} = 4986$.

Example 4. An experiment to determine if the survival rate of downstream migrant salmon is significantly reduced by passage over a dam might involve the release of one group (experimental) of fingerlings in the forebay and another group (control) in the tailrace of the dam. Fyke nets or other such gear would be employed some distance downstream to recover the fingerlings. Setting N_C and N_E equal to the respective numbers of controls and experimentals released, n equal to the total number of recaptures and q equal to the survival rate of the experimentals, test the $H\colon q = 1$ vs $\overline{H}\colon q = q_1 < 1$. If the experimenter wishes to be 80 percent sure of detecting a mortality of five percent or greater and uses an $\alpha = 0.05$, how many recoveries are required?

Solution: Entering Table 1 with $\rho\ (= q_1) = 0.95$, $\alpha = 0.05$, $\beta = 0.20$; n is found to be 9402 for $N_C/N_E + N_C = 0.5$. In this case the experimenter has the option of varying either the number of fingerlings released or the recovery effort to obtain the desired number of recoveries. The number of fish recovered may be proportional to the fraction of the total cross-sectional area of the stream covered by nets at the recovery site and, if so, the cost of recovering a given percentage of the fish released at the dam could then be easily computed. The relative costs of sampling and of obtaining and marking fingerlings would then determine the optimum allocation of funds to minimize the total cost of the experiment.

Comments

The plan presented here for estimating incomplete reporting should not be confused with examining the catch for tags that the fishermen failed to remove. Such posterior examinations are quite valuable in helping to bridge the gap between the number of

---

* A survival rate of one was assumed for simplicity. The method illustrated is equally applicable if the survival of the late plant was taken as γ where $0 < \gamma < 1$ and the null hypothesis and the alternative were $H\colon q = \gamma$ and $\overline{H}\colon q = q_1 < \gamma$, respectively.

tags the fishermen catch and the number that are eventually returned to the research agency, but do not measure nonresponse error.

Examination of the uninspected portion of the catch for tags not removed by the fishermen (supposedly the inspected portion of the catch will contain no such tags) is a means of separating the incomplete reporting bias into its components. One component is the fisherman's failure to remove the tag from the catch and the other is the fisherman's failure to report recovered tags to the research agency.

The required sample sizes tabulated in Table 1 demonstrate the difficulty of detecting incomplete tag reporting even when a number of strong assumptions are satisfied. The evaluation and interpretation of tagging results usually requires many more assumptions, e.g., that the immediate mortalities suffered as a direct result of the tagging operation are negligible, that the fish's normal behavior pattern has not been drastically altered by the application and presence of the tag, that the recovery gear is not selective for tagged fish, etc. In many cases the experimental results will not provide an adequate test of these assumptions. Careful advance planning and execution of tagging experiments is required if the results are to be meaningful. The design of the experiment must take into account the nature of the fish and of the fishery, and the experiment should involve substantial numbers of fish and an extensive recovery operation.

Summary

A table is presented which gives the total number of tags that must be recovered in order to have a prescribed probability of discovering non-reporting by fishermen of a certain percentage of recaptured tags when a portion of the catch or of the effort is inspected by special observers. The table gives the required sample sizes for probabilities of detection of 0.50, 0.80, 0.90, 0.95, and 0.99 at various levels of catch inspection. The table may also be used to find the sample size needed to detect with prescribed probability a differential mortality between two identifiable groups of fish whose initial numbers are known. A number of examples of the use of the table are included.

Acknowledgements

The author would like to gratefully acknowledge the stimulating guidance and encouragement provided by Dr. Douglas G. Chapman of the Department of Mathematics of the University of Washington during the preparation of the paper. Mr. Charles Junge of the Fisheries Research Institute suggested the application given in Example 4 and contributed a number of other helpful ideas.

References

ATWOOD, E. L. and A. P. GEIS. 1960. Problems associated with practices that increase the reported recoveries of waterfowl bands. *J. Wildlife Mgt.* **24** (3), pp. 272—279.

BENNET, B. M. and P. HSU. 1960. On the power function of the exact test for 2 × 2 contingency table. *Biometrika*, **47** (3 and 4), pp. 393—398.

BEVERTON, R. J. H. and S. J. HOLT. 1957. On the dynamics of exploited fish populations. *Fish. Invest. Lond.Series* 2. **19.** 533 pp.

BROWNLEE, K. A. 1960. *Statistical theory and methodology in science and engineering.* John Wiley and Sons, New York. 570 pp.

CHAPMAN, D. G. 1951. Some properties of the hypergeometric distribution with application to zoological sample censuses. *Univ. Calif. Publ. Stat.*, 1, pp. 131—160.

CHAPMAN, D. G. 1954. The estimation of biological populations. *Ann. Math. Stat.*, **25** (1), pp. 1—15.

CHAPMAN, D. G. 1960. Statistical problems in the dynamics of exploited fish populations. Paper presented at the *Fourth Berkeley Symposium on Probability and Statistics*, July 22. 29 pp.

DIXON, W. J. and F. J. MASSEY. 1957. *Introduction to statistical analysis.* Second ed., McGraw-Hill, New York. 488 pp.

FELLER, WILLIAM. 1957. *An introduction to probabilitiy theory and its applications*, Vol. I, 2nd ed., John Wiley and Sons, New York. 461 pp.

FISHER, R. A. 1954. *Statistical methods for research workers.* 11th ed., Oliver and Boyd, Edinburgh. 354 pp.

HSU, PAUL. 1960. On the power function of the test for the 2 × 2 contingency table. M. A. Thesis, Univ. of Wash., Seattle, Wash., 77 pp.

IDYLL, CLARENCE. 1952. Salt water tagging experiments on sockeye salmon (*Oncorhynchus nerka* (Walbaum)). Ph. D. Thesis, Univ. of Wash., Seattle, Wash. 187 pp.

McCAMMON, G. W. and D. A LaFAUNCE. 1961 Mortality rates and movement in the channel catfish population in the Sacramento valley. *Calif. Fish Game*, **47** (1) pp. 5—23.

MITRA, SUJIT KUMAR. 1958. On the limiting power function of the frequency chi-square test. *Ann. Math. Stat.* **29** (4), pp. 1221—1233.

MULLAN, JAMES W. 1959. Probable effectiveness of tag reporting from trout stocked in two Massachusetts streams drainages. *Mass. Div. Fish Game.* 13 pp. (mimeo).

RICKER, W. E. 1958. Handbook of computations for biological statistics of fish populations. *Fish. Res. Bd Canada*, Bull. No. 119, 300 pp.

ROUNSEFELL, G. A. and W. H. EVERHART. 1953. *Fishery science, its methods and applications.* John Wiley and Sons, New York. 444 pp.

SCHAEFER, MILNER B. 1958. *Inter-American Tropical Tuna Comm. Ann. Report for the year* 1957. LaJolla, Calif., 134 pp.

STROUD, R. H. and H. BITZER. 1955. Harvests and management of warm-water fish populations in Massachusetts lakes, ponds and reservoirs. *Prog. Fish-Cult.*, **17** (2) pp. 51—63.

39.

Non-mutilation Marks for Fish

By

SHELBY D. GERKING*

Introduction

The ideal fish mark is individually recognizable over a long period of time and will neither affect the mortality rate nor influence feeding, growth, or movement. This ideal has not been achieved by conventional tagging or mutilation marking, but in the last ten years some inventive schemes of marking fish by less injurious methods have been suggested which are a sign of progress in this direction. Four non-mutilation marking methods have had limited success: (1) total immersion in a biological stain, (2) tattoo, (3) injection of various substances, and (4) marking with radioactive phosphorus. These are called "non-mutilation marks," although the puncture of tattoo needles or the insertion of a hypodermic needle causes some tissue injury. Less injury is involved, however, than with the attachment of tags, removal of fins, or excising a piece of bone. Radioactive phosphorus and stain immersion can be used to mark fish with no individual handling. Non-mutilation marks can be applied rapidly and have avoided affecting adversely mortality and behavior. Their chief compromise with the ideal has been a loss of individuality. The marks are either applied simultaneously to a large number of fish, in the case of radioactive marking and immersion, or with too few combinations of tattoos or injections for individual recognition.

Most of the non-mutilation marks have not been tested critically for long-term studies, but enough work has been done to indicate that they can be used successfully for short-term observations of less than a year. Some of the marks show enough promise to deserve consideration in situations where either increased mortality or altered behavior may influence the outcome of experiments.

Tattoo

Gandolfi-Hornyold (1929) was the first to tattoo marks on fish. Six "elvers" were tattooed in the oriental fashion with india ink. The mark was recognizable for six weeks in the laboratory (Table 1). This work was followed by Kask's (1936) experiments with halibut. Numbers and letters were tattooed on the white side with India ink by a hypodermic needle and syringe. Over 300 were marked in the vicinity of the Queen Charlotte Islands, British Columbia. Slightly more than 8 percent were recovered, and the tattoo was as clear when the fish were recaptured as when it was put on. The longest period of liberty was 99 days. Dr. Heward Bell, Assistant Director of Investigations, International Pacific Halibut Commission, reports (personal communication) that these initial attempts to tattoo halibut on the white side proved unsatisfactory for long-term marking experiments. Plaice and soles (species not given) were marked by Hickling (1945) with a professional tattooing device. Numbers and letters faded and were faint after seven weeks. Rays were not marked successfully. The present author tried a similar technique (Gerking 1953) on a variety of warmwater species after Wigley's (1952) success with two species of lampreys. His india ink marks lasted 18 months, but mine faded after three weeks.

All of the above workers, with the exception of Kask, have used the time-honored method of tamping inert pigments beneath the skin with a bundle of needles either by hand or with an electric, portable, vibrating device. A portable device was designed by Dunstan and Bostick (1956) for field work, and they were able to tattoo 300 to 400 fingerling coho salmon per hour. They conducted the most ambitious experiment to date with a stationary tattooing machine in a hatchery. A total of 40,000 chinook salmon fingerlings were marked at a rate of 3,000—6,000 per day. Four analine dyes were tested in separate experiments, but they faded after 65 days. Because of their unsatisfactory staining properties they were discarded in favour of several inert materials. In one experiment metal oxide pigments were recognizable after 97 days when the observations were terminated. Chapman (1957a) improved Dunstan and Bostick's design of the stationary tattooing device and reported that a titanium dioxide-india ink mark could be recognized for five months.

India ink has been used most often, probably because this was the first material to be tried. Retention of the india ink tatoo with this material varies considerably with the species. Lampreys held the mark for 18 months but scaled fish varied from three weeks to three months. The scales probably interfere with needle puncture and the effectiveness of tamping the carbon particles beneath the skin. Other inert materials show more promise, but observations have not extended beyond five months. This is sufficient time to perform observations on short-term migratory movements or to estimate populations where marking

---

* Contribution No. 705 from the Department of Zoology, Indiana University, Bloomington, U.S.A.

Table 1

Results of marking fish by tattooing with various substances

Author	Species	No. of Specimens	Material	Observed duration of mark	Conditions of experiment
Gandolfi-Hornyold (1929)	"elvers"	7	India ink	6 weeks	Marked in oriental fashion by bundle of needles. Laboratory test.
Kask (1936)	*Hippoglossus stenolepis*, Halibut (Adult)	343	India ink	99 days	Applied with hypodermic syringe in small dots. Numbers and letters applied on cheek or nape on white side. Field tests.
Hickling (1945)	Plaice, sole, ray. (Adult) (species not given)	69	"India ink" Cephalopod sepia "Vermilion"	Faded by 7 weeks. Unsuccessful on rays.	Tattooed with professional electric tattooing needle. Pigments used in each case were not recorded. Tattoo placed on white side of fish. Used letters and numbers. Laboratory tests.
Wigley (1952)	*Petromyzon marinus*, Sea lamprey. (Larvae) *Lampetra lamottei*, American brook lamprey. (Larvae)	(not given)	India ink	18 months	Applied with special tattooing device. Laboratory tests.
Gerking (1953)	Variety of warmwater species. (Adult)	69	India ink	3 weeks	Applied with portable, battery-operated tattoo device. Field tests.
Dunstan and Bostick (1956)	*Oncorhynchus tshawytscha* Chinook salmon (*ca* $1^1/_2$ inches long) *Oncorhynchus kisutch*, Coho salmon. (Fingerling)	40,000	Analine dyes (congo red, trypan blue, fast green, bismark brown, nigrosine). Insoluble pigments (aluminum oxide, titanium dioxide, ferric oxide, chrome green, aluminum phospbomolybdate, elemental carbon)	Analine dyes began to fade after 65 days. Insoluble pigments recognizable after 97 days.	Applied with special tattooing device. Laboratory and field tests.
Chapman (1957a)	*Salmo gairdneri*, Rainbow trout. (Juvenile)	(not given)	Titanium dioxide, TiO_2 as vehicle for india ink and trypan blue	5 months	Applied with special tattooing device. Field test wiht TiO_2 plus india ink.

Table 2

Results of marking fish by immersion in a biological stain

Author	Species	No. of Specimens	Material	Observed duration of mark	Conditions of experiment
Bouchard and Mattson (1961)	*Oncorhynchus gorbuscha*, Pink salmon. (Fingerling)	1000	Alizarin red	Faded after 2—6 hours.	Total emersion for 4—7 hours in concentrations varying from 1 part stain to 1,000,000 parts water to 1 part in 50,000. Neutral red most successful in concentration of 1 part to 300,000 parts water and fish immersed for 7 hours. Field tests.
	Oncorhynchus keta, Chum salmon. (Fingerling)		Malachite green	Caused distress or death.	
	Oncorhynchus kisutch, Coho salmon. (Fingerling)		Neutral red	Recognizable for 7 days.	
			Eosine yellowish	Not successful.	
			Nile blue A	Faded in 2 hours.	
			Toluylene blue	Not successful.	
Deacon (1961)	22 warm-water species *Pimephales promelas*, Fathead minnow. (Adult) (principal species)	1500	22 stains, Bismark brown Y most successful	2 weeks	Total immersion for 3 hours at a concentration of 1:5,000 at 65° F or 1:20,000 at 85° F. Dye dispersed through body musculature with concentrations at body surface and in kidneys. Field tests.

and recapture are done simultaneously. No mortality has been observed as a result of tattooing that could not be attributed to handling. Behavior is unaffected.

Immersion in Biological Stains

Of the three non-mutilation methods of marking fish, immersion in a water-soluble biological stain has received the least attention. Two recent papers have explored this possibility. Bouchard and Mattson (1961) and Deacon (1961) stained fish by placing them in a water solution of various dyes. Up to 1500 fish were stained simultaneously, but several hours were required for the stain to become impregnated. Bouchard and Mattson worked in Alaska on fry and fingerlings of three species of Pacific salmon. Deacon stained 22 species of warmwater fish from Kansas streams. Neither research uncovered a water-soluble stain which was recognizable for over two weeks (Table 2). A total of twenty-eight stains have been used, and none were duplicated in the two series of experiments. Bouchard and Mattson had most success with neutral red which could be recognized for seven days after treatment. Deacon found that Bismark brown Y lasted 1—2 weeks. The method was tested in the field in both cases, but detailed results have not yet been reported.

Several advantages stem from whole-body staining. Handling time is reduced. This is especially important in the case of small fish where a significant mortality results from handling associated with fin-clipping or some other mutilation procedure. Large numbers can be stained simultaneously, and stained fish in a mixed sample can be identified quickly. Short-term experiments are already possible with present techniques, and stains of longer duration may be discovered in the future.

Injection

Twenty-five different materials have been injected intramuscularly, intraperitoneally, and subcutaneously with the prospect of producing a conspicuous, non-mutilation mark (Table 3). Seventeen of these have been biological stains. Dunn and Coker (1951), Al-Hamid (1954), and Bond and Culver (1952) all agree that trypan blue was non-lethal, but faded in 3—6 weeks. Tests have not been consistent with several other stains. Bismark brown Y, which was a successful immersion stain, was lethal when injected intramuscularly just anterior to the caudal fin in the dorsal half of the peduncle by Dunn and Coker. Trypan red was visible in Atlantic coast marine species for four weeks but was lethal to bluegills when tested by Al-Hamid. The opposite result was obtained with alizarin red S and congo red. Bluegills held these stains for 90 days, but they killed marine species in three days. Davis's (1955) alizarin mark faded in two months. Retention of fast green varied from 6 to 30 days in the two series of tests. Safranin 0 was lethal in both tests. Of the remaining stains only brilliant vital red, chlorazol fast pink B, and nigrosine seem to have possibilities.

Both Al-Hamid's and Dunn and Coker's method produced "spots" or limited areas of color. The former was able to color the entire dorsal or caudal fin by injecting the stain at the base of the fin rays. If this method is to prove successful, a large number of stains should be screened systematically under controlled conditions.

Hasler and Faber (1941) were the first to inject a material which produced a lasting "mark." They employed thorothrast, a slightly radioactive suspension of colloidal thorium dioxide (ThO_2) in a carbohydrate carrier. A sub-lethal dose of 1 mg per 2—3 gram trout (species not given) was concentrated chiefly by the spleen and was detectable by X-ray. The method may have application in special circumstances, but it cannot be used in the field because roentgenograms are required. Thorothrast is retained quantitatively throughout life.

Cadmium sulfide, mercuric sulfide, and carbon were injected between the skin and muscles of larval lampreys by Wigley (1952). Each produced a lasting mark, but observations did not extend beyond 18 months. This method obviously has promise, but the work has not been followed up with critical tests of survival with large numbers of individuals.

Since Davis (1955) successfully injected a colored latex "spot" beneath the skin of sunfishes, several other workers have tested the method. The present author (Gerking 1958) injected several hundred redear sunfish and bluegills in Wyland Lake, Indiana in 1955 and 1956 and compared their survival with a group marked by fin-clipping. Most of the work was done with redear sunfish and the results have since been confirmed with the bluegill (Gerking, 1962). Red, yellow, and white latex was injected in four locations on the body: right and left occiput region, and right and left side at the posterior base of the dorsal fin. In the former site the hypodermic needle was inserted beneath the skin and a spot of latex was forced between the dermis and the muscle. The "posterior dorsal" injection was made by forcing the latex into a small channel, presumably a lymph channel, which runs the length of the dorsal fin. The mark appears as a colored streak along the base of the fin, its length depending upon the degree to which the channel is filled.

No difference in survival between latex-injected and fin-clipped sunfishes could be detected, if the latex was injected at a favorable site. The posterior dorsal injection mark and fin-clips were returned in

Table 3
Results of marking fish by injecting various substances

Author	Species	No. of Specimens	Material	Observed duration of mark	Conditions of experiment
Hasler and Faber (1941)	Trout (species not given) (Fingerling)	330	Thorothrast, a slightly radioactive suspension of colloidal thorium dioxide (ThO_2) in a carbohydrate base.	Observed for $2^{1}/_{2}$ months but should be retained throughout life.	Injected intraperitoneally. 1 mg per 4—6 cm fish is harmless. Detected by X-ray. Laboratory test.
Dunn and Coker (1951)	*Fundulus heteroclitus* Mummichog *Fundulus majalis* Striped killifish *Leiostomus xanthurus*, Spot *Micropogon undulatus*, Croaker *Roccus saxatilis*, Striped bass *Morone americana*, White perch. (All adult)	82	Fast green Bismark brown Y Janus green B Bordeaux red Alizarin red S Brilliant cresyl blue Trypan blue Trypan red Methyl violet Safranin O Congo red Methylene blue	Faded after 6 days Lethal, 30 hours Lethal, 32 hours Lethal, 3 days Lethal, $3^{1}/_{2}$ days Lethal, 5 hours Visible for 6 weeks Visible after 4 weeks Lethal, 48 hours Lethal, 24 hours Lethal, 3 days Faded in 36 hours	Injected intramuscularly just anterior to caudal fin in dorsal half of peduncle. First three stains used in 1% solution with distilled water. Others used in 1% solution with 0.85% NaCl solution. Fish kept in boxes staked out in river.
Bond and Culver (1952)	*Salmo clarki*, Cutthroat trout. (Juvenile)	150	Trypan blue	Faded in 3 weeks	Injected on mentum and base of fins. 1% solution of dye in 0.85% NaCl solution. Laboratory tests.
Wigley (1952)	*Petromyzon marinus*, Sea lamprey. (Larvae) *Lampetra lamottei*, Brook lamprey. (Larvae)	(not given)	Cadmium sulfide Mercuric sulfide Carbon	Carbon and mercuric sulfide did not fade for 18 months. Cadmium sulfide observed for 6 months.	Injected between skin and muscles. Laboratory tests.
Al-Hamid (1954)	*Lepomis macrochirus*, Bluegill. (2—4 inches)	98	Brilliant vital red Alizarin red S Congo red Chlorazol fast pink Nigrosine Trypan blue Fast green Trypan red Safranin O Gentian violet	Detectable for 90 days ,, ,, ,, ,, Faded after 36 days Faded after 30 days Lethal Lethal Lethal	Injected at base of caudal fin, at base of dorsal fin, and on cheek below eye. Both pond and aquarium observations.
Johnson and Posekany (1954)	Centrarchidae, Sunfishes, (Size not given)	(not given)	Fluorescin	Not detectable after 1 week	Injected intraperitoneally in water solution. Detected under ultraviolet light. Laboratory tests.
Davis (1955)	*Lepomis cyanellus*, Green sunfish. (Adult) (principal species)	300	Colored latex Carmine India ink Liquid plastic Alizarin	6—10 months 7 months 7 months, less successful than carmine. Not successful Faded in 2 months	Subcutaneous "spot" injection on various parts of body. Latex used on occiput only. Laboratory and pond tests.
Chapman (1957b)	*Salmo gairdneri*, Rainbow trout. (Juvenile)	600	Colored latex	Recognizable after 8 weeks	Subcutaneous "spot" injection on ventral side between pelvic fins. Field test.
Gerking (1958)	*Lepomis microlophus*, Redear sunfish. (Adult)	145	Colored latex	Recognizable after 1 year	Subcutaneous "spot" injection on occiput and just posterior to dorsal fin. Occiput injections recognizable for at least a year but a high proportion are "lost". Posterior dorsal injections returned in same proportion as fin-clips after 1 year. Field tests.

the same proportion during the summer in which they were applied and also the year following. The recovery of occiput injection marks compared favorably with fin-clips during a two-week period immediately after marking, but a very small proportion (4 percent) of occiput marks were recovered the following year compared with the return of posterior dorsal marks (25 percent) and fin-clips (28 percent). The occiput mark was either responsible for the death of the fish or was sloughed. An occasional individual was found with a raw spot in the occiput region which resembled an open sore, and the latex spot was "pulling out" of its place beneath the skin in a few specimens. In our experience latex marking does not possess an advantage over fin-clipping from the point of view of survival but if the injection sites are carefully chosen the method offers an increased variety of marks.

A subcutaneous latex injection between the pelvic fins of rainbow trout has been performed by Chapman (1957b). In the initial experiments the mark was recognizable for two months. He has reported (personal communication) that further experience has shown that the mark was held for three months but was lost, or at least was not recognizable, five months subsequent to injection.

Dr. Thomas G. Northcote of the Institute of Fisheries, University of British Columbia, Vancouver, B. C., and Dr. Donald E. Wohlschlag, Department of Zoology, Stanford University, Stanford, California, have both used the latex marking method, and they have kindly supplied brief résumés of their results. Like Chapman, Northcote was not able to mark rainbow trout successfully and the same was true for the northern squaw fish (*Ptychocheilus oregonensis*). Long-term recognition of longnose suckers (*Catostomus catostomus*) and white suckers (*Catostomus commersoni*) was possible, however. From a total of 800—1400 fish of each species spawning in an inlet stream of Baker Lake near Quesnel, British Columbia, in 1957 and 1958, approximately 50 percent bore a latex spot which had been applied in 1956. The latex marks were still being recovered in 1960 when 10—13 percent of the spawning run exhibited the original mark. Northcote reports that the marks were recognizable four years after marking, but some difficulty was encountered in a few cases due to skin pigmentation and a heavy incidence of "black spots," cysts of a trematode parasite which occur beneath the skin. These observations of the latex mark are the longest on record and inspire confidence that the technique has considerable promise for certain species. Combinations of red and blue latex "spots" on different locations on the body permitted a correlation of the time of entrance of the suckers in the stream in 1956 with similar observations in following years.

Wohlschlag used latex marks for three years on bluegills and largemouth bass (*Micropterus salmoides*) in Felt Lake on the Stanford University campus. His marking experiments required many classes of marks, and he was able to achieve this by injecting red and yellow latex and also a clear latex solution in which titanium dioxide was suspended. Marks were applied at the bases of the paired fins, the posterior dorsal site described above, and the fleshy portion at the upper anterior part of the operculum. Red latex was more distinct than the others after a period of a year, but all were recognizable for six months. Wohlschlag stated that the method was highly successful for his purposes in which marks were intended to last for three or four months.

The injection technique may be applied to the study of crustacean populations as well. Joseph Kutkuhn of the Bureau of Commercial Fisheries Laboratory at Galveston, Texas, has stained pink shrimp (*Penaeus duorarum*) in the Gulf of Mexico off the coast of Texas and southwest Florida by injecting fast green, Trypan blue, and Trypan red into the body (personal communication). Initially, the dye colors the whole body. In a few hours most of the dye is excreted, but enough remains concentrated in the gill filaments to be visible through the carapace. Many thousands have been injected in a short time. The stain is retained by the gills for about three months. (See also Costello, this Symposium No. 23.) Slack (1955) developed a method of injecting crayfish (*Orconectes sp.*) with black Bates Numbering Machine Ink (No. 4929A) beneath the exoskeleton on the ventral side of the abdomen. The mark was not lost during moulting.

Neither behavior nor mortality seem to be affected by injecting various non-toxic materials into the body, and from this point of view the method has achieved a degree of success. Injection of latex and metalic oxides has been more lasting than biological stains. A few long-term studies, lasting a year or more, have been fruitful, but more work of this nature is required to use the injection technique with confidence. Already injections have been used successfully for estimating populations and survival rates and for studying migration. The chief advantage of subcutaneous marking is that a variety of classes of marks can be designed using different colors at various locations on the body, more so than by clipping various combinations of the paired fins. There appears to be no hope of producing a sufficient variety of injection marks for individual recognition.

Marking with Radioactive Substances and Branding

Branding fish with a hot wire has recently been attempted without complete success. The results of these efforts have not yet been published and are included here for the benefit of those who may have considered using this technique. Branding mutilates the skin, and therefore should not be classed as a non-mutilation mark.

Preliminary branding experiments were done by Buss (1953) who marked young brook trout (*Salvelinus fontinalis*) with a woodburning pencil. The experiments were not uniformly successful. Some brands lasted for 21 months. Johnson and Fields (1959) repeated the experiments using a nichrome wire heated to white heat by a four-volt alternating current. The brand was a straight mark about 0.5 cm long applied to various parts of the body. Eight groups of 30 rainbow trout, averaging $4^1/_2$ inches long, each received a brand on a different location on the body. The fish were held in laboratory aquaria. Survival was the same as unbranded controls, but after 158 days not one of the 238 survivors showed a mark which could be positively identified. The brand healed without the deposition of an unusual pigment pattern or the development of scar tissue.

Three differently shaped nichrome resistance wire branding "irons" heated with a variable 110-volt transformer were used to mark rainbow trout by Peterka (1960). The three marks were placed on six body locations for a total of 1000 combinations. The method was tested by releasing young rainbow trout in two small lakes in northern Wisconsin from which the fish had been removed by poisoning. Branded fish suffered a greater mortality than either an unmarked group or those marked by fin-clipping. Branding made the trout more susceptible to fungus infection. By fin-clipping and branding a group of fish simultaneously, it was learned that 20 percent of the branded fish could not be recognized during the year of marking, and the figure rose to 33 percent a year later. The brands were distorted as the fish grew. Peterka has more hope for success with adult fish. Seven recaptures of mature trout branded in 1960 from a total of 31 marked the year before bore a recognizable mark which showed little or no distortion.

Hot wire branding has also been done by Dr. Weldon Larimore of the Illinois State Natural History Survey, Urbana, Illinois. The results of his work have not been fully evaluated, but he reports (personal communication) that the success of branding different species was related to the size of their scales. Carp (*Cyprinus carpio*) and other large-scaled fishes were not satisfactorily marked. Fish with smaller scales, i.e. Centrarchidae, took the brand more successfully, and catfishes (Ictaluridae) were the best subjects in Larimore's experience.

Shekhanova (1958) has devised a practical method of marking fingerling sturgeon (species not given) with radioactive phosphorus, P^{32}, by feeding them "tagged" oligochaetes. Large numbers of fish can be "marked" in a short time with no handling. The worms were fed dry yeast or flour which had been soaked in a solution of "hot" Na_2HPO_4. Over 95% of the phosphorus in the food was assimilated. After feeding the oligochaetes for two days, the worms were then fed to larval sturgeon. The greatest effect in the sturgeon was noticed after feeding four or five rations. At that time the radioactivity of the sturgeon ranged from 100 to 2370 impulses per minute above background. The radiophosphorus tag could be detected for about three months. Counting was done either on live fish in a specially constructed chamber or on fish preserved in 4 percent formalin.

Field tests were done to learn the distribution of the fingerling sturgeon in the Kura River, U.S.S.R., after release from a rearing farm and the subsequent migration toward the sea. About 96,000 sturgeon larvae, each weighing about 200 mg, were fed two kg of "hot" oligochaetes in two feedings. The larvae were reared to fingerling size, about 2 grams, and planted in the Kura River. About 72,500 were released in company with 150,000 unmarked individuals. Trawling in the river and estuary caught a total of 306 fingerlings from two to six days after release, and 109 were radioactive. The proportion of marked to unmarked fish in the catch was the same as when they were planted. The experiment demonstrated that the fingerlings stayed near the area of release for 2 or 3 days before proceeding downstream to the sea. They traveled 25—27 km to enter the estuary.

An internal radioactive tag for herring (*Clupea harengus pallasii*) is feasible on a large scale. The tag and the detection equipment have been developed and are in current use in southeastern Alaska (see Wilimovsky, this Symposium No. 60). Scott (1961) has recently injected Iron-59 into the body cavity of brook trout (*Salvelinus fontinalis*). The biological half-life was approximately 1000 days under laboratory conditions, and Scott suggested that the material could be used for short-term marks, probably up to a year.

Summary

Attempts to mark fish by immersion in a biological stain, tattoo, injection of various substances, and "feeding" radiophosphorus have met with variable success. Immersion in an appropriately diluted solution of biological stain is the simplest procedure of all and is especially useful for small fish because a minimum of handling is required. Although large numbers can be stained in a short time, no dye has been found which will produce a permanent mark. Stained fish can be recognized for no longer than two weeks. Individual handling is avoided also by marking fish with radiophosphorus. Larval sturgeon have been

marked by feeding them oligochaetes which had become radioactive after ingesting "hot" Na_2HPO_4. Radioactive marking has been successfully tested in the field.

A wide variety of materials have been tattooed on the skin or injected intraperitoneally, intramuscularly and subcutaneously. Colored metallic oxides and colored latex injected subcutaneously as "spots" have promise for long-term field studies. These substances are recognizable in certain species for lengths of time varying from one to four years. A wide variety of classes of marks can be obtained by injecting "spots" of different colors on various parts of the body. Behavior and mortality are not affected if the injection sites are chosen carefully. There is no hope of producing a significantly large number of injection or tattoo marks for individual recognition. Up to 1000 individual marks have been produced by branding fish with a hot wire, but the brands can be recognized for only a few months, with the present methods.

Many of the non-mutilation marks reported here are suitable for short-term observations on migration and for estimating population size and survival rates where marking and recapture are done simultaneously.

References

AL-HAMID, MAHMOUD IBRAHIM. 1954. The use of dyes for marking fish. *Progr. Fish Cult.*, **16** (1): 25—29.

BOND, CARL E., and ROY CULVER. 1952. Marking cutthroat trout with trypan blue. *Progr. Fish Cult.*, **14** (1): 9.

BOUCHARD, LOYAL G., and CHESTER R. MATTSON. 1961. Immersion staining as a method of marking small salmon. *Progr. Fish Cult.*, **23** (1): 34—40.

BUSS, KEEN. 1953. A method of marking trout hy branding. *Penn. Fish Comm., Progr. Rept.*, Sept. 1953.

CHAPMAN, DONALD W. 1957a. An improved portable tattooing device. *Progr. Fish Cult.*, **19** (4): 182—184.

CHAPMAN, DONALD W. 1957b. Use of latex injections to mark juvenile steelhead. *Progr. Fish Cult.*, **19** (2): 95—96.

DAVIS, CLAUDE S. 1955. The injection of latex solution as a fish marking technique. *Invest. Ind. Lakes*, **4**: 111—116.

DEACON, JAMES E. 1961. A staining method for marking large numbers of small fish. *Progr. Fish Cult.*, **23** (1): 41—42.

DUNN, ARNOLD, and COIT M. COKER. 1951. Notes on marking fish with biological stains. *Copeia*, **1951** (1): 28—31.

DUNSTAN, WILLIAM A., and WALLACE E. BOSTICK. 1956. New tattooing devices for marking juvenile salmon. *Fish. Res. Pap., Wash. Dept. Fish.* **1** (4): 1—10.

GANDOLFI-HORNYOLD, A. 1929. Une nouvelle methode pour marquer des Anguilles: le tatouage. *Bull. Soc. cent. Aquic. Pêche*, **36**: 53—54.

GERKING, SHELBY D. 1953. Evidence for the concepts of home range and territory in stream fishes. *Ecology*, **34** (2): 347—365.

GERKING, SHELBY D. 1958. The survival of fin-clipped and latex-injected redear sunfish. *Trans. Amer. Fish. Soc.*, **87**: 220—228.

GERKING, SHELBY D. 1962. Production and food utilisation in a population of bluegill sunfish. *Ecol. Monogr.*, **32**: 31—78.

HASLER, ARTHUR D., and WILLIAM M. FABER. 1941. A tagging method for small fish. *Copeia*, 1941 (3): 162—165.

HICKLING, C. F. 1945. Marking fish with the electric tattooing needle. *J. mar. biol. Ass.*, U. K. **26**: 166—169.

JOHNSON, DONALD E., and PAUL E. FIELDS. 1959. The effectiveness of an electric-hot-wire branding technique for marking steelhead fingerling trout. *Tech. Rpt. Dep. Oceanog. Wash.* No. 47: 1—4.

JOHNSON, LEON, and LOUIS POSEKANY. 1954. Fluorescent fish. *Progr. Fish Cult.*, **16** (3): 138.

KASK, J. L. 1936. The experimental marking of halibut. *Science*, N.S., **83**: 435—436.

PETERKA, JOHN. 1960. Consideration of some problems in estimating trout populations in small lakes. M.S. Thesis, Univ. of Wisconsin, 34 pp.

SCOTT, D. P. 1961. Radioactive iron as a fish mark. *J. Fish. Res. Bd Canada*, **18** (3): 383—391.

SHEKHANOVA, I. A. 1958. Method of mass marking of young acipenserid fishes using radioactive phosphorus. Ikhtiologicheskaia Komissia Akademii Nauk, SSSR, Trudy Soveshchanii, **8**: 327—331. (*Fish. Res. Bd Canada, Trans. Ser.* No. 315.)

SLACK, KEITH V. 1955. An injection method for marking crayfish. *Progr. Fish Cult.*, **17** (1): 36—38.

WIGLEY, ROLAND L. 1952. A method of marking larval lampreys. *Copeia*, **1952** (3): 203—204.

40.

Measurement of the Efficiency of Recovery and Reporting of Tags from Recaptured Fish

By

A. R. MARGETTS*

Introduction

An essential part of a fish tagging experiment is the provision for the reporting and return of recaptured tagged fish. In the United Kingdom, as in many other countries, notices are posted on fish markets, in fish houses and in factories, and handbills are distributed throughout the catching, marketing and processing sections of the fishing industry, telling of tagging experiments, what the tags look like, where they are attached to the fish, to where the tag should be returned, and that a reward will be paid for returns. In England and Wales the reward is in most cases five shillings (approximately 72 cents U.S.) and the value of the fish itself can also be paid; at each of the major fishing ports there is a fisheries office and at smaller places an appointed representative of the Ministry of Agriculture, Fisheries and Food to receive tagged fish. From time to time additional publicity is given to fish tagging and its results by articles in the trade press.

Nevertheless there has been good reason to suppose that, from at least some of the English experiments, more tagged fish were being recaptured than were being reported; if this were so, then clearly the value of the data for fishing rate calculations was limited. To test whether there was an appreciable loss of tagged fish or tags between their being recaptured and the information being reported to the Ministry, dead fish have been tagged and secretly "planted" in catches, and the fate of such tags followed (1959—1961).

Methods

In the major part of the British fishing industry there are broadly five stages at which tagged fish may be recovered. They are:—

1. On the ship at sea by the fishermen sorting, gutting, washing and icing the fish.
2. On the quayside by a docker discharging the ship, sorting, weighing and boxing the fish.
3. On the premises or stand of the wholesaler buying, repacking and often filleting the fish, or at a curing house, or at a processing factory such as a cannery, or animal food manufacturer.
4. At a retail shop.
5. In the home of a consumer.

Generally, external fish tags will not be recovered at a fish meal factory dealing with fish in bulk.

By "planting" tags in catches it has been possible to test the reporting efficiency at stages 2 and 3 and thereafter. The tags used have been identical to those which might reasonably be expected to be caught by the particular ship at a particular fishing ground; in fact some already returned tags have been re-used for the purpose. The number of persons knowing of the existence of the "planted" tagged fish in the catches has been kept to a minimum. The number of tags put into the catch of any one ship has never exceeded three. A number of trawler skippers have very kindly co-operated by tagging fish as they were being packed in ice in the fish room at sea; this allows testing reporting efficiency at stage 2 (unloading and sorting) and thereafter. On the fish market, after sorting and boxing of the catch, a few tagged fish have been slipped into the boxes; this tests reporting efficiency at stage 3 (wholesaling, filleting and processing) and thereafter. So far the experiment has been confined to two major fishing ports and to distant water (Barents Sea) cod tagged both at sea and on the market with the yellow plastic flag tag on nylon loop, to a few distant water and North Sea haddock similarly tagged on the market, and to North Sea plaice tagged on the market with Petersen discs.

Results

Tables 1 and 2 summarise results. The numbers are rather small but nevertheless indicate grave deficiencies in the reporting of tags.

Table 1

Returns of tagged fish "planted" in catch at sea

Distant water cod — plastic flag tag

Port	Ship	No. tagged	No. returned		
			As from correct ship	As from wrong ship	No information
Z	A	3	0	1	0
Z	B	3	0	1	0
Z	C	3	1	0	0
Z	D	2	1	0	0
Z	E	3	2	0	0
Z	F	2	1	0	0
Total		16	5	2	0
Y	A	3	0	0	0
Y	B	3	1	1	0
Total		6	1	1	0

---

* Fisheries Laboratory, Lowestoft, England.

Table 2

Returns of tagged fish "planted" in catch on fish market

Fish and Tag	Port	No. tagged	No. returned		
			As from correct ship	As from wrong ship	No information
Distant water cod —					
flag tag	Z	14	1	0	1
ditto	Y	22	8	2	1*
N. Sea plaice —					
Petersen disc	Y	5	4	0	0
N. Sea haddock —					
flag tag	Y	1	1	0	0
Distant water					
haddock—flag tag	Z	3	0	0	0
ditto	Y	1	0	0	0

* from merchant inland

The reporting efficiency of tagged cod from stage 2 (the quayside discharging, sorting and packing) and onwards was only about 44% and 33% at the two ports. From stage 3 (wholesale merchants, filleters and processors) and onwards it was 14% and 50%. The reporting efficiency of tagged plaice from stage 3 onwards has been about 80%, but that of haddock nil. These results do, of course, apply only to the ports and species involved in the tests and cannot reasonably be expected to apply to other species at other ports.

Since the recovery at stage 3 et seq. is a percentage of the number not recovered at stage 2 it is not correct to sum the percentages at each stage to obtain the total percentage recovery. Similarly, if all the fish pass through the same sequence of sorting stages and all tags found are reported, although the actual efficiency at stage 2 may range from much greater than through to much less than that at stage 3, the recovery rate at, say, stage 3 et seq. cannot be greater than that for stage 2 et seq. Such anomalous results as the 33% and 50% reports from stage 2 et seq. and stage 3 et seq. respectively at port Y will have been caused by small numbers and perhaps by a substantial recovery and removal, but not reporting, of tags at stage 2. Such a "planting" experiment cannot show what proportion of recovered tags are in fact reported; there is known to be a loss of tags from experiments by their being found (i.e. "recovered", in the Symposium definition) but never reported.

It is relevant here to consider briefly from what sections of the industry tags are normally reported and returned; for that purpose the reports and returns so far from a tagging of distant water cod in 1959 (live fish liberated in the sea) are listed in Table 3. The fact that a tag is returned by someone other than a fisherman does not always mean that the fisherman overlooked it; frequently fishermen recover tagged fish and put them aside for market workers to deal with or hand them to shore workers. The practices as regards the handling of recovered tagged fish are many and varied, differing between ports (affected by factors such as ease of accessibility to the fisheries office, etc) and between different firms within a port, so that the figures in the table should not be taken entirely at their face value. However, they do serve to show how very important is the land-based part of the industry in returning fish tags; at one port only about half and at another much less than half of all the tagged fish reported were reported by fishermen. Thus a loss of 50% of the tags at the stages where the fish are handled on land will mean an overall loss of at least 25% of recoveries from a tagging experiment.

Table 3

Numbers of tagged cod (released live at sea) returned by different groups of workers in the fishing industry

From	Port Z	Port Y	Inland
Fishermen	37	8***	
Unloader*	4	10	
Fishworker or merchant ..	31**	14	1
No information	5	4	
Reported, not returned ...	1	0	
Total	78	36	1

* Some returns by unloaders may be included under fishworkers.

** May include a very few returns by fishermen.

*** Includes two returned by a trawler passenger.

Discussion

With tag losses at the rate indicated by these tests, the reliability of data for fishing rate calculations is very poor, yet it could be improved and made usable if reliable adjustment factors could be applied to allow for tag losses subsequent to the tagged fish being recaptured.

The method employed in these tests of recovery efficiency can easily be used on a larger scale to follow the fate of tagged fish subsequent to their being landed and thus to obtain a reliable figure for percentage loss of tags still in the catch exposed for sale. But, depending as it does upon the co-operation of already fully occupied responsible skippers, the scale of taggings at sea cannot conveniently be much increased to measure more exactly the efficiency of recovery by unloaders and sorters; this is unfortunate in so far as the earlier in the chain of handling stages at which tags can be planted the more valuable will be the results.

The method of these tests cannot measure what proportion of tags are not found or are found and then lost by fishermen as distinct from fishery workers ashore. Recovery and reporting efficiency at this stage (stage 1) might be estimated when it is known how many tags come ashore not carried by fishermen (that is, the number returned by shore agencies plus the number not returned, as estimated by tests) and how many of the tags available for unloaders, sorters and market workers to find had, in fact, first been found by fishermen and put aside in the fish room; obtaining this latter information requires that each ship shall be met as it docks by a person designated to enquire about any tagged fish known to be aboard. This will not be easy or cheap to do, but for a species such as the English distant water cod, most of which is landed at two ports, enough information to estimate the recovery efficiency at sea might be obtained if such a watch were kept even if for only a few weeks. Finding out how many tags are found and then lost by fishermen is practically impossible, but the meeting of ships by a tag collector might help to stem such a leakage of tags from an experiment. For the purpose of calculating catching rate a knowledge of the total loss of tags is important; if it is known at which stages in the handling of the fish the losses occur, then it might be possible to improve the system of recovery of tagged fish.

The substantial reliance on returns of tags by shore workers introduces errors such as the reporting of tags from the wrong catching ship (see Tables 1 and 2). The ground where each ship did most of its fishing is known; if this is assumed to be where the tagged fish was caught then an error in the name of the ship that a tag is from can give a very misleading result as regards distribution of tagged fish. Furthermore a ship often fishes on more than one ground, and the tagged fish may not have been recaptured on the main fishing ground which is the only one recorded. Thus the data about the locality of recapture of tagged fish reported by persons other than fishermen should be treated with caution.

The four most obvious causes which may contribute towards loss of recaptured tags from an experiment are:—

1. Tags not conspicuous enough.
2. Inadequate publicity and instructions to finders as to what to do with tags.
3. Inadequate reward incentive.
4. Carelessness by tag finders.

The conspicuousness of the tag on the fish is very important. This will depend upon the tag itself and its position on the fish; it is always a problem to link tag conspicuousness with harmlessness of the tag to the fish. It is recognised that the yellow plastic flag tag with flexible braided nylon loop used in the English cod taggings (and in these recovery tests) can often fall into a position where it is not easily seen. Mr. J. de Veen (this Symposium No. 43) found that in a sole tagging experiment using two types of tag, whereas the total percentage returns of Petersen disc and a plastic arrow tag were similar, of the 35 Petersen disc returns all were spotted on board ship and none on the market, yet of the arrow tags, although 133 were spotted on board ship a further 29 were first spotted on the fish market: this indicates that the arrow tag, as attached, was more easily missed than the Petersen disc, assuming that the Petersen disc is not more likely to be missed on the market than the arrow tag.

In planning a tagging experiment, and particularly if it is to yield data for catching rate calculations, all possible attention should be given to making the tags conspicuous yet harmless, to publicity and education, which should be frequent and varied, and to providing rewards for returns of tags with recapture information that are attractive enough to be effective. The factor of human carelessness causing loss of recaptured tags will always remain but may be offset to some extent by publicity and reward. Then, having taken these steps to try to make sure that recaptured tags are recovered and reported, it is advisable to check on tag losses by such methods as the "planting" of tags described here.

Summary

A check on losses of tags from an experiment caused by failure in picking them out from catches and reporting or returning them was made by "planting" tagged fish in catches both aboard trawlers when the fish were being stowed and on markets when the fish were exposed for sale. Results indicated that for the species and ports concerned, where normally something like half of the tag returns were by shore workers, tag recovery ashore was only about 50% efficient, which would mean a 25% complete loss of tags from a tagging experiment. Precautions to achieve good returns and checking of recovery efficiency are recommended.

Reference

de VEEN J. F. 1963. On the tag reporting efficiency of Dutch fishing vessels. *This Symposium, contribution* No. 43.

41.

The Application of a Method for the Estimation of Growth Parameters from Tagging Data at Unequal Time Intervals

By

D. J. GARROD*

Introduction

The estimation of the rate of growth of tropical species of fish frequently presents a great obstacle to research, because the uniformity of the tropical environment does not lead to the deposition of the indicators of age that are commonly used in the estimation of growth of temperate-water species. Breeding activity may result in ring formation on skeletal structures, but frequently the spawning period is so poorly defined that the time interval between successive rings is obscured. The use of tagging techniques provides valuable information on this time interval, but in itself the method is very limited in its application to growth studies. Tag returns from experiments carried out in Lake Victoria have been very disappointing, both in their scarcity and in the apparent physiological effect of the tagging wound, which may result in a complete cessation of growth for a considerable period of time.

During the past four years some 11,000 fish of four *Tilapia* species have been tagged and released, but of those returned only 290 have shown appreciable growth. The uncertainty of the true numbers recaptured prevents the data from being used in the estimation of exploitation rates, and until recently the information could not be interpreted in growth studies because so very few fish were free for long periods. Of the 290 fish referred to above, only 90 were free for more than one year, so that the data have not been sufficient to permit the use of a conventional Ford-Walford plot of l_t against l_{t+1} for data at equal time intervals.

More recently von Bertalanffy's equation of growth in length has been extended to enable its application to data at unequal time intervals (Gulland and Holt, 1959).

From von Bertalanffy's equation:—

$$l_t = L_\infty\left(1 - e^{-K(t - t_0)}\right) \qquad (1)$$

where l_t = length at time t
L_∞ = asymptotic length
K = a constant rate.

Thus the growth, y, per unit time a is given by

$$y = L_\infty e^{-K(t - t_0)}\,\frac{1 - e^{-Ka}}{a} \qquad (2)$$

and the mid point of the growth increment,

$$\frac{1}{2}\,(l_t + l_{t+a}),$$

is given by

$$\frac{1}{2}(l_t + l_{t+a}) = L_\infty\left[1 - \frac{1}{2}e^{-K(t-t_0)}\left(1 + e^{-Ka}\right)\right]$$

so that:—

$$L_\infty e^{-K(t - t_0)} = \frac{2\left[L_\infty - \frac{1}{2}\left(l_t + l_{t+a}\right)\right]}{1 + e^{-Ka}} \qquad (3)$$

Substituting this in Equation (2);

$$y = \frac{L_\infty - \frac{1}{2}\left(l_t + l_{t+a}\right)}{1 - e^{-Ka}} \cdot \frac{2\ (1 - e^{-Ka})}{a}$$

and putting $b = \frac{1}{2}\,Ka$

$$y = \left[L_\infty - \frac{1}{2}\left(l_t + l_{t+a}\right)\right]\frac{K\left(1 - e^{2b}\right)}{b\left(1 + e^{-2b}\right)}$$

$$= K\left[L_\infty - \frac{1}{2}\left(l_t + l_{t+a}\right)\right]\frac{\tanh\ b}{b}$$

Thus a plot of y, the increment per unit time, against the mid-point of the total increment will have an intersect on the x axis at L_∞ and a slope of $-K\frac{1}{b}$ tanh b. K is a constant, so that the slope of the line will vary with $\frac{1}{b}$tanh b, but for small time intervals b approximates to 1, so that the slope can be used as an estimate of K.

The application of this method to data for *T. leucosticta*

The tagging data from *T. leucosticta* are adequate for the application of this technique. The distribution of the time intervals of the available returns is given below.

---

* East African Freshwater Fisheries Research Organization Jinja. Present address: Fisheries Laboratory, Lowestoft, England.

	Time interval (years)							
	< 0.29	0.30—0.49	0.50—0.69	0.70—0.89	0.90—1.09	1.00—1.29	1.30—149	> 1.50
Number of fish	31	19	39	24	12	7	7	12

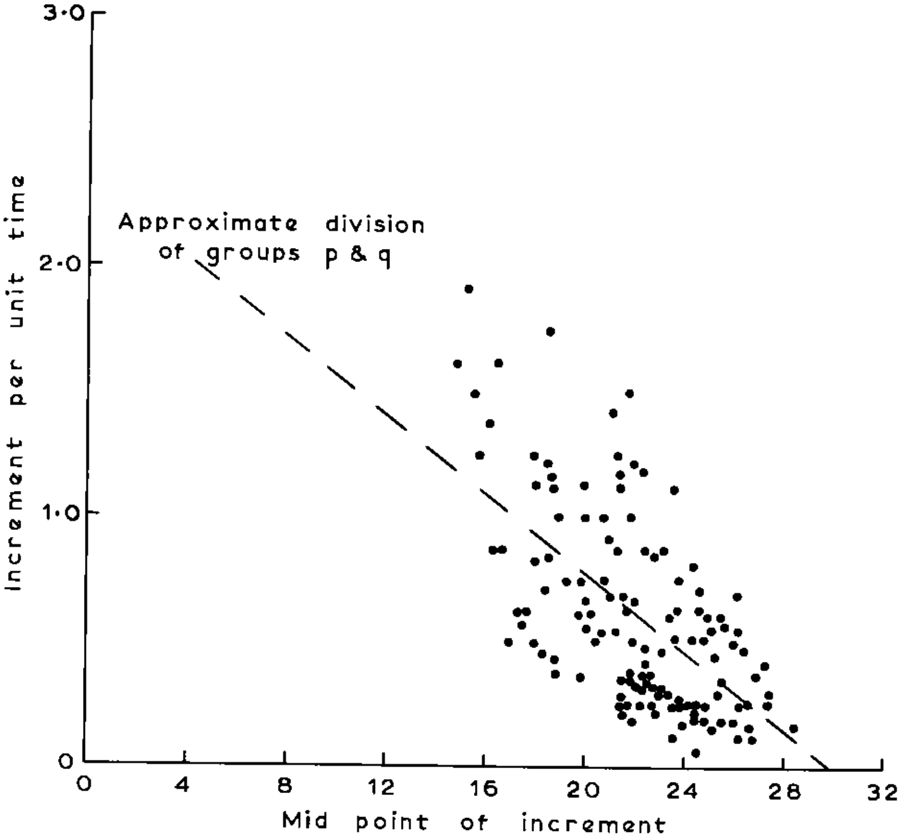


Figure 1. Increment in length per unit time at liberty of tagged *Tilapia*, plotted against mean length.

For each return the increment is divided by the relevant time interval to give increment per unit time of 0.1 year, which is plotted against the mid point of the increment in Fig. 1. The data are extremely variable, as is to be expected with such a short time interval, but there are indications of two main groups, which are designated p and q for convenience and replotted in Fig. 2. The regressions fitted to these data in Fig. 2 enable the calculation of the parameters of growth which are given below:

Group	K	L∞
p	1.160	30.5 cm
q	0.625	28.0 cm

The validity of these parameters is ascertained by calculating the average lengths l_t and l_{t+a} for each time interval for the two groups p and q, and comparing the length of the time period required for the same increment if growth conforms to a curve defined by the calculated parameters (Table 1). The comparison between the observed time intervals and the predicted intervals shows a close correspondence except where the samples were very small. This indicates that the calculated growth curves give an adequate representation of the tagging data; the asymptotic lengths also correspond with maximum sizes of male and female *T. leucosticta* found in Lake Victoria.

It is suggested that the two groups p and q represent the sexual dimorphism of growth rate which is known to occur in *T. leucosticta*, although there are no records of the sex of the fish used in the analysis. This is one of the chief merits of this technique, because it is frequently impossible to sex fish from their external appearance at tagging, and the sexual dimorphism of the growth rates may obscure the true growth rate when it is estimated by other techniques.

However, this determination can be taken as only a first approximation of the growth curve, because it assumes that the growth can be represented by von

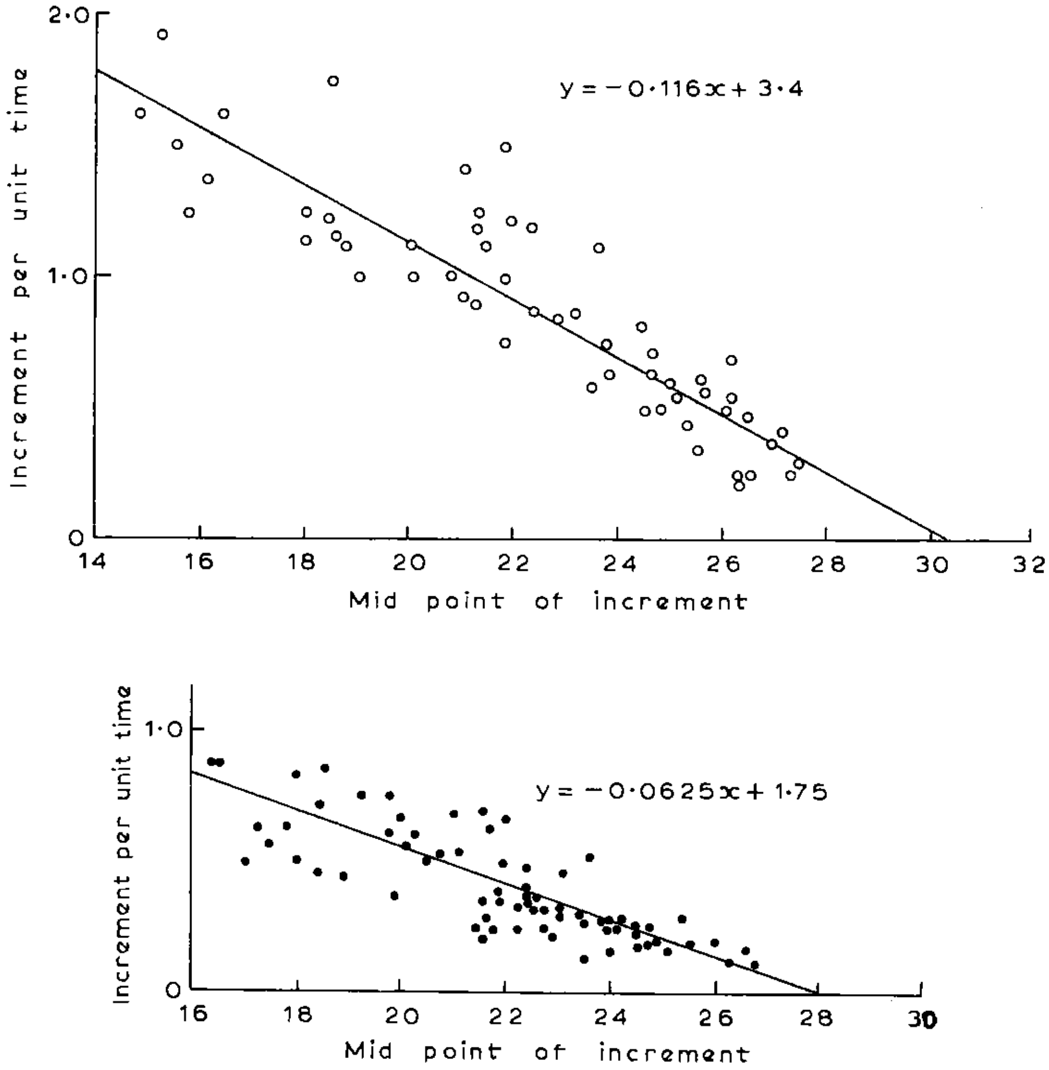


Figure 2. Growth data of Figure 1 replotted to distinguish the two groups of fish.

Table 1

A comparison between the observed increment during the period at liberty and the time required for the same increment when predicted from the estimated growth curve

Time Period (years)	Group p				Group q			
	No. in Sample	l_t	l_{t+a}	Calculated Interval (years)	No. in Sample	l_t	l_{t+a}	Calculated Interval (years)
< 0.29	13	19.4	21.6	0.19	9	19.3	20.3	0.20
0.30—0.49	5	17.6	22.6	0.43	11	21.2	22.9	0.46
0.50—0.69	15	21.6	26.1	0.62	20	20.2	23.0	0.70
0.70—0.89	6	20.3	26.9	0.91	14	22.1	24.4	0.79
0.90—1.09	8	19.1	27.0	1.03	4	20.6	24.6	1.25
1.10—1.29	3	19.8	28.7	1.61	4	20.9	25.4	1.61
1.30—1.49	2	16.1	28.5	1.73	5	17.3	24.1	1.61
1.50—1.69	5	14.8	27.8	1.53	5	17.7	25.5	2.27

Bertalanffy's equation. This particular species, *T. leucosticta*, lives in a very stable environment with no radical change of habitat during its life history, so that the assumption is reasonable, but it has been pointed out by several workers that von Bertalanffy's formulas will rarely represent the growth of a fish throughout its entire life history. In the present study the numbers of returns of very small fish are not adequate to permit the extrapolation of the growth curve to t_0, because of the difficulty of tagging such very small fish.

Summary

Gulland and Holt's method of estimating the growth rate from tagging data at unequal time intervals has been applied to results for *T. leucosticta* (Pisces-Cichlidae) in Lake Victoria, East Africa. It is shown that the method will give an adequate representation of the tagging data in the form of a growth curve, but that more information is necessary on the growth of very small, untaggable fish before the curve can be extrapolated to t_0. The method obviously leans very heavily on the assumption that the growth of the species can be represented by von Bertalanffy's equation, but it is of especial value in distinguishing sexual dimorphism of the growth rate even if the tagged fish are not sexed.

Reference

GULLAND, J. A. and HOLT, S. J. 1959. Estimation of growth parameters for data at unequal time intervals. *J. Cons. int. Explor. Mer*, **25**: 47—49.

42.

King Crab Tagging Methods in Alaska

By

MURRAY L. HAYES*

King crabs, *Paralithodes camtschatica* (Tilesius), have been harvested commercially by Alaska fishermen since at least 1909, but the catch remained small until after World War II when processing and marketing problems were solved. From 1945 to 1950 the annual catch in Alaska increased from 0.2 million to 1.5 million pounds. Since 1950 the rate of annual increase has been rapid, and 27 million pounds were taken in 1960. This growth continues, with catches in 1961 running ahead of those in 1960.

King crabs are known to occur in the coastal waters of Alaska from St. Lawrence Island in the Bering Sea to the southern part of the Alexander Archipelago. The Alaska fishery has developed in four local areas however: the southeastern Bering Sea, the waters south of the Alaska Peninsula from Shumagin Islands to False Pass, the waters surrounding Kodiak Island, and Kachemak Bay in Cook Inlet (Fig. 1). Japanese and Russian fishermen take large numbers of king crabs in the Bering Sea. In Alaska, crabs are taken with pots (traps), otter trawls, and ring nets, pots taking the majority of the catch. Tangle net gear is illegal. Females are protected, and the minimum size for males is $6^1/_2$ inches, or 165 mm in carapace width.

Biology of the king crab is fairly well known (Marukawa, 1933: Weber and Miyahara, in press; Bright et al., 1960; and Powell, 1960). Crabs mate in relatively shallow water in early spring. Eggs are spawned and attached to the swimmerets beneath the

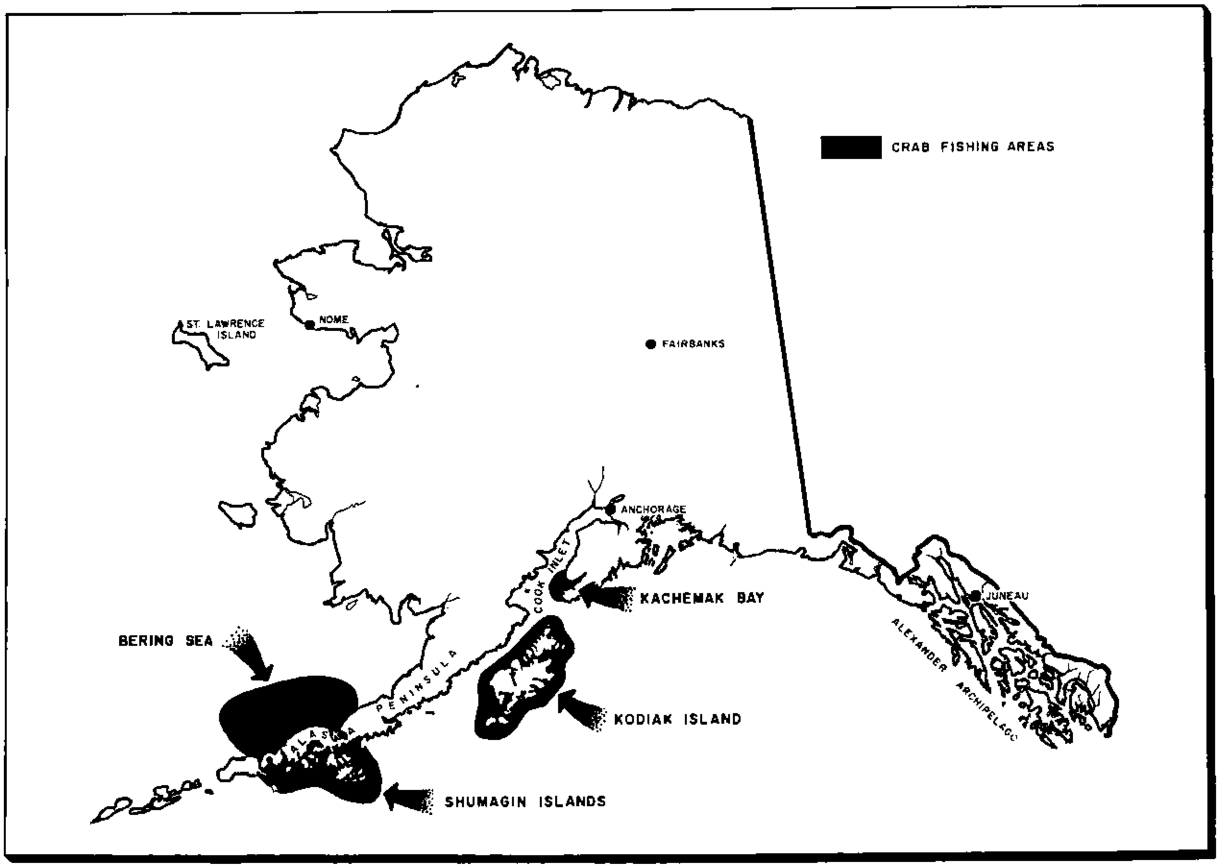


Figure 1. Alaska, showing the four principal king crab fishing areas.

---

* Fish. Res. Biologist, Bur. Com. Fish., Biol. Lab., Auke Bay, Alaska, U.S.A.

abdomen of the newly molted female, where they develop for about 11 months before hatching into free-swimming larvae. There are five planktonic larval stages which take about 6 weeks to complete. The small crabs then settle to the bottom and begin the benthic phase of their life history. Growth depends on molt frequency and size increase per molt. In both sexes molting occurs several times per year in the juvenile stages, becoming less frequent as size increases. After sexual maturity molting is annual in females. In males it is progressively annual, biennial, or even triennial as age increases. Growth studies indicate that king crabs reach sexual maturity in about 4 to 5 years. Males reach the legal minimum size in 6 or 7 years, at which time they weigh about 2.4 kg. The largest male measured in recent years was caught in Kodiak and weighed 10.1 kg, was 224 mm in carapace length and 272 mm in carapace width.

In Alaska, research on king crabs has developed in parallel with the growth of the fishery. The U.S. Fish and Wildlife Service started exploratory fishing, technological studies, and biological investigations in 1940. This work was interrupted by the war. It was not until 1953 that the Alaska Department of Fish and Game started a modest research program on king crabs at Kodiak. In 1954 the research program of the International North Pacific Fisheries Commission began in the Bering Sea. In 1957 the Bureau of Commercial Fisheries initiated studies on the south side of the Alaska Peninsula and in Cook Inlet at Kachemak Bay. All of these programs relied on tagging studies for information on movements and migrations, growth, and mortality.

King crabs share with other crustaceans the characteristic that growth in size can occur only immediately after molting and before hardening of the new exoskeleton. All hard parts are lost during ecdysis and therefore cannot be used for age determination. Also, since tags placed through any of the hard parts would be lost in molting, some other method of attachment is required for long-term tag retention. For these reasons a tagging method that permits tag retention through successive molts is essential to a study of growth or long-term movements.

After reviewing early tagging methods and carefully observing the molting process, Ed J. Huizer (*In* Alaska Department of Fisheries, 1954) perfected the method of tagging that has proved successful to date. The tag is inserted through the muscular isthmus between the posteriodorsal portion of the cephalothorax and the abdomen. Here the isthmus is covered with a parchmentlike chitinous membrane that is one of the first parts of the exoskeleton to slough away during ecdysis. The molting crab exsheaths through a posterior split between the abdomen and the carapace by means of a series of alternate body shifts. Since the tag is attached to the arthral muscle in the isthmus, it is freed at the time of this split and does not appear to hinder molting.

Figure 2. "Spaghetti" type loop tag being inserted through the isthmus of large female king crab. (Photo by courtesy of Alaska Department of Fish and Game).

A "spaghetti" type loop tag is used on adult crabs (Fig. 2). It is made from a 12-inch length of polyvinylchloride plastic tubing, with an oval plastic button bearing identification and a serial number. In placing the tag, the carapace and abdomen are spread to expose the isthmus. The tag is then threaded through the muscular part of the isthmus with a curved stainless steel needle. Care must be taken to avoid the large blood sinuses anterior to the muscular part. The two ends of the tubing are brought together and tied in an overhand knot. The trailing ends of the "spaghetti" provide conspicuous identification of tagged crabs even at some distance. After tagging measurements are taken and data recorded. The crab is immediately returned to salt water where recovery from tagging shock appears to be rapid. Salt water seems to promote blood clotting and consequently to prevent excessive bleeding. Similar tagging techniques with smaller materials have been successful with crabs as small as 25 mm in carapace length.

Immediate tagging mortality is small. In several tagging experiments crabs were kept in holding boxes from 1 to 3 days after tagging. Mortality in these periods was less than 1 percent. Of 2886 crabs tagged in Kachemak Bay in June 1960, 15 appeared weak or were dead after the post-tagging holding period. Although some of the weak crabs might have survived, all were discarded. After this same period careful inspection of the tagged crabs showed no initial tag loss.

Tag loss over longer periods of time has been studied by use of floating and submerged holding boxes and cages. Powell (personal communication) of the Alaska Department of Fish and Game placed several large underwater pens on the bottom of Kodiak harbor, which he tended periodically by means of free-diving equipment. Tag retention over a period of nearly 10 months was studied. Although some crabs escaped from the confines of the cages, those remaining showed tag losses of 38 percent (19 of 50) after 170 days and 68 percent (34 of 50) after 291 days. Tag losses were of two kinds. Sometimes the plastic tubing was severed, leaving a hole scar in the isthmus. Other times the entire loop was ripped out of the isthmus, leaving a cut scar. Tag loss from these experiments was very high, but the results are not considered conclusive. The artificial conditions under which the crabs were held may have caused excessive tag loss.

In another experiment, conducted at Kachemak Bay, 86 king crabs were tagged and kept in surface holding pens. On 51 of these crabs tags were tied with overhand knots and on the remaining 35 crabs with square knots. After 22 weeks no tags were lost among the overhand-knot group, but five tags, 14 percent, were lost among the square-knot group. Tag loss is being further studied by additional holding and double-marking experiments.

Tag return is the most important aspect of any marking program. Perfect tagging methods are to no avail unless observations or returns are made. In Alaska, tagging programs for salmon and halibut have been used for more than 30 years, and more or less standard procedures have been adopted. Fishermen are well acquainted with such programs. In Kachemak Bay a reward of one dollar has been paid for each tagged crab reported. Recently, the reward was increased to two dollars. The additional dollar is the approximate market value of a legal sized crab.

Fishermen are paid for tagged crabs when they make deliveries to the processing plant. At these plants the tagged crabs are placed in holding tanks, held for examination by biologists, and then released.

Each fisherman and processor is supplied with tag return forms. On one side of this form is a map on which the fisherman records the location of capture of each tagged crab caught. On the other side are instructions and blanks for the fisherman's name, the tag number, and the date. When these forms are returned to the biologist, he adds location of tag release, original and recovery measurements, growth data, previous returns, and any other pertinent notes on the returned crab. A copy is made and the original tag return form is sent back to the fisherman for his information and as his record for the specific tagged crab caught. Tag returns are summarized at intervals and the results posted on bulletin boards in each processing plant and the field laboratory. In this way fishermen are informed of the progress of the tagging program as a whole. Other information is supplied to the fishermen by means of brief non-technical information bulletins posted along with tag summary charts at processing plants, and by publicity in the local newspapers. Frequent personal contacts and prompt return of information allow the fishermen a measure of personal participation in the program and have greatly improved tag returns.

Failure to detect recaptured tagged king crabs is believed low because of the conspicuous nature of the tag used and the fact that crabs are handled individually at least three times before processing: (1) when removed from the crab pot; (2) when unloaded from the boat hold, and (3) when butchered at the processing plant. Of more than 2400 tags returned from Kachemak Bay experiments, fewer than 10 were from the butchering stage, the final examination where tags might be detected.

Analysis of data is simplified by use of punch card methods. Original tagging data punched into IBM cards include: tag number, carapace length and width, weight, release location, release depth, and remarks. These cards have fields reserved for recovery information. When recoveries are made, the data are punched into separate cards of the same format as the original tagging card. These are sorted into the original tag decks and the data transferred to the master card. Second and third returns are placed on separate cards and marked by means of a special code.

Locations are recorded by a grid system that measures distance north and east from a reference location. Straight-line movements are easily calculated from the co-ordinates of release and return, by use of the elementary distance and direction formulas of analytical geometry.

Machine tabulations of these cards are made periodically and are sent to field personnel. Together with the original tagging plan these supply a complete history of the tagging program up till the date of the last return cards. In this way information and preliminary analyses are available to field biologists with very little delay.

Summary

The commercial fishery for king crabs, *Paralithodes camtschatica*, has developed since World War II. Research on the species includes tagging to study movements, migration and mixing, growth, and mortality. In tagging, a spaghetti-type loop tag is threaded through the muscular isthmus between the posteriodorsal portion of the cephalothorax and the abdomen. Here the isthmus is covered with a

parchmentlike chitinous membrane that is one of the first parts to slough away during ecdysis, thus freeing the tag and allowing its retention after the crab molts. Tagging mortality and initial tag loss are small. Tags are recovered by the commercial fishery, and "on-the-spot" rewards are paid. Analysis of data is facilitated by use of IBM punch-card methods.

References

ALASKA DEPARTMENT OF FISHERIES 1954. 1954 annual Report (Report No. 6). Alaska Dept. of Fish., Juneau. 92 p.

BRIGHT, DONALD B., DURHAM, FLOYD E., and KNUDSEN, JENS W. 1960. King crab investigations of Cook Inlet, *Alaska. Dept. of Biology,* Allan Hancock Fdn 180 p. (Processed).

MARUKAWA, HISATOSHI 1933. Biological and fishery research on the Japanese king crab *Paralithodes camtschatica* (Tilesius). *J. Imp. Fish. Exp. Sta.*, Tokyo, No. 4, Paper No. 37, 152 p. (In Japanese with English abstract).

POWELL, GUY C. 1960. Investigation of the growth rates of king crab in the Kodiak area. *Alaska. Dept. of Fish and Game*, 43 p. (Processed).

WEBER, DOUGLAS D., and MIYAHARA, TAKASHI 1962. Growth of the adult male king crab *Paralithodes camtschatica* (Tilesius) population. *Fish. Bull. U. S.*, **62** (200): 53—75.

43.

On the Tag Reporting Efficiency of Dutch Fishing Vessels

By

J. F. de VEEN[*]

In looking through the card files of tag reports by Dutch ships attention was drawn to the fact that some ships had reported rather large numbers of tags, whereas the majority appeared to have reported only one or two tags annually. The question arose whether the special attention paid to tagged fish might perhaps have differed between ships, so that on some vessels more tags have been overlooked than on others. Analysis of these differences might make it possible to find correction factors for the percentage of overlooked tagged fish on board the fishing vessels.

We could study this problem from the frequency distribution of the number of reports per ship. What kind of frequency distributions can be expected in the event of no difference in attention existing between ships? If it is assumed that (*a*) the tagged fish are distributed roughly at random in the area where the ships operated, and (*b*) the number of tagged fish remains approximately constant throughout the year in the fished area, the expected frequency distribution of the recaptures will be a Poisson distribution. In order to approximate to assumption (*a*) we only considered tagged fish recaptured and reported three months or more after liberation. Assumption (*b*) is more or less valid, since tagging of plaice and sole took place in various periods of the year.

The reports were of tagging experiments of plaice and sole and were considered irrespective of the type of tag used and the nationality of the country which did the tagging. In 1959 and 1960 various countries have been tagging plaice and sole in the southern North Sea, the principal fishing area of the Dutch fishing fleet. The reports were made by ships from IJmuiden and Katwijk throughout 1960.

Strictly, the expected frequency-distribution of the recaptures will only be a Poisson distribution if there are not too great differences between the annual total catches of the ships. In the case of the Dutch fishing vessels it was found earlier that the fishing power of a ship is correlated with its engine-power. This will result in the more powerful ships having a greater annual catch than the less powerful, thus producing a fairly wide variation in the total catches. For this reason the ships were subdivided into four categories according to engine-power. Within each category the requirement of not too great differences in total catches is met sufficiently well to allow a comparison of frequency distributions of the reports with Poisson distributions.

If a difference in attention between ships does exist an excess in the zero and in the higher frequencies of the reports as compared with the Poisson distribution will be the result.

Table 1

Frequency distributions of the number of annual reports of plaice and sole per ship compared with expected Poisson distributions for various ships' categories

Ships' category	Number of annual reports per ship	Plaice		Sole	
		actual distr.	Poisson distr.	actual distr.	Poisson distr.
100—150 B.H.P.	0	19	19.7	19	19.2
	1	9	7.6	9	8.1
	2	1	1.5	0	1.6
	3	0	0.2	1	0.1
	4	0	0	0	0
151—200 B.H.P.	0	23	21.3	19	18.0
	1	12	13.7	14	15.0
	2	4	4.7	5	6.0
	3	1	1.1	3	1.6
	4	1	0	0	0.3
201—250 B.H.P.	0	24	25.0	23	19.6
	1	9	6.9	6	10.2
	2	0	0.9	1	2.6
	3	0	0.2	3	0.5
	4	0	0	0	0.1
> 250 B.H.P.	0	27	26.0	20	18.0
	1	11	12.4	10	15.3
	2	3	3.1	11	6.2
	3	1	0.4	0	1.9
	4	0	0.1	1	0.6

In Table 1 the frequency distributions found and those expected are given for the reports of plaice and sole by categories of ships. In none of the cases are the deviations significant at the 5% level. If the chi squares per fish species are pooled we get a total chi square of 0.7 for plaice and 4.9 for sole, both not significant. The deviations are very small in the case of the plaice, and we have therefore no reason to take a difference in attention between ships into account. Soles show a less good fit to the Poisson distributions; moreover the deviations are always in the direction that would be expected in the case of a difference in attention between ships. Is it possible that such a difference does exist but that the number of observations was too small to obtain a

---

[*] Netherlands Institute for Fishery Investigations, IJmuiden, Holland.

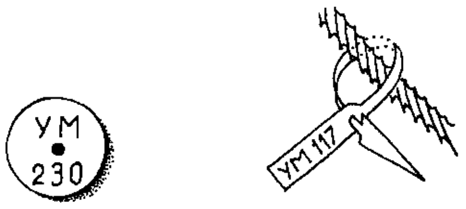


Figure 1. Petersen disc (left) and Albrechtsen tag (right).

significant difference? More information on this possibility is provided by one of our tagging experiments.

In this experiment both plaice and sole were tagged on the same fishing grounds in the winter of 1959/60, i. e. on the plaice spawning grounds in the southern North Sea. For both fish species two types of tag were used, the white Petersen disc and the yellow plastic Albrechtsen arrow tag (sec Fig. 1).

In Table 2 the number of reports after three quarters of a year are given:

Table 2

Fish species	Tag type	Number tagged	Number reported in $^3/_4$ year	Percentage reports
Plaice	Petersen disc	1336	218	16.3
	Albrechtsen tag	1836	55	3.0
Sole	Petersen disc	426	27	6.3
	Albrechtsen tag	500	33	6.6

In the case of the plaice the percentage of reports of the Albrechtsen tag is considerably lower than those of the Petersen disc. This suggests that the Albrechtsen tag is more easily overlooked because of its shape, its colour or its location on the body of the fish, or perhaps because of unfamiliarity of the fishermen with this new type of tag, although attention has repeatedly been drawn to it in fishermen's periodicals, by posters in the fish markets, in lectures, in exhibitions and by personal contacts too.

That Albrechtsen tags are indeed more easily overlooked can be confirmed by the data of Table 3, giving the reports of all Dutch tagging experiments in 1960, subdivided into those noticed on board and those found ashore (on the fish markets, in the fishing industry or even by housewives).

Table 3

Fish species	Tag type	Reports noticed on board	ashore
Plaice	Petersen disc	212	6
	Albrechtsen tag	43	12
Sole	Petersen disc	35	0
	Albrechtsen tag	133	29

This table shows that in the case of the plaice the Petersen discs, of which a relatively greater number has been reported, have nearly all been discovered on board and that practically none were left to be discovered ashore. In the case of the Albrechtsen tag however a much smaller percentage has been discovered, only partly on board the ships; fair numbers of these tags have evidently been overlooked on board and were noticed and reported after landing the catch.

The important point is that the difference between the percentages of total reports of Albrechtsen tags and Petersen discs, which is considerable in plaice, does not occur in sole (Table 2).

This was to be expected from the way in which these fish species are handled. On board of the Dutch fishing vessels each sole is treated with care, which is also the case on the fish market and in the fish trade. Plaice on the other hand are treated less carefully, more like bulk fish. Therefore both types of tag, but particularly the Albrechtsen tag, will be overlooked more easily in plaice than in sole. (The lower total percentage of reports of sole as compared with plaice is attributed to real differences in the rate of recapture.)

Thus if a difference in attention paid to tagged fish between ships exists, it would be logical to expect a greater deviation from the Poisson distribution in plaice, for which at least many Albrechtsen tags are overlooked, than in sole. In reality it was found that there is no reason to assume any substantial difference in the amount of overlooking between ships in the case of plaice. Therefore we can conclude that deviations from the Poisson distribution can neither in the sole nor in the plaice be explained in terms of differences in reporting efficiency between ships.

Summary

Possible differences in reporting efficiency between ships were studied by comparing the frequency distributions of the number of fish reported per ship with Poisson distributions, which under certain conditions can be expected when no dissimilarity occurs between ships.

Neither in the case of the plaice nor of the sole was a significant difference found, although the sole showed greater deviations from the Poisson distribution than the plaice.

It was shown that these deviations in sole, if real, could not in any case be attributed to differences in reporting efficiency.

44.

Tagging as a Technique in Population Studies of the Sea Scallop

By

J. A. POSGAY*

Introduction

The tagging experiments described here were originally designed to provide data on growth rates and identification of stocks. Later in the investigation it became important to know something of mortality rates, and the accumulated tag return data were analyzed for this purpose.

Methods

It is extremely simple to tag a sea scallop. There is a deep byssal notch in one ear of the lower valve which is not present in the upper valve. A touch causes the scallop to withdraw the mantle and a fine hole is drilled in the ear of the upper valve just over the byssal notch. A stainless steel pin bearing a numbered Petersen disc is pushed through the hole and bent over to hold it in place.

The disturbance of being fished up, handled, and tagged causes the scallop to lay down a check mark on the shell, permanently defining its size when tagged. In addition, so that there will be no uncertainty about locating the tagging check on recaptured animals, the margin of the shell is nicked with a triangular file. This eliminates the necessity of measuring and recording the size of the tagged scallops before they are released.

Recovery Methods

Since all sea scallops are shucked at sea — the shells and viscera are discarded at the time — and only the adductor muscles ("eyes" or "meats") landed, recovery depends upon alerting the fishermen to watch for the tagged animals. Since over 70 percent of United States sea scallop catches are landed at New Bedford, Massachusetts, and sold through a single auction room, our publicity effort is concentrated there. A Bureau of Commercial Fisheries agent interviews each skipper in the auction room for data on the location he fished and days spent on the grounds. The agents are encouraged to ask about tags and generally keep the fishermen aware of this as well as other tagging programs. In addition, they have a cash fund from which they pay the one dollar reward on the spot. Other agents in other ports have similar instructions and funds. Posters are put up in places where fishermen congregate and there are occasional articles in newspapers and magazines. Under a reciprocal arrangement, our tags are returned and paid for by agents of the Fisheries Research Board of Canada in their ports from their fishermen.

All reported tagged shells are forwarded to the laboratory in Woods Hole together with the location and date of recapture, name of the person to whom the reward was paid, and the boat. The vital statistics of the tagged shell are entered on a file card, and a form letter of appreciation is sent to whoever reported the tagged shell. This letter includes information on the date and location of release on the tags which were reported.

Early Releases

In December 1955 we tagged and released 825 sea scallops at three locations on Georges Bank. Another 2100 were released at 11 locations in July 1956 (Figure 1). Returns from these experiments were disappointingly low (Table 1). Some of the tagged scallops had been released in areas where there was little fishing during the first year after release, but other areas should have been heavily fished. We suspected that many of our tagged animals were being caught and shucked but that the tags were not noticed. Apparently, since the upper valve is held down in the palm of the left hand during the shucking operation, few fishermen saw the tag,

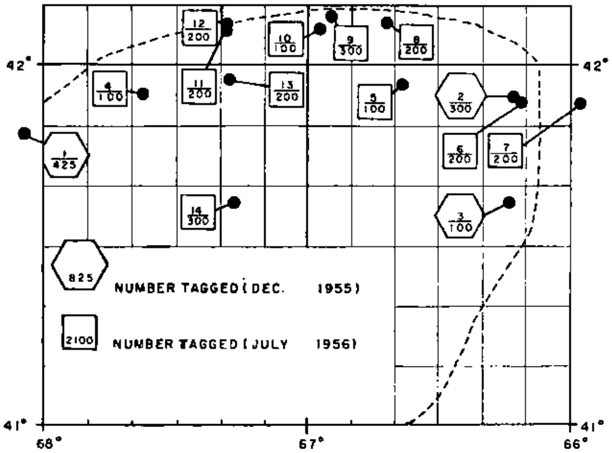


Figure 1. Locations of tagged sea scallops released in 1955 and 1956. The upper number is the number of the drop; the lower, the number released.

---

* U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

although some had reported seeing the tag on the shell while it was in the air after they had tossed it overboard. Shucking scallops is a monotonous task and an experienced scalloper does it automatically, without looking, so it seems likely that many more tagged animals were recaptured than were reported.

Table 1

Tag returns from the 1955 and 1956 experiments

Drop no.	Date	No. tagged	Number returned				
			Year 1	Year 2	Year 3	Year 4	Year 5
1	12 Dec 1955	425	0	0	0	0	0
2	13 Dec 1955	300	12	3	0	3	0
3	17 Dec 1955	100	0	0	0	0	0
4	6 July 1956	100	0	0	0	0	0
5	6 July 1956	100	0	0	0	0	0
6	7 July 1956	200	0	0	0	0	0
7	7 July 1956	200	0	0	0	0	0
8	7 July 1956	200	0	1	0	0	0
9	7 July 1956	300	3	4	0	0	2
10	8 July 1936	100	10	3	0	0	
11	8 July 1956	200	0	0	0	0	
12	8 July 1956	200	29	0	0	0	
13	8 July 1956	200	20	0	0	0	
14	8 July 1956	300	0	0	0	0	
	Total	2925	74	11	0	3	2

Later Releases

We decided to increase the visibility of the tag by adding a yellow plastic streamer to the disc, and also to increase the possiblity of recovering a good number of the tags by releasing them in a restricted area. We thus tagged and released 5375 animals in September 1957 (Figure 2). In the first six months at large, 758 (14 percent) were reported. Encouraged by these results we tagged and released another 7539 at 13 locations (Figure 2) in June 1958. The returns from these drops have been very good (Table 2).

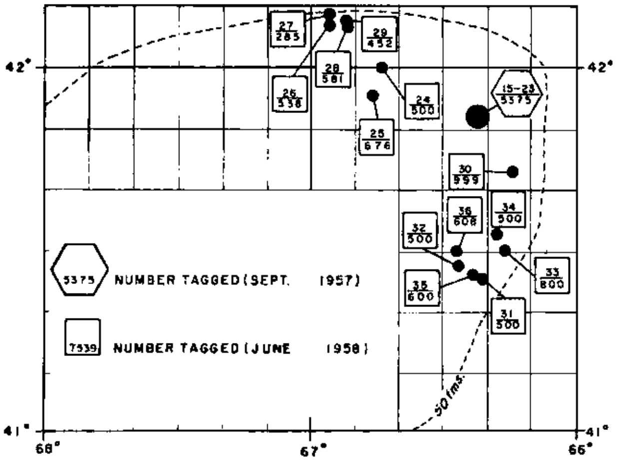


Figure 2. Location of tagged sea scallops released in 1957 and 1958. The upper number is the number of the drop; the lower, the number released.

Table 2

Tag returns from the 1957 and 1958 experiments

Drop no.	Date	No. tagged	Number returned		
			Year 1	Year 2	Year 3
15	22 Sept 1957	294	11	0	0
16	22 Sept 1957	498	59	119	30
17	22 Sept 1957	589	0	3	0
18	22 Sept 1957	297	31	4	0
19	23 Sept 1957	495	103	67	2
20	23 Sept 1957	575	200	84	6
21	23 Sept 1957	790	230	99	22
22	23 Sept 1957	355	5	4	0
23	23 Sept 1957	1482	351	225	21
24	23 June 1958	500	0	0	
25	23 June 1958	676	85	46	
26	22 June 1958	538	119	61	
27	23 June 1958	285	0	0	
28	23 June 1958	581	55	4	
29	23 June 1958	452	60	2	
30	21 June 1958	999	318	61	
31	23 June 1958	500	42	0	
32	24 June 1958	500	42	0	
33	24 June 1958	800	206	1	
34	24 June 1958	500	62	1	
35	25 June 1958	600	160	0	
36	25 June 1958	608	3	8	
	Total	12914	2142	789	

Movement

The sea scallop is a vigorous swimmer and there have been persistent reports of beds moving away, to the distress of the fishermen. There have also been reports, at least one of which I know to be reliable, of large numbers of small scallops being seen at the surface in water as deep as 25 fathoms.

Table 3 gives a summary of the reported locations of capture of 2191 tagged sea scallops on which we had complete recovery data. Over a period of $2^{1}/_{2}$ years, 80.4 percent were reported within 2 miles of the release location, 97.1 percent within 10 miles. A small tendency for dispersal to increase with time is apparent. This may be the result of the disturbance caused by dredging. It must be stressed that some of the reported locations of capture may be considerably in error.

Table 3

Distance of reported location of recapture from location of release for 2191 tagged sea scallops (by half-yearly periods)

Half-year periods	Less than 2 miles %	2—10 miles %	Over 10 miles %	Total number
1	84.3	12.0	3.7	1115
2	84.2	13.9	1.9	374
3	83.9	14.5	1.6	380
4	51.7	45.3	3.0	232
5	75.6	21.1	3.3	90
Total	80.4	16.7	2.9	2191

From these results, it seems that we are reasonably safe in concluding that the movements of individual sea scallops are not large and that aggregations do not move about but may become dispersed somewhat. All of these scallops were larger than 75 mm in length; smaller scallops have fragile shells which usually break if an attempt is made to tag them. Large-scale movement of smaller scallops still remains a possibility. It is also possible, but I believe unlikely, that the tag inhibits movement.

Growth

The large number of returns from the 1957 and 1958 tagging experiments provided very satisfactory data for calculating growth rates; but, since the important grounds were widely separated, we felt that different areas would have different growth patterns. Tagging all over Georges Bank would be a tedious and expensive operation, so we made a vigorous attempt to master the technique of locating annual rings on the shell as had been done by Stevenson and Dickie (1954) working with sea scallops from the area off Digby, Nova Scotia.

After we had developed a satisfactory technique for locating what we considered to be annual rings, we were faced with the need to validate our results. For this purpose we used a sample of 392 tagged shells which had been returned after being at large for about a year. The Walford regression for this sample, calculated from the increment added between release and return was $L_{t+1} = 47.3 + 0.662\ L_t$. The annual rings on a sample of 411 shells from the same location gave us $L_{t+1} = 42.4 + 0.706\ L_t$. To avoid subjective bias, the different methods were used by different investigators. The two equations give almost the same results when used to determine the growth of scallops from an arbitrary length of 85 mm onwards.

	L_t	L_{t+1}	L_{t+2}	L_{t+3}	L_{t+4}	L_{t+5}
Tags	85.0	103.6	115.9	124.0	129.4	133.0 mm.
Rings	85.0	102.4	114.7	123.4	129.5	133.8 mm.

From our tag recoveries we have been able to estimate the time of year when the annual ring is laid down, by assuming that the equable temperature regime of Georges Bank causes only a slight difference in the seasonal growth rate and that the tagging check ring is the effect of only a short time inhibition of growth. If these assumptions are true, the position of the annual ring between the tagging check ring and the margin shows that it was formed in late spring, between April 1 and June 1. This suggests that the annual ring is the result of minimum water temperatures.

Tagging Mortality

Mortality due to tagging in these experiments is, in our opinion, low. The animal is not wounded by the tag or pin and scallops returned shortly after tagging have already sealed off the hole and that part of the pin in contact with the mantle, with new shell. The coincidence of the growth rates of tagged and untagged scallops also suggests low tagging mortality. There is a possibility that improperly applied tags may get between the valves of some few individuals and cause some mortality soon after tagging. We receive some tagged shells, out for some time, which show no growth and we assume this means that the animal died soon after it was tagged.

Calculation of Mortality Rates

Unlike fin fish, a tagged sea scallop which dies from any cause but is not recovered is not removed from the tagged population. The valve, with tag attached, persists for some time, perhaps 2 or 3 years. Some of our recovered shells have fouling organisms on their inner surface and were certainly dead when recaptured. Others still have part of the adductor muscle attached and were certainly alive. There remain, however, quite a few returns which we cannot identify certainly as being alive or dead when recaptured. Because dead animals do not leave the population and all cannot be identified among those recovered, any mortality rate calculated from the rate of return of tagged shells can be regarded as a fishing mortality rate.

There are other complications in the analysis. The tagged individuals do not distribute themselves at random through the total population, nor is fishing conducted at random. The number of tagged shells reported is certainly less than the number recaptured, while the amount of effort reported for the trip on which they were caught is larger than that which was expended on the tagged animals. The tagged scallops occupy only a limited amount of the space over which the boats range in fishing them up.

Accepting these limitations and complications, the iterative analysis of Beverton and Holt (1957, p. 192) was applied to the data of Table 4. The iterations would not converge. A simple analysis, plotting the logarithm of the numbers remaining against the sum of the effort required to effect the reduction in the manner of a survival curve, was then attempted (Figure 3). The sharp decrease in slope after the first six months and again after the eighteenth month suggests that quite a few tags either fall off the shell or are being recaptured but not reported.

Table 4

Number of tagged sea scallops returned from drops 15—23, and the reported effort required to catch them, summed by half-yearly periods

Period	1	2	3	4	5	6
No. recaptured	758	229	376	233	59	23
Days fished	158	108	237	317	34	36
% recaptured	14.1	5.0	8.6	5.8	1.6	0.6
Cumulative days fished	158	266	503	820	854	890
Number remaining .	4617	4388	4012	3779	3720	3697
Log. nos. remaining	8.439	8.388	8.299	8.239	8.223	8.217

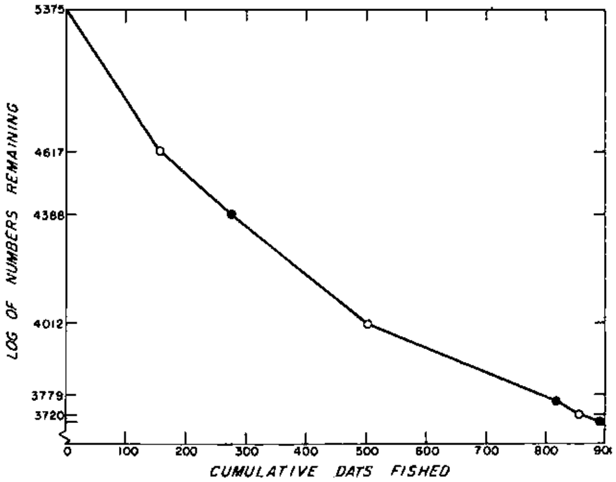


Figure 3. Apparent survival curve of the sea scallops tagged in September 1957, plotted at 6 month intervals as a function of the reported effort in the area of release.

With all the bias in the data, it does not seem to be worthwhile to try a more sophisticated analysis. During the first six months after the tagged sea scallops were released, 158 days of fishing spread over the area in which the tags were located (about 15 square miles) resulted in the return of 14.1 percent of the tags. This gives us a minimum figure for the fishing mortality generated by this effort over this area. It is impossible to say from these data by how much this figure must be multiplied to arrive at the true fishing mortality. For this purpose, it will be necessary to conduct a specifically designed experiment.

Summary

The release of 2925 sea scallops tagged with a single Petersen disc led to the return of only 90 after 5 years at large. The addition of a 6-inch length of yellow plastic tape on 12914 tagged scallops led to the return of 2931 during 2 years at large.

The returned shells show that the beds move little if at all. They have been used to estimate growth rates, validate the technique of locating annual rings, and deduce the season of ring formation.

References

BEVERTON, R. J. H. and S. J. HOLT. 1957. On the dynamics of exploited fish populations. *Fish. Invest.*, Lond., Ser. **II**, **19**.

STEVENSON, J. A. and L. M. DICKIE. 1954. Annual growth rings and the rate of growth of the giant scallop, *Placopecten magellanicus* (Gmelin), in the Digby area of the Bay of Fundy. *J. Fish. Res. Bd Canada*, **11** (5): 660—671.

45.

Comparison of Returns from Different Tags and Methods of Attachment Used in Cod Tagging in the Newfoundland Area, 1954 and 1955

By

WILFRED TEMPLEMAN*

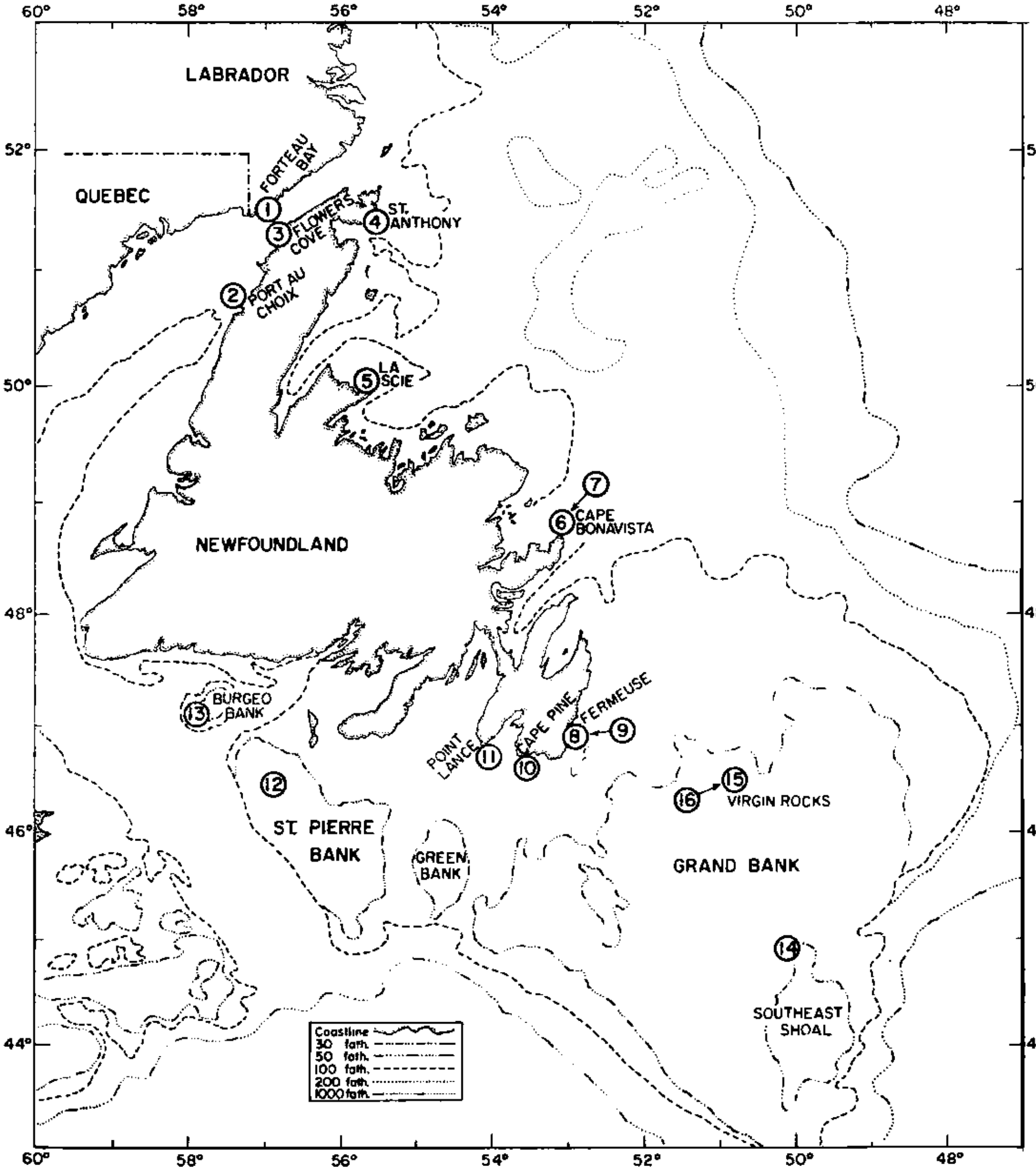


Figure 1. Series numbers and tagging localities, 1954—55. (The centre of the circle containing the series number is at the tagging location.)

---

* Fisheries Research Board of Canada, Biological Station, St. John's, Nfld., Canada.

Introduction

During 1954—55 about 19,000 cod (*Gadus morhua* L.) were successfully tagged in the 13 Newfoundland and Labrador inshore and bank areas shown in Fig. 1 and Table 2. Returns for 1960 are incomplete.

In each of the Series 4—13 (Table 2), all tagged during 1954 in 8 localities, the same varieties of tags were used and attached or inserted by the same methods, numbers and proportions. These 10 series are thus directly comparable, both overall and for individual tags and methods of attachment.

In the remaining series some of the varieties of tags were lacking and some methods of attachment were omitted, so that they cannot be combined directly and in all respects with Series 4—13.

In this paper only the returns to November 1, 1960 from the tagging in 1954—55 are considered. There will still be returns from this tagging for the next 4 or 5 years but the total number of returns during this period should be approximately the same as that for the whole year 1960 and thus will not usually be large enough to invalidate the conclusions in this paper. However, a final assessment will be published later when all the returns have been reported. At that time, also, tag returns will be considered in relation to size of fish tagged. The tests of statistical significance are also left for the final paper. Time and space have not permitted the inclusion of such details in this preliminary paper. There is, however, usually a pattern or trend in returns by size of tag or by size and type of wire, etc., consistent enough to be convincing.

Tags and Methods of Attachment

The various tags used are described in Table 1 and are shown in Fig. 2.

The wire used for attachment consisted of:

A-type nickel wire with diameters of 0.020, 0.025, 0.032 and 0.040 inches (0.51, 0.64, 0.81 and 1.02 mm); and soft stainless steel wire, type 304, with diameters of 0.015, 0.020, 0.025 and 0.032 inches (0.38, 0.51, 0.64 and 0.81 mm). The nickel wire was considerably more pliable than the stainless steel and was used exclusively in our earlier cod-tagging experiments in the Newfoundland area. In these experiments nickel was used as well as stainless steel to test the value of its greater flexibility and ease of use, to provide a comparison with our previous experiments, and also, because to our knowledge no major comparison of nickel and stainless steel wire has been made for cod tagging or for the tagging of any fish in the Atlantic area. The Lea attachment for the hydrostatic tag was of stainless steel considerably harder than type 304 soft and was of 0.024-inch (0.6-mm) diameter. (Metric equivalents of tag sizes used in this paper are given in Table 1.)

Only cod of fork length 50 cm and over which appeared to be in excellent condition were tagged. The fish were taken directly from the longline or handline or placed for a short time in a tagging tank with running sea water, or, in the case of trap-caught fish, taken usually from a floating bag of fish, measured on the measuring board and tagged as quickly as possible. The methods of insertion, attachment and retrieval of tags are described in Templeman and

Table I

Characteristics of tags used in 1954—55 cod tagging. (int. = internal. ext. = external. I inch = 25.4 mm. All tags except the hydrostatic consisted of a central coloured plastic strip with a lamination of 0.05-inch clear plastic on each side. All had rounded ends. In this paper the 25/32-inch tags are for convenience called $^{3}/_{4}$-inch tags. Millimetre equivalents to inch sizes are shown in parentheses)

Tag description	Material	Colour	Length inches (mm)	Width inches (mm)	Thickness as ordered inches (mm)	Thickness as used (average 10 tags inches (mm)	Weight (average 5 tags) g
2-inch orange-int.	Vinylite	Bright orange	2 (51)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.034 (0.9)	0.59
3-inch orange-int.	Vinylite	Bright orange	3 (76)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.034 (0.9)	0.88
4-inch orange-int.	Vinylite	Bright orange	4 (102)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.033 (0.8)	1.14
5-inch orange-int.	Vinylite	Bright orange	5 (127)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.035 (0.9)	1.50
$^{3}/_{4}$-inch red-ext.	Vinylite	Red	$^{25}/_{32}$ (20)	$^{3}/_{16}$ (4.8)	0.030 (0.8)	0.028 (0.7)	0.09
$^{3}/_{4}$-inch orange-ext.	Vinylite	Bright orange	$^{25}/_{32}$ (20)	$^{3}/_{16}$ (4.8)	0.025 (0.6)	0.033 (0.8)	0.10
$^{3}/_{4}$-inch yellow-ext.	Vinylite	Yellow	$^{25}/_{32}$ (20)	$^{3}/_{16}$ (4.8)	0.030 (0.8)	0.030 (0.8)	0.09
$1^{1}/_{4}$-inch orange-ext.	Vinylite	Bright orange	$1^{1}/_{4}$ (33)	$^{5}/_{16}$ (7.9)	0.030 (0.8)	0.031 (0.8)	0.25
$1^{1}/_{4}$-inch yellow-ext.	Vinylite	Yellow	$1^{1}/_{4}$ (33)	$^{5}/_{16}$ (7.9)	0.030 (0.8)	0.029 (0.7)	0.23
2-inch red-ext.	Cellulose nitrate	Cerise red	2 (51)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.036 (0.9)	0.58
2-inch orange-ext.	Vinylite	Bright orange	2 (51)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.034 (0.9)	0.59
3-inch orange-ext.	Vinylite	Bright orange	3 (76)	$^{3}/_{8}$ (9.5)	0.035 (0.9)	0.034 (0.9)	0.88
Hydrostatic (Lea)	Celluloid	Yellow with blue ends	1.8 (46)	0.153 (3.9)		0.153 (3.9)	0.49

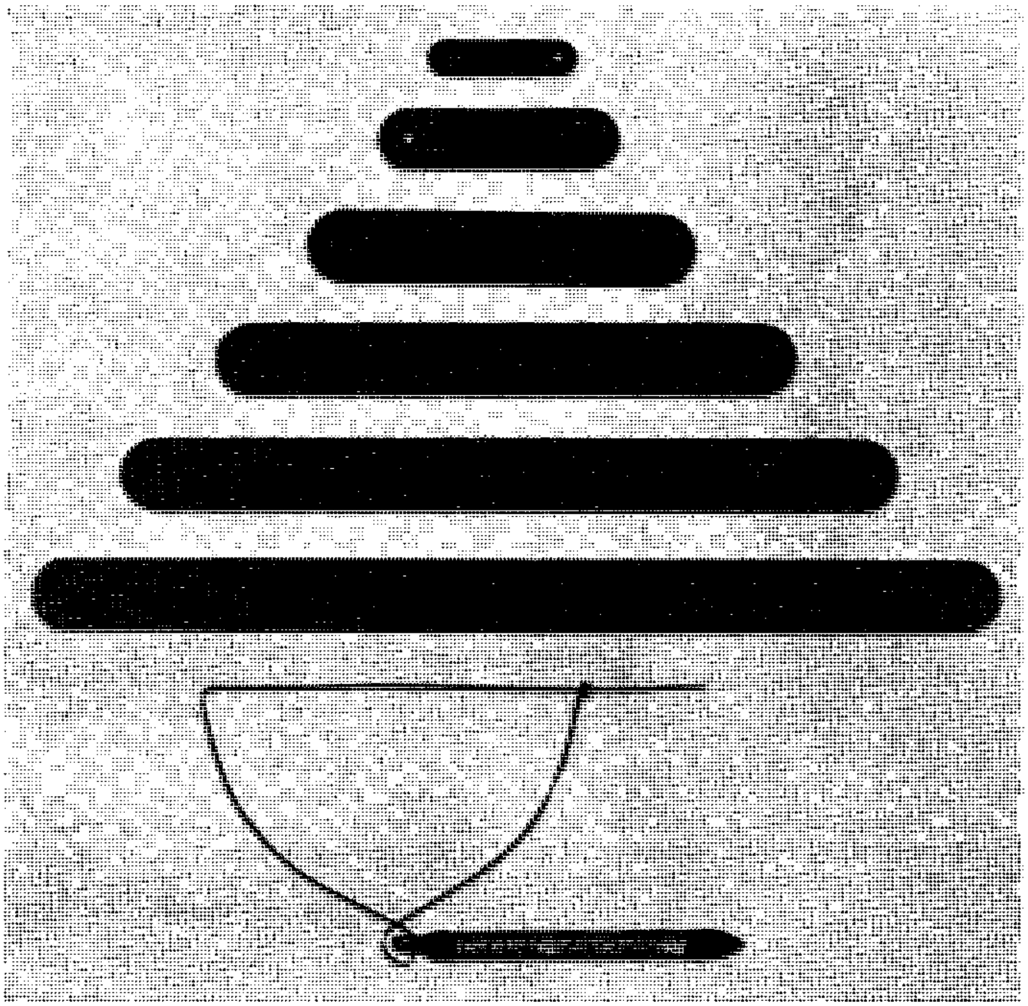


Figure 2. Sizes of tags used in the 1954—55 tagging: $^{25}/_{32}$ ($^{3}/_{4}$)-, $1^{1}/_{4}$-, 2-, 3-, 4- and 5-inch tags and hydrostatic tag with Lea attachment. (Tags approximately natural size).

Pitt (this Symposium, contr. No. 47) and Templeman and Fleming (1962), and loop and single wire and button attachments are illustrated in Figs. 3 and 4.

Tags were attached individually in groups of 10 of each type of tag and each method of attachment. As a rule the tagging operation for one series took only a few days (Table 2) and on the average only a small proportion of the tagged fish was recaptured in the tagging year. Also, the results of 10 similar repetitive tagging experiments are combined. It is, therefore, unlikely that the position of the different tag and attachment variations in each tagging series introduced significant bias.

As noted in Table 2, in most of these tagging series the cod for tagging were caught by longline and in the remainder mainly by inshore trap and occasionally by handline.

Only cod which appeared to be successfully tagged are included in this paper. Fish which floated away on the surface after tagging, whether the tags were eventually returned or not, are not included.

General Results

Table 2 gives the depths, surface and bottom temperatures, sources, dates, numbers successfully tagged and number of returns, and Table 3 the percentage returns, from 16 cod-tagging experiments in 13 Newfoundland and Labrador areas, 1954—55. Except for Series 1, 4, 5, 12 and 13 tagging was carried out after the main fishery in the area was over for the year, and thus in most series and in the overall total the greatest number of recaptures was in the year after the tagging year.

Figure 3. Tags attached by loop around preopercular. Photographs after recapture.
Above: 2-inch orange tag, nickel wire 0.032 inches in diameter. Tagged Series 10 near Cape Pine, 75 cm long, Oct. 5, 1954 and recaptured in approximately same area, Sept. 13, 1955, 81 cm long. Sores 0.8 cm in diameter at surface. Cheek swollen and flesh around wire decayed and somewhat blackened. Inside the gill cover a large hole about 1.5 cm long and 0.8 cm wide had rotted around wire. Tag firmly attached and in good condition but wire in flesh tarnished and with corrosion beginning.
Below: 2-inch red tag, stainless steel wire 0.020 inches in diameter. Tagged Series 8, Fermeuse, Nov. 14, 1954, 58 cm long and recaptured near St. John's, June 30, 1959, 69 cm long. Tag firmly attached with only a small area of soreness immediately around insertion of wire. No serious wounds. No corrosion of wire. No swelling of opercular region.

Series 4—13 were tagged in 1954, the remainder in 1955. In order to even out irregularities, at the bottom of Table 2 returns from tagging in the same area, in neighbouring areas and in areas of the same type are combined. The returns from the 1954 tagging in the inshore Newfoundland and the close-to-shore Burgeo Bank and northern St. Pierre Bank areas gave, up to November 1, 1960, returns ranging from 33.5% in Series 8 tagged at Fermeuse to 17.3% from Series 6 tagged off Bonavista.

Returns from different tagging experiments in the same and also in neighbouring or similar type areas (see the various combinations of areas at bottom of Table 3) generally gave the same trend of returns.

Returns were lowest, 12.4—16.8% (average 15.3%), from the tagging on the Virgin Rocks and Southeast Shoal of the Grand Bank. The tagging in these areas, however, was carried out in 1955.

The average overall returns, apart from the Grand Bank tagging, up to November 1, 1960 were 25.9%. It must be remembered that in these experiments

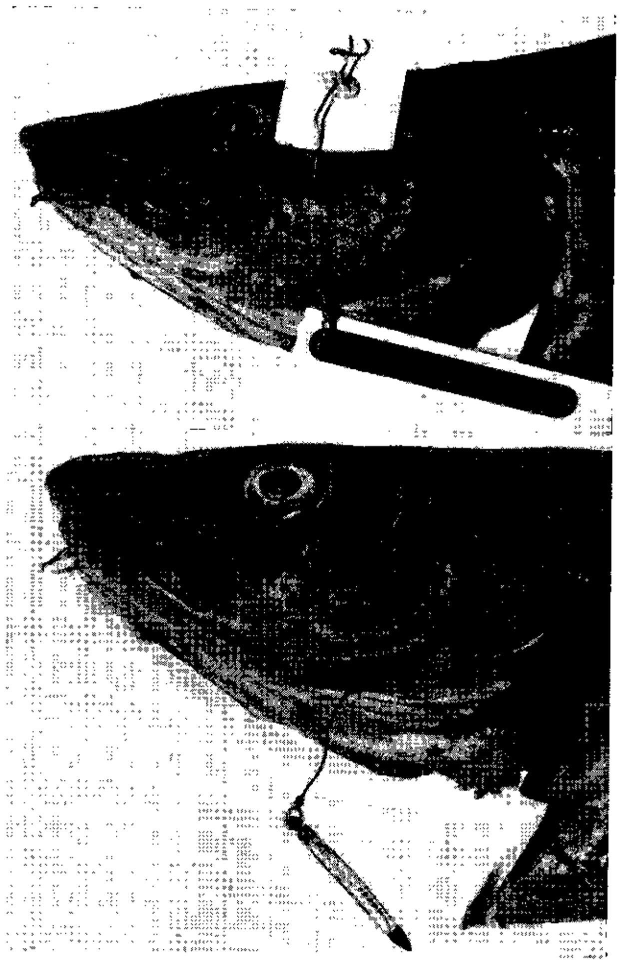


Figure 4. Tags attached around preopercular by single wire and 10-mm button. Photographs after recapture.
Above: 3-inch orange tag, nickel wire 0.040 inches in diameter. Tagged Series 8 off Fermeuse, Nov. 13, 1954, 57 cm long and recaptured on northern Grand Bank April 26, 1956, 59 cm long. Injuries around wire at points of entrance about 0.8 cm in diameter. Injuries clean, no outward sign of infection. Internally a small pocket of infection around wire. Tag firmly attached, no indication of corrosion. The coils of wire for retaining the button have been unwound by the retriever of the tag but can be seen in the lower photograph. In both photographs the wire and button have been pulled back to show the wounds below.
Below: Lea's hydrostatic tag, nickel wire 0.032 inches in diameter. Tagged Series 10 off Cape Pine, Oct. 16, 1954, 58 cm long and recaptured off Fermeuse, Aug. 28, 1955, 60 cm long. On outside, sore 1.0 × 0.5 cm at upper point where wire entered and about 0.5 cm diameter at lower point. A hole about 0.5 cm in diameter had rotted through to the inside of the gill cover.

Table 2

Returns from cod tagging in the Newfoundland area, 1954—55. (0 + = tagging year. 1 = 1st calendar year, January—December, after tagging year)

Series No.	Locality of tagging	Depth fm	Temperatures (°C) Surface	Temperatures (°C) Bottom	Source of tagged cod	Year of tagging	Inclusive dates of tagging	No. successfully tagged	No. returns up to and including Nov. 1, 1960 in years after tagging 0+	1	2	3	4	5	6	Total
1	Forteau Bay	7—10	9.6— 9.9	8.5— 9.2	Trap, handline, longline	1955	July 6—8	1,124	72	94	39	27	30	6		268
2	$3^1/_2$ & $1^1/_2$ miles NNE Port au Choix light	24—60	9.6—12.8	—0.1 — +0.5	Longline	1955	Sept. 14—24	1,095	7	112	55	67	23	8		272
3	2 miles NW Flowers Cove	12—25	3.6— 6.9	2.4 — 6.1	Longline	1955	Sept. 27—Oct. 3	1,105	7	85	46	45	21	11		215
4	Cape St. Anthony	16—25	9.5— 9.9	—0.4 — +1.3	Trap	1954	Aug. 2—5	1,353	113	110	57	21	10	4	3	318
5	North Bill, La Scie	17—30	4.4—10.3	—0.3 — —0.7	Trap	1954	Aug. 11—14	1,364	153	137	69	36	12	11	2	420
6	Old Harry, Bonavista	20—40	10.2—10.6	—0.3 — —0.6	Longline	1954	Sept. 24—28	1,342	20	73	56	53	12	15	3	232
7	Old Harry, Bonavista	20—40	9.9—10.7	0.6 — 4.3	Longline	1954	Sept. 28—Oct. 2	1,348	15	73	61	50	22	17	8	246
8	5 miles S from Fermeuse	22—50	3.6— 4.9	0.1 — 3.1	Longline	1954	Nov. 10—16	1,342	3	221	107	75	24	15	4	449
9	5 miles S from Fermeuse	20—50	3.5— 4.1	0.4 — 2.3	Longline	1954	Nov. 17—27	1,351	3	156	106	45	19	11	10	350
10	3—4 miles SW Cape Pine	20—24	7.7	7.1 — 7.2	Longline	1954	Oct. 15—17	1,351	12	201	94	48	14	10	3	382
11	5 miles SW Point Lance	28—34	7.8— 7.9	1.5 — 3.5	Longline	1954	Oct. 19—21	1,335	13	204	102	63	29	12	7	430
12	St. Pierre Bank	27—28	3.2— 4.2	1.2 — 2.6	Longline	1954	May 20—June 2	1,343	109	133	66	16	15	10	3	352
13	Burgeo Bank	36—40	1.1— 2.6	1.1 — 1.5	Longline	1954	Apr. 22—May 14	1,327	127	124	79	43	20	7	4	404
14	SE Shoal, Grand Bank	30—31	15.5—16.2	1.5 — 1.8	Longline	1955	Sept. 11—14	490	12	21	19	6	2	1		61
15	Virgin Rocks, Grand Bank	30—36	10.8—10.9	2.4 — 3.1	Longline	1955	Sept. 27—29	726	1	56	38	17	8	2		122
16	Virgin Rocks, Grand Bank	30—38	10.9—11.1	24. — 3.7	Longline	1955	Sept. 30—Oct. 1	826		75	31	17	5	2		130
Total 1—3	Forteau Bay-Flowers Cove	7—60	3.6—12.8	—0.1 — +9.2	Trap, handline, longline	1955	July 6—Oct. 3	3,324	86	291	140	139	74	25		755
4—5	Cape St. Anthony & La Scie	16—30	4.4—10.3	—0.7 — +1.3	Trap	1954	Aug. 2—14	2,717	266	247	126	57	22	15	5	738
6—7	Old Harry, Bonavista	20—40	9.9—10.7	—0.6 — +4.3	Longline	1954	Sept. 24—Oct. 2	2,690	35	146	117	103	34	32	11	478
8—11	5 miles S from Fermeuse	20—50	3.5— 7.9	0.1 — 7.2	Longline	1954	Oct. 15—Nov. 27	5,379	31	782	409	231	86	48	24	1,611
12—13	St. Pierre Bank & Burgeo Bank	27—40	1.1— 4.2	1.1 — 2.6	Longline	1954	Apr. 22—June 2	2,670	236	257	145	59	35	17	7	756
14—16	The Grand Bank	30—38	10.8—16.2	1.5 — 3.7	Longline	1955	Sept. 11—Oct. 1	2,042	13	152	88	40	15	5		313
Total excluding 14—16 (The Grand Bank)		7—60	1.1—12.8	—0.7 — +9.2	Trap, handline, longline	1954—55	Apr. 22—Nov. 27	16,780	654	1,723	937	589	251	137	47	4,338
Total 1—16		7—60	1.1—16.2	—0.7 — +9.2	Trap, handline, longline	1954—55	Apr. 22—Nov. 27	18,822	667	1,875	1,025	629	266	142	47	4,651

Table 3
Percentage returns from cod tagging in the Newfoundland area, 1954—55

Series No.	Locality of tagging	Depth fm	Year of tagging	Inclusive dates of tagging	No. successfully tagged	% returns up to and including Nov. 1, 1960 in years after tagging							
						0+	1	2	3	4	5	6	Total
1	Forteau Bay, Labrador	7—10	1955	July 6—8	1,124	6.4	8.4	3.5	2.4	2.7	0.5		23.8
2	$1^1/_2$& $3^1/_2$ miles NNE Port au Choix light, Nfld.	24—60	1955	Sept. 14—24	1,095	0.6	10.2	5.0	6.1	2.1	0.7		24.8
3	2 miles NW Flowers Cove, Nfld.	12—25	1955	Sept. 27—Oct. 3	1,105	0.6	7.7	4.2	4.1	1.9	1.0		19.5
4	Cape St. Anthony, Nfld.	16—25	1954	Aug. 2—5	1,353	8.4	8.1	4.2	1.6	0.7	0.3	0.2	23.5
5	North Bill, La Scie, Nfld.	17—30	1954	Aug. 11—14	1,364	11.2	10.0	5.1	2.6	0.9	0.8	0.1	30.8
6	Old Harry, Bonavista	20—40	1954	Sept. 24—28	1,342	1.5	5.4	4.2	3.9	0.9	1.1	0.2	17.3
7	Old Harry, Bonavista	20—40	1954	Sept. 28—Oct. 2	1,348	1.1	5.4	4.5	3.7	1.6	1.3	0.6	18.2
8	5 miles S from Fermeuse, Nfld.	22—50	1954	Nov. 10—16	1,342	0.2	16.5	8.0	5.6	1.8	1.1	0.3	33.5
9	5 miles S from Fermeuse, Nfld.	20—50	1954	Nov. 17—27	1,351	0.2	11.5	7.8	3.3	1.4	0.8	0.7	25.9
10	3—4 miles SW Cape Pine, Nfld.	20—24	1954	Oct. 15—17	1,351	0.9	14.9	7.0	3.6	1.0	0.7	0.2	28.3
11	5 miles SW Point Lance, Nfld.	28—34	1954	Oct. 19—21	1,335	1.0	15.3	7.6	4.7	2.2	0.9	0.5	32.2
12	St. Pierre Bank	27—28	1954	May 20—June 2	1,343	8.1	9.9	4.9	1.2	1.1	0.7	0.2	26.2
13	Burgeo Bank	36—40	1954	Apr. 22—May 14	1,327	9.6	9.3	6.0	3.2	1.5	0.5	0.3	30.4
14	SE Shoal, Grand Bank	30—31	1955	Sept. 11—14	490	2.4	4.3	3.9	1.2	0.4	0.2		12.4
15	Virgin Rocks, Grand Bank	30—36	1955	Sept. 27—29	726	0.1	7.7	5.2	2.3	1.1	0.3		16.8
16	Virgin Rocks, Grand Bank	30—38	1955	Sept. 30—Oct. 1	826	0.0	9.1	3.8	2.1	0.6	0.2		15.7
Total													
1—3	Forteau Bay-Flowers Cove	7—60	1955	July 6—Oct. 3	3,324	2.6	8.8	4.2	4.2	2.2	0.8		22.7
4—5	Cape St. Anthony& La Scie	16—30	1954	Aug. 2—14	2,717	9.8	9.1	4.6	2.1	0.8	0.6	0.2	27.2
6—7	Old Harry, Bonavista	20—40	1954	Sept. 24—Oct. 2	2,690	1.3	5.4	4.3	3.8	1.3	1.2	0.4	17.8
8—11	5 miles S from Fermeuse	20—50	1954	Oct. 15—Nov. 27	5,379	0.6	14.5	7.6	4.3	1.6	0.9	0.4	29.9
12—13	St. Pierre Bank& Burgeo Bank	27—40	1954	Apr. 22—June 2	2,670	8.8	9.6	5.4	2.2	1.3	0.6	0.3	28.3
14—16	The Grand Bank	30—38	1955	Sept. 11—Oct. 1	2,042	0.6	7.4	4.3	2.0	0.7	0.2		15.3
Total excluding 14—16 (The Grand Bank)		7—60	1954—55	Apr. 22—Nov. 27	16,780	3.9	10.3	5.6	3.5	1.5	0.8	0.3	25.9
Total 1—16		7—60	1954—55	Apr. 22—Nov. 27	18,822	3.5	10.0	5.4	3.3	1.4	0.8	0.2	24.7

some tags and methods of attachment gave much better returns than others. For Series 4—13 the 2- and the 3-inch external tags with the 0.032-inch stainless steel wire attachment each had 38% returns (Table 6), and returns of the 2-inch external tag with 0.025 stainless steel wire, for the dorsal position only, were 41%.

Some of the more unusual results can be explained by changes in the location of effort in the fishery. Although in the total of all areas the returns for the second and third years after the tagging year were 55 and 61% respectively of the returns in the previous year, in the Bonavista tagging the comparable returns for the second and third years after the tagging year were 80 and 88% respectively. The sources of the returns indicate that the high percentage of returns in 1956 and 1957 was largely due to a concentration of European trawlers in the Bonavista area during these years, which increased considerably the total fishing effort in the Bonavista and neighbouring areas. Since, of the large European trawler fleets, returns for the remaining countries are very much below those from the Portuguese fleet (Poulsen, MS, 1957, and our own results, also) the low returns from the Bonavista tagging were doubtless partly due to non-reporting of recaptured tags by trawlers other than Portuguese. Additionally, since the returns of tags from Portuguese dory vessels, relative to their catch of cod, are more than twice as many as from Portuguese trawlers (Poulsen, MS, 1957), and almost all the Portuguese fishing off Bonavista was by trawlers, the Portuguese tag returns were very likely low, also, in relation to captures of tagged cod. The generally low returns from the Bonavista tagging were partly due, also, to a considerable decline in the Newfoundland inshore and longline cod catches in the Bonavista area in recent years (Fleming, MS,1959; Templeman, 1959). It is presumed that a greater percentage of cod tags is detected and returned when the tagged fish are captured by the inshore fishermen, since each fish is handled many times individually.

It will be noted also that Series 1—3 (Totals, Table 3) in the northern Gulf of St. Lawrence near the southern end of the Strait of Belle Isle have given as many returns in the third year after tagging (1958) as in the second (1957). This is due partly to an increase in European trawler fishing in the spring along the southern part of the west coast of Newfoundland, and also to an increase in dory-vessel and trawler fishing in summer and autumn in the northern Gulf and east of the Strait of Belle Isle.

Tag Success

Successful and unsuccessful tags

The percentage returns of the various types of tags from the tagging in Series 4—13 are shown in Table 4. The most successful tags were: the 2-inch orange external and the hydrostatic with loop or button attachments, both with 34.3% returns; the 3-inch orange external, 32.8%; the hydrostatic tag with Lea's attachment, 32.6%; the $1^1/_4$-inch orange external, 31.6%; and the 2-inch red external, 31.3%. For long-term returns the 2-inch orange external gave the best results, followed closely by the 2-inch red and the $1^1/_4$-inch orange.

The internal tags and the small $^3/_4$-inch tags were relatively unsuccessful, presumably in both cases because they were more difficult to see. A higher proportion of the smaller than of the larger tags is also likely to be lost between capture and return to the Biological Station. There has, also, very likely been some loss of internal tags due to an increasing tendency in recent years to fillet round cod.

Tag sizes

Of the internal tags the 2-inch tag was relatively unsuccessful (15.4% returns), due most likely to its poor visibility because of its small size, and the 4-inch tag (24.0% returns) gave slightly better results than the 3- and the 5-inch tags. This is somewhat different from the results of previous experiments on the same tags (Templeman and Pitt, this Symposium, contr. No. 47) in which although the 2-inch tag was again the least successful the 5-inch tag was the most successful. These differences in the success of the 5-inch tags relative to that of the 4-inch tags will very likely be explicable when the sizes of the fish tagged have been considered in relation to the returns. In total returns the 2- and 3-inch sizes were the most successful of the external flat tags and the 2-inch external was the most successful for long-term returns, followed closely by the $1^1/_4$-inch tags.

Colours

The orange colour was the most successful for external tags. For the $^3/_4$-inch size the bright orange tags gave slightly more returns than the yellow and the yellow slightly more than the red. In the $1^1/_4$-inch tags the bright orange gave slightly more returns than the yellow and for the 2-inch tags the hright orange gave more returns than the bright red.

Hydrostatic tag attachments

For the hydrostatic tag in dorsal position the loop and button attachments were better (37.2% returns) than Lea's attachment (32.5%) but in the preopercular position Lea's attachment was slightly superior (32.8 against 31.4%). Whereas in both positions Lea's attachment for the hydrostatic tag was stainless steel, in the loop and button attachments for the hydrostatic tag stainless steel was used in the dorsal

Table 4

Comparison between returns of various tag sizes and colours from cod tagging, Series 4—13 (Tables 2 & 3) 1954. (1 inch = 2.54 cm.)

Tag	No. successfully tagged			No. returns 1954—60 (up to and including Nov. 1, 1960)							1954—60		1955—60		1956—60		1957—60		Total %			
	Dorsal	Preop.	Total	1954	1955	1956	1957	1958	1959	1960	Dorsal %	Preop. %	Dorsal %	Preop. %	Dorsal %	Preop. %	Dorsal %	Preop. %	1954—60	1955—60	1956—60	1957—60
2-inch orange-int.			996	24	61	28	27	5	7	1									15.4	13.0	6.8	4.0
3-inch orange-int.			983	41	89	45	30	9	5	3									22.6	18.4	9.4	4.8
4-inch orange-int.			988	42	84	57	32	15	6	1									24.0	19.7	11.2	5.5
5-inch orange-int.			979	31	80	61	24	8	5	4									21.8	18.6	10.4	4.2
$^3/_4$-inch red-ext.	492	496	988	31	98	36	27	5	8	2	22.6	19.4	19.9	15.7	9.8	6.0	5.3	3.2	21.0	17.8	7.9	4.3
$^3/_4$-inch orange-ext.	495	491	986	35	94	58	27	10	9	2	24.4	23.4	20.4	20.4	9.7	12.0	3.8	5.9	23.9	20.4	10.9	4.9
$^3/_4$-inch yellow-ext.	494	492	986	40	96	47	31	9	7		23.7	23.0	19.6	18.9	9.7	9.3	4.9	4.7	23.3	19.3	9.5	4.8
$1^1/_4$-inch orange-ext.	694	690	1,384	63	174	91	57	25	16	11	32.4	30.7	27.5	26.5	15.7	13.2	8.4	7.4	31.6	27.0	14.5	7.9
$1^1/_4$-inch yellow-ext.	692	694	1,386	62	144	104	47	25	10	9	28.6	29.3	23.6	25.4	13.0	15.1	6.6	6.5	28.9	24.5	14.1	6.6
2-inch red-ext.	470	475	945	47	109	67	44	15	11	3	31.9	30.7	26.6	26.1	15.5	14.1	8.3	7.2	31.3	26.3	14.8	7.7
2-inch orange-ext.	476	477	953	49	130	75	34	20	14	5	34.5	34.2	27.7	30.6	14.7	16.4	8.2	7.1	34.3	29.2	15.5	7.7
3-inch orange-ext.	467	472	939	45	137	67	40	9	6	4	34.3	31.4	28.9	27.1	13.7	13.1	6.2	6.4	32.8	28.0	13.4	6.3
Hydrostatic, loop and button-ext.	239	236	475	31	67	34	16	8	7		37.2	31.4	29.7	25.8	14.6	12.7	5.9	7.2	34.3	27.8	13.7	6.5
Hydrostatic, Lea's attachment-ext.	234	235	469	27	68	26	14	13	3	2	32.5	32.8	27.8	26.0	12.8	11.9	6.0	7.7	32.6	26.9	12.4	6.8
Total																						
2-inch internal			996	24	61	28	27	5	7	1									15.4	13.0	6.8	4.0
3- to 5-inch internal			2,950	114	253	163	86	32	16	8									22.8	18.9	10.3	4.8
$^3/_4$-inch external	1,481	1,479	2,960	106	288	141	85	24	24	4	23.6	21.9	20.0	18.3	9.7	9.1	4.7	4.6	22.7	19.2	9.4	4.6
$1^1/_4$-inch external	1,386	1,384	2,770	125	318	195	104	50	26	20	30.5	30.0	25.5	25.9	14.4	14.2	7.5	6.9	30.3	25.7	14.3	7.2
2-inch external	946	952	1,898	96	239	142	78	35	25	8	33.2	32.5	27.2	28.4	15.1	15.2	8.2	7.1	32.8	27.8	15.2	7.7
3-inch external	467	472	939	45	137	67	40	9	6	4	34.3	31.4	28.9	27.1	13.7	13.1	6.2	6.4	32.8	28.0	13.4	6.3
Hydrostatic external	473	471	944	58	135	60	30	21	10	2	34.9	32.1	28.8	25.9	13.7	12.3	5.9	7.4	33.5	27.3	13.0	6.7
Total	4,753	4,758	13,457	568	1,431	796	450	176	114	47	29.7	28.3	24.8	24.2	12.9	12.5	6.5	6.2	26.6	22.4	11.8	5.8

position and in the preopercular position the less effective nickel wire. Thus, when the superiority of the stainless steel attachment is considered (Table 6), the loop and button attachments were also superior to Lea's attachment in the preopercular position.

Dorsal and preopercular positions

All external tags gave slightly better overall returns from the dorsal (total 29.7%) than from the preopercular position (28.3%). The differences in favour of the dorsal position ranged from 0.5% for the $^3/_4$-inch tag to 2.9% for the 3-inch tag. This small difference in favour of the dorsal over the preopercular position is a similar result to that found in our previous experiments with a small $^{25}/_{32}$-inch tag (Templeman and Pitt, this Symposium, contr. No. 47). The preopercular position seems to offer a very firm and long-lasting attachment, but there are certain to be failures to observe preopercular tags, due to the position of the tag on the left side of the head and its consequent failure to be seen because the head is quickly discarded in salt fish operations, and because of occasional left-handed cutters who turn the right side of the fish upward before cutting the fish open.

In the long-term returns the dorsal position maintained a slight overall advantage; the preopercular position was superior for some tags, but with the small number of long-term returns these small differences probably have no significance. As will be noted later, however, for the larger wire diameter (0.032 inches, Table 7) the preopercular position gave the greatest number of returns both total and long-term.

Comparison of Loop and Buttons

In each 10 fish tagged in succession with each type of external tag and wire 4 or 6 were tagged with a loop of wire and 6 or 4, in groups of 2, with a single wire attached posteriorly to a tag and anteriorly passing through a central hole of 3 or 2 types of round buttons of translucent cellulose acetate plastic, 0.040 inches (1.0 mm) thick and 8, 10 and 13 mm in diameter. Since for each tag each type of button and loop attachment was made in the same proportion with each type of wire, in Table 5 all types of wire have been combined so as to present direct comparisons between button and loop attachments.

Overall Comparison, Dorsal + Preopercular Positions. Comparison between Returns for Loop and Button Techniques

Total returns

In the whole period 1954—60 for the smaller ($^3/_4$- and $1^1/_4$-inch) tags loops were superior to the best buttons (for the $^3/_4$-inch tag 26.3 compared with 17.8% returns and for the $1^1/_4$-inch tag 33.5 compared with 30.5% returns), and still more superior to the totals of all buttons. For the large tags, however, the situation is reversed. For the 2-inch tags the best button (34.8% returns) was superior to the loop (32.9%) and the total button returns (32.7%) were approximately the same as the loop returns. For the 3-inch tag the best button returns (34.9%) were better than the loop (32.1%) and the total button returns (33.5%) were also higher than those from the loop. For the hydrostatic tag (1.8 inches long) both 10- and 13-mm buttons were better (35.8 and 35.0%) than the loop returns (33.2%).

Long-term returns after the tagging year, 1954

Neglecting the tagging year, for the $^3/_4$-inch tag the loop was clearly superior in long-term returns to the buttons (Table 5). For the $1^1/_4$-inch tag, although the early returns were higher from the loop attachment, the loop gradually lost its superiority after 1955 and after 1957 became inferior to the best button attachment. For the larger 2- and 3-inch tags in the years after 1956 the best button increased its advantage over the loop relative to its advantage over the whole period, 1954—60.

For the hydrostatic tag the long-term returns 1955—, 1956— and 1957—60 were higher for the best button and slightly higher for the total of all buttons, but the small number of returns makes the significance of these results doubtful.

Comparison between buttons

For all sizes of tags with the exception of the hydrostatic tag the 10 mm was the best button attachment both for the whole period and for the long-term returns. It was, however, only slightly better than the 8-mm button for the $^3/_4$-inch tag. It gave better returns than the 8- and the 13-mm buttons for the $1^1/_4$-inch tag and than the 13-mm button for the 2- and 3-inch tags. For the hydrostatic tag the 10-mm button was slightly better for the total returns, and the 13-mm button better for the long-term returns, but only a small number of fish were tagged with the hydrostatic tag button attachments.

Preopercular and dorsal positions in relation to loop and button attachments

While in the total returns from all types of attachments for the various tags (Table 4) the dorsal position had a slight advantage over the preopercular, in Table 5 in which button and loop attachments are presented separately there is, as one would expect, more variety of results, the total buttons usually having more returns from the dorsal position for

Table 5

Comparison of returns from loop and various button attachments of different external tags in cod tagging, Series 4—13 (Tables 2 and 3) 1954. (1 inch = 2.54 cm.)

Type	Attachment	No. successfully tagged			% returns 1954—60 (up to and including Nov. 1, 1960)								Total dorsal + preopercular %			
					1954—60		1955—60		1956—60		1957—60		1954 —60	1955 —60	1956 —60	1957 —60
		Dorsal	Preop.	Total	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.				
$^{3}/_{4}$-inch	Total-8 mm button	300	295	595	19.0	14.9	15.7	12.2	7.7	5.1	3.3	2.4	17.0	13.9	6.4	2.9
	Total-10 mm button	295	296	591	16.9	18.6	14.6	15.5	6.1	8.8	2.4	3.4	17.8	15.1	7.4	2.9
	Total-button	595	591	1,186	18.0	16.8	15.1	13.9	6.9	6.9	2.9	2.9	17.4	14.5	6.9	2.9
	Total-loop	886	887	1,773	27.3	25.4	23.3	21.3	11.6	10.6	5.9	5.7	26.3	22.3	11.1	5.8
$1^{1}/_{4}$-inch	Total-8 mm button	275	275	550	26.2	28.0	22.9	21.8	13.1	10.2	7.6	5.5	27.1	22.4	11.6	6.5
	Total-10 mm button	278	277	555	32.0	28.9	25.5	26.0	16.9	13.4	9.0	7.2	30.5	25.8	15.1	8.1
	Total-13 mm button	277	275	552	30.0	23.3	26.0	21.1	14.4	12.4	9.0	5.1	26.6	23.6	13.4	7.1
	Total-button	830	827	1,657	29.4	26.7	24.8	23.0	14.8	12.0	8.6	5.9	28.1	23.9	13.4	7.2
	Total-loop	556	557	1,113	32.2	34.8	26.6	30.3	13.7	17.4	6.1	8.3	33.5	28.5	15.5	7.2
2-inch	Total-10 mm button	237	240	477	35.9	33.8	29.5	29.2	17.3	17.1	10.1	7.9	34.8	29.4	17.2	9.0
	Total-13 mm button	237	239	476	32.9	28.5	26.2	22.6	14.3	10.5	8.9	5.9	30.7	24.4	12.4	7.4
	Total-button	474	479	953	34.4	31.1	27.8	25.9	15.8	13.8	9.5	6.9	32.7	26.9	14.8	8.2
	Total-loop	472	473	945	32.0	33.8	26.5	30.9	14.4	16.7	7.0	7.4	32.9	28.7	15.6	7.2
3-inch	Total-10 mm button	117	118	235	32.5	37.3	29.1	34.7	13.7	16.1	6.0	8.5	34.9	31.9	14.9	7.2
	Total-13 mm button	118	118	236	32.2	32.2	28.0	27.1	12.7	11.0	5.9	6.8	32.2	27.5	11.9	6.4
	Total-button	235	236	471	32.3	34.7	28.5	30.9	13.2	13.6	6.0	7.6	33.5	29.7	13.4	6.8
	Total-loop	232	236	468	36.2	28.0	29.3	23.3	14.2	12.7	6.5	5.1	32.1	26.3	13.5	5.8
Hydrostatic	Total-10 mm button	60	60	120	43.3	28.3	30.0	23.3	21.7	5.0	5.0	1.7	35.8	26.7	13.3	3.3
	Total-13 mm button	60	60	120	33.3	36.7	30.0	33.3	11.7	16.7	10.0	10.0	35.0	31.7	14.2	10.0
	Total-button	120	120	240	38.3	32.5	30.0	28.3	16.7	10.8	7.5	5.8	35.4	29.2	13.8	6.7
	Total-loop	119	116	235	36.1	30.2	29.4	23.3	12.6	14.7	4.2	8.6	33.2	26.4	13.6	6.4
	Lea's attachment	234	235	469	32.5	32.8	27.8	26.0	12.8	11.9	6.0	7.7	32.6	26.9	12.4	6.8

Table 6

Comparison of returns of external tags of various sizes attached by stainless steel (SS) and nickel (N) wire of different diameters in cod tagging, Series 4—13 (Tables 2 and 3) 1954. (1 inch = 2.54 cm.)

Tag	Wire diameter inches		No. successfully tagged			% returns 1954—60 (up to and including Nov. 1, 1960)								Total dorsal + preopercular %			
						1954—60		1955—60		1956—60		1957—60		1954	1955	1956	1957
			Dorsal	Preop.	Total	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.	—60	—60	—60	—60
$^3/_4$-inch	SS	0.015	292	295	587	22.9	19.7	19.2	17.6	8.2	6.4	3.4	3.1	21.3	18.4	7.3	3.2
	SS	0.020	298	296	594	30.9	23.3	26.2	20.3	13.4	11.1	6.0	5.7	27.1	23.2	12.3	5.9
	SS	0.025	295	297	592	23.7	25.6	18.6	20.9	10.5	10.1	6.1	4.7	24.7	19.8	10.3	5.4
	N	0.025	298	295	593	23.2	22.0	21.1	18.3	10.4	10.8	5.0	5.8	22.6	19.7	10.6	5.4
	N	0.020	298	295	593	17.1	19.0	14.8	14.6	6.0	7.1	2.7	3.7	18.0	14.7	6.6	3.2
$1^1/_4$-inch	SS	0.015	200	199	399	29.0	26.6	25.0	24.6	14.0	10.6	8.0	2.5	27.8	24.8	12.3	5.3
	SS	0.020	198	198	396	35.4	23.7	29.8	20.7	13.1	12.1	9.1	6.6	29.5	25.3	12.6	7.8
	SS	0.025	198	199	397	33.8	35.2	28.3	31.7	21.2	17.6	11.1	9.5	34.5	30.0	19.4	10.3
	SS	0.032	199	193	392	28.1	36.3	24.6	31.6	11.1	18.7	4.5	8.3	32.1	28.1	14.8	6.4
	N	0.032	197	198	395	25.9	30.3	21.3	26.3	12.7	15.2	4.1	6.6	28.1	23.8	13.9	5.3
	N	0.025	200	200	400	28.0	32.5	22.5	25.5	13.5	14.0	8.0	7.5	30.3	24.0	13.8	7.8
	N	0.020	194	197	391	33.5	25.4	27.3	21.3	13.9	9.6	7.2	5.6	29.4	24.3	11.8	6.4
2-inch	SS	0.020	156	158	314	31.4	29.7	25.6	27.8	16.7	16.5	9.0	5.7	30.6	26.8	16.6	7.3
	SS	0.025	158	157	315	41.1	31.2	36.1	25.5	20.3	12.1	12.7	5.7	36.2	30.8	16.2	9.2
	SS	0.032	158	160	318	38.6	36.9	33.5	34.4	17.7	20.6	8.2	9.4	37.7	34.0	19.2	8.8
	N	0.040	158	160	318	30.4	28.8	25.3	25.6	13.9	13.1	7.0	5.6	29.6	25.5	13.5	6.3
	N	0.032	158	160	318	29.7	31.9	22.2	26.3	12.0	14.4	6.3	9.4	30.8	24.2	13.2	7.9
	N	0.025	158	157	315	27.8	36.3	20.3	30.6	10.1	14.6	6.3	7.0	32.1	25.4	12.4	6.7
3-inch	SS	0.020	79	77	156	34.2	31.2	30.4	27.3	17.7	11.7	8.9	3.9	32.7	28.8	14.7	6.4
	SS	0.025	79	79	158	35.4	26.6	32.9	25.3	22.8	12.7	12.7	10.1	31.0	29.1	17.7	11.4
	SS	0.032	80	79	159	38.8	38.0	27.5	31.6	12.5	15.2	3.8	10.1	38.4	29.6	13.8	6.9
	N	0.040	80	80	160	40.0	31.3	32.5	28.8	15.0	16.3	3.8	3.8	35.6	30.6	15.6	3.8
	N	0.032	72	80	152	27.8	30.0	23.6	25.0	5.6	13.8	4.2	6.3	28.9	24.3	9.9	5.3
	N	0.025	77	77	154	28.6	31.2	26.0	24.7	7.8	9.1	3.9	3.9	29.9	25.3	8.4	3.9
2-inch and 3-inch	SS	0.020	235	235	470	32.3	30.2	27.2	27.7	17.0	14.9	8.9	5.1	31.3	27.4	16.0	7.0
	SS	0.025	237	236	473	39.2	29.7	35.0	25.4	21.1	12.3	12.7	7.2	34.5	30.2	16.7	9.9
	SS	0.032	238	239	477	38.7	37.2	31.5	33.5	16.0	18.8	6.7	9.6	37.9	32.5	17.4	8.2
	N	0.040	238	240	478	33.6	29.6	27.7	26.7	14.3	14.2	5.9	5.0	31.6	27.2	14.2	5.4
	N	0.032	230	240	470	29.1	31.3	22.6	25.8	10.0	14.2	5.7	8.3	30.2	24.3	12.1	7.0
	N	0.025	235	234	469	28.1	34.6	22.1	28.6	9.4	12.8	5.5	6.0	31.3	25.4	11.1	5.8

the $^3/_4$-, $1^1/_4$- and 2-inch tags and from the preopercular position for the 3-inch tags. For the loop attachment returns were greater from the dorsal position for the $^3/_4$- and 3-inch tags and from the preopercular attachment for the $1^1/_4$- and 2-inch tags. The returns for the two positions for the hydrostatic tag cannot be considered directly, because for these tags stainless steel wire was used for the dorsal attachment and the somewhat inferior nickel wire for the preopercular attachment.

The total returns for the hydrostatic tag with Lea's attachment were approximately equal from both the dorsal and the preopercular positions.

There does not seem to be any pattern in relation to tag size in these various predominances of returns from the dorsal and the preopercular positions.

Returns from Stainless Steel and Nickel Wire of Various Diameters

The returns for different tag and wire sizes and types of wire are shown in Table 6. The various external tags were attached individually in groups of 10 with either stainless steel wire 0.015—0.032 inches in diameter or with nickel wire 0.020—0.040 inches in diameter. The wires of smallest diameter were not used with the largest tags and the largest diameter wires were not used with the smallest tags.

Total dorsal and preopercular positions

It is apparent from Table 6 that, although occasionally the difference was very small, in all 9 cases the stainless steel wire gave greater total returns than nickel wire of the same diameter. In the long-term results, however, for the $^3/_4$-inch tag the nickel 0.025 inch gave equally as good returns as the stainless steel 0.025 inch, but no nickel wire gave as good returns for this tag as the stainless steel 0.020 inch. In the remaining 8 groups of long-term returns the stainless steel wire gave superior returns to nickel wire of the same diameter.

In the more effective stainless steel attachments there appears to be, with increase in size of tag, a general pattern of an increase in the diameter of stainless steel wire giving the greatest returns. For the $^3/_4$-, $1^1/_4$-, 2- and 3-inch tags the diameters of stainless steel wire giving the greatest returns were respectively 0.020, 0.025, 0.032 and 0.032 inches. In the long-term returns, however, (see Table 6, combined 2 and 3 inch) the 0.025-inch stainless steel may be equally as effective for the 2- and 3-inch tags.

Dorsal and preopercular positions

With allowance for variation due to smaller numbers than in the previous comparisons of dorsal + preopercular positions by totals, for the dorsal attachment stainless steel almost invariably gave greater returns — both total and long-term — than nickel wire of the same diameter. Much the same statement is generally true for the preopercular attachment but there are more exceptions.

There was a tendency for the diameter of the stainless steel wire giving the highest percentage total returns to be greater for the preopercular (P) than for the dorsal (D) position. Thus for the $^3/_4$-, $1^1/_4$-, 2- and 3-inch tags the most effective wire diameters were respectively: D. 0.020″, P. 0.025″; D. 0.020—0.025″, P. 0.025—0.032″; D. 0.025—0.032″, P. 0.032″; D. 0.032″, P. 0.032″. For the largest tags the best diameter for the dorsal attachment gradually increased to the same wire size as that for the preopercular, since no stainless steel wire sizes with a greater diameter than 0.032 inches were used. It is possible in any case that with the largest tags the maximum effective size of stainless steel wire may have been reached for both positions. However, for the nickel wire the best returns for the 3-inch tags were from the 0.040-inch diameter wire. Apart from the smallest tag, in which this difference between the most favourable stainless steel wire diameters for the dorsal and preopercular positions gradually disappeared in the years following tagging, the long-term returns showed a similar effect, with the most favourable preopercular returns being from stainless steel wire of a greater diameter than the dorsal returns. For long-term results beyond the tagging year, apart from the smallest tag the most effective wire for the dorsal position was in almost all cases the stainless steel 0.025-inch wire. The nickel wire appeared to have no regular pattern of returns in relation to size of wire and size of tag.

Totals

Table 7 has been made up from the combined totals for the cases (in Table 6) in which stainless steel and nickel wire of the same diameters were used in the same proportions with each tag of the same size. In these totals it will be noted that in each of 12 cases for both the dorsal and the preopercular positions and consequently in all totals of both positions and totals of all wires in every instance, both total and long-term, the stainless steel wire gave greater and often substantially greater returns than nickel wire of the same diameter (0.020, 0.025 and 0.032 inches). The difference in favour of stainless steel wire increased in the long-term results for the 0.020- and 0.025-inch wires but not for the 0.032-inch.

Although in the totals for the 0.020- and the 0.025-inch stainless steel wire the dorsal attachment had the advantage in returns over the preopercular, this advantage is lost for the stainless steel 0.032-inch

Table 7

Summaries (from Table 6) of returns of external tags attached in approximately equal numbers with stainless steel (SS) and nickel (N) wire of the same diameters. (″ = inch. 1 inch = 2.54 cm.)

Tags	Wire diameter inches		No. successfully tagged			% returns 1954—60 (up to and including Nov. 1, 1960)								Total dorsal + preopercular %			
						1954—60		1955—60		1956—60		1957—60		1954	1955	1956	1957
			Dorsal	Preop.	Total	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.	Dorsal	Preop.	—60	—60	—60	—60
Percentage returns of number successfully tagged																	
$^3/_4$″, $1^1/_4$″	SS	0.020	496	494	990	32.7	23.5	27.6	20.4	13.3	11.5	7.3	6.1	28.1	24.0	12.4	6.7
	N	0.020	492	492	984	23.6	21.5	19.7	17.3	9.1	8.1	4.5	4.5	22.6	18.5	8.6	4.5
$^3/_4$″, $1^1/_4$″, 2″, 3″	SS	0.025	730	732	1,462	31.5	29.5	26.6	25.3	16.8	12.8	9.6	6.8	30.5	25.9	14.8	8.2
	N	0.025	733	729	1,462	26.1	28.9	21.8	23.6	10.9	12.3	6.0	6.3	27.5	22.7	11.6	6.2
$1^1/_4$″, 2″, 3″	SS	0.032	437	432	869	33.9	36.8	28.4	32.6	13.7	18.8	5.7	9.0	35.3	30.5	16.2	7.4
	N	0.032	427	438	865	27.6	30.8	22.0	26.0	11.2	14.6	4.9	7.5	29.2	24.0	12.9	6.2
Total	SS	0.020—0.032	1,663	1,658	3,321	32.5	29.6	27.4	25.8	15.0	14.0	7.9	7.2	31.0	26.6	14.5	7.5
	N	0.020—0.032	1,652	1,659	3,311	25.7	27.2	21.2	22.4	10.5	11.7	5.3	6.1	26.5	21.8	11.1	5.7
Percentage returns of total number returned from tagging with stainless steel wire																	
$^3/_4$″, $1^1/_4$″	SS	0.020	496	494	990	100.0	100.0	84.6	87.1	40.7	49.1	22.2	25.9	100.0	85.6	44.2	23.7
	N	0.020	492	492	984	71.6	91.4	59.9	73.3	27.8	34.5	13.6	19.0	79.9	65.5	30.6	15.8
$^3/_4$″, $1^1/_4$″, 2″, 3″	SS	0.025	730	732	1,462	100.0	100.0	84.3	85.6	53.5	43.5	30.4	23.1	100.0	85.0	48.7	26.9
	N	0.025	733	729	1,462	83.0	97.7	69.6	79.6	34.8	41.7	19.1	21.3	90.1	74.4	38.1	20.2
$1^1/_4$″, 2″, 3″	SS	0.032	437	432	869	100.0	100.0	83.8	88.7	40.5	50.9	16.9	24.5	100.0	86.3	45.9	20.8
	N	0.032	427	438	865	79.7	84.9	63.5	71.7	32.4	40.3	14.2	20.8	82.4	67.8	36.5	17.6
Total	SS	0.020—0.032	1,663	1,658	3,321	100.0	100.0	84.3	87.0	46.1	47.3	24.3	24.2	100.0	85.5	46.7	24.2
	N	0.020—0.032	1,652	1,659	3,311	78.7	92.1	65.0	75.6	32.0	39.5	16.1	20.6	85.1	70.0	35.6	18.2
Percentage returns of total number returned from tagging with nickel wire																	
$^3/_4$″ $1^1/_4$″	N	0.020	492	492	984	100.0	100.0	83.6	80.2	38.8	37.7	19.0	20.8	100.0	82.0	38.3	19.8
$^3/_4$″, $1^1/_4$″, 2″, 3″	N	0.025	733	729	1,462	100.0	100.0	83.8	81.5	41.9	42.7	23.0	21.8	100.0	82.6	42.3	22.4
$1^1/_4$″, 2″, 3″	N	0.032	427	438	865	100.0	100.0	79.7	84.4	40.7	47.4	17.8	24.4	100.0	82.2	44.3	21.3
Total	N	0.020—0.032	1,652	1,659	3,311	100.0	100.0	82.6	82.1	40.7	42.9	20.5	22.3	100.0	82.3	41.8	21.4

wire, for which the preopercular position was consistently superior. This is in agreement with the previous observation that the stainless steel wire diameter giving the highest returns was greater for the preopercular than for the dorsal position.

For the smallest tags and the 0.020-inch nickel wire there were more returns from the dorsal than from the preopercular position, but the superiority was not nearly as great as in the case of the 0.020-inch stainless steel.

Whereas with the 0.025-inch stainless steel wire the dorsal position was superior, especially for the long-term results, for the 0.025-inch nickel wire the preopercular position gave the greater returns. For both the stainless steel and nickel 0.032-inch wires the preopercular position gave greater total and especially greater long-term returns than the dorsal. For the 0.020- and 0.025-inch wires and in the overall total of all wires, although the stainless steel wire gave higher returns for both attachment positions, the relative predominance of the stainless steel over the nickel was much greater for the dorsal than for the preopercular position. Indeed for the 0.025-inch diameter the predominance of the stainless steel over the nickel in the preopercular position is barely noticeable in the long-term returns. For the 0.032-inch wires on the other hand the stainless steel maintained approximately the same relative predominance in returns over tbe nickel both for the dorsal and the preopercular positions.

Discussion and Conclusions

Most, if not all, of the experiments in which nickel and stainless steel wires have hitherto been compared extensively in the tagging of marine fishes have been in the Pacific Ocean.

Calhoun, Fry and Hughes (1951), using Petersen disc tags on the striped bass (*Roccus saxatilis* Walbaum), found from aquarium tests of nickel wire 0.036 inches (0.91 mm) in diameter no corrosion after 19 months, but badly corroded nickel tag wires cut from the same coil were returned from striped bass in less than a year. In the same aquarium experiments stainless steel wire 0.032 inches (0.81 mm) in diameter showed no corrosion after 19 months. Similarly Calhoun (1953), in additional aquarium tests with striped bass tagged with Petersen disc tags, found stainless steel wire showing no corrosion after 2 years.

Forrester and Ketchen (1955) used Petersen disc tags on the lemon sole (*Parophrys vetulus* Girard) with 0.032-inch diameter stainless steel wire and with 0.036-inch diameter nickel wire. The stainless steel gave greater but not significantly greater returns than the nickel wire up to 25 months after tagging. This nickel wire, however, was obtained from nickel pins by cutting off the heads and it is possible that the corrosion-favouring effects of the stresses required to make the head (Calhoun, Fry and Hughes, 1951; Forrester and Ketchen, 1955) may to some degree still have been present at the head end of the wire.

Some experiments have been done on the use of nickel and stainless steel pins for fish tagging in the Atlantic area. Merriman (1941) reported for Petersen disc tags on striped bass little or no success using stainless steel insect pins of small diameter, but considerably more success when heavier nickel pins were used. These nickel pins never showed any tendency to corrode in salt water. However, few tags were recovered after the tagging year.

Rounsefell (1942) used nickel pins with Petersen discs to mark haddock in the Gulf of Maine. According to Jensen (1958), when these tags were recovered many of them were corroded.

Jensen (1958) carried out in Woods Hole aquarium tests of nickel and type 304 stainless steel pins to hold Petersen discs on haddock tagged through the operculum. The stainless steel pins proved to be superior in retaining the tags and the nickel pins showed serious corrosion after 2 months. Control experiments on nickel pins in the harbour for the same time showed only minor corrosion.

In the 1954—55 cod-tagging experiments described in this paper the superiority of the stainless steel wire in producing greater returns than the nickel wire is evident. Although the corrosion of these wires has not yet been examined in detail, enough observations have been carried out to determine that while the stainless steel showed no signs of corrosion the nickel wires, although usually showing no severe indications of corrosion after several years, were occasionally corroded so badly that they could be broken and the tag lost. This corrosion of the nickel wire should act more quickly on the smaller wires than on the larger and there was some indication of this for the 0.020-inch diameter nickel wire (Table 7). The losses due to corrosion of the wire, however, would be expected to be more severe with the passage of time and although this was evident for the 0.020- and 0.025-inch nickel wire (Table 7) it was not evident in the 0.032-inch nickel wire compared with stainless steel of the same diameter. Thus since the 0.032-inch nickel wire also gave fewer returns than the stainless steel wire of the same diameter, there is probably a cause other than corrosion which produces fewer returns of tags attached by nickel wires.

Forrester and Ketchen (1955) say that in their tagging of lemon sole off British Columbia the percentage of recaptured fish with the tagging wound in "good" condition, with no sign of abrasion or erosion of flesh under the Petersen discs, was highest with stainless steel wire. The highest percentage of "poor" wounds (large, raw or deeply eroded) occurred with the nickel. (Silver wire was also used.) In our tagging only a few of the recaptured cod were returned to the Biological Station. In the fish tagged with nickel wires there was generally a darkening of the flesh around the wound, and sometimes moderately severe wounds, but at other times relatively good healing. The wounding due to the effect of metal corrosion should be greatest with the nickel wires of greatest diameter, and flesh injuries would be much more effective in releasing wires from the dorsal than from the preopercular position. Flesh injury with consequent loss of tags is, therefore, probably a factor in the relatively more favourable returns from the preopercular compared with the dorsal position for nickel than for stainless steel wire of the two smaller diameters, and in the gradual increase in the preopercular returns with respect to the dorsal returns with increase in size of the nickel wire (Table 7). However, the largest size (0.032-inch) stainless steel wire also shows a considerable predominance of preopercular returns, and there must be some comparable wounding or other releasing effect from the dorsal position in this case. If the larger stainless steel wire produces unfavourable flesh wounds or other releasing effects, this would partly explain the tendency of the diameter of the stainless steel wire giving the highest returns to be greater for the preopercular than for the dorsal position.

The increasing stainless steel wire sizes giving greater returns with increase in size of tag is presumably due to the drag on the wire increasing with increase in size of tag and to the probability that a fine wire would pull out more quickly than a thicker one. There must, however, be some long-term unfavourable effects for large wires, since the stainless steel wire of intermediate diameter (0.025-inch) gave better long-term returns than the 0.032-inch wire (Table 6).

Summary

In 1954—55 about 19,000 cod (*Gadus morhua* L.) were tagged in 13 Newfoundland and Labrador inshore and offshore areas. Although in overall returns all the tagging is discussed, in the comparisons between the returns from different kinds of tags and methods of attachment the paper is concerned with 10 tagging experiments carried out in 1954 in which the same varieties of tags, methods of attachment and numbers of tags of each variety were used in each experiment.

Four sizes of internal (body-cavity) tags were used: 2-, 3-, 4- and 5-inch (51-, 76-, 102- and 127-mm) bright orange vinylite. The following external tags were used: $^3/_4$-inch (20-mm) red, orange and yellow vinylite; $1^1/_4$-inch (33-mm) orange and yellow vinylite; 2-inch (51-mm) cerise red cellulose nitrate; 2- and 3-inch (51- and 76-mm) bright orange vinylite; and Lea hydrostatic tags. The external tags were attached either by stainless steel wire with a diameter of 0.015, 0.020, 0.025 or 0.032 inches (0.38, 0.51, 0.64 or 0.81 mm) or by nickel wire with a diameter of 0.020, 0.025, 0.032 or 0.040 inches (0.51, 0.64, 0.81 or 1.02 mm) and also, in the case of some hydrostatic tags, by the Lea attachment. External tags were attached in front of the first dorsal or around the preopercular bone either by a loop or by a single wire with a button of cellulose acetate, 8, 10 or 13 mm in diameter, at one end.

Returns from the inshore and close-to-shore tagging in the period under review, between 1954 and November 1, 1960, ranged from a return of 33.5% for cod tagged at Fermeuse to 17.3% for Bonavista. Returns were lowest, 12.4—16.8% (average 15.3%), from the tagging on the Virgin Rocks and the Southeast Shoal of the Grand Bank. The average overall returns, apart from the Grand Bank tagging, were 25.9%. Individual tags and methods of attachment, however, gave much higher returns. In the totals of the 1954 tagging the 2- and 3-inch (51- and 76-mm) external tags with 0.032-inch (0.81-mm) stainless steel wire gave 38% returns and the 2-inch (51-mm) tag with 0.025-inch (0.64-mm) stainless steel wire, for the dorsal position, 41%.

The most successful tags were the 2-inch (51-mm) orange external and the hydrostatic with loop or button attachment (34.3% returns), the 3-inch (76-mm) orange external (32.8%) and the hydrostatic tag with Lea's attachment (32.6%).

For the internal tags the 4-inch (102-mm) tag was the most successful (24.0% returns) and the 2-inch (51-mm) tag the least successful (15.4%).

The orange external tags gave slightly more returns than the yellow and the red tags of the same size.

External tags gave slightly greater combined total returns from the dorsal (29.7%) than from the preopercular position (28.3%).

Stainless steel wire gave more returns than nickel wire of the same diameter. The diameter of the stainless steel wire giving the greatest tag returns increased with increase in tag size, and was usually smaller for the dorsal than for the preopercular position. For the stainless steel wire the dorsal attachment gave more returns for the 0.020- and 0.025-inch (0.51- and 0.64-mm) diameter wire, whereas for the 0.032-inch (0.81-mm) wire the preopercular position was consistently superior. For the 0.020- and 0.025-inch (0.51- and 0.64-mm) wires the preopercular position was more favourable, compared with the dorsal, for nickel wire than for stainless steel wire of the same diameters. For the 0.032-inch (0.81-mm) wires the stainless steel maintained approximately the same relative predominance in

returns over the nickel both for the dorsal and the preopercular positions.

The best button attachment was 10 mm in diameter. For the smaller tags ($^3/_4$ and $1^1/_4$ inch, 20 and 33 mm) the loop attachment was superior to the button attachment, whereas for the larger tags the best button attachment gave greater percentage returns than the loop attachment (34.8 compared with 32.9 for the 2-inch, 51-mm, tag and 34.9 compared with 32.1 for the 3-inch, 76-mm, tag).

Acknowledgements

The author is very grateful to the following people who assisted in the tagging investigation: Mr. C. I. Barbour, Mr. M. V. Hodder, Mr. A. M. Fleming, Miss Eleanor M. Squires and Miss Dolores A. Bursey.

References

CALHOUN, A. J. 1953. Aquarium tests of tags on striped bass. *Calif. Fish Game*, **39**: 209—18.

CALHOUN, A. J., D. H. FRY Jr. & E. P. HUGHES. 1951. Plastic deterioriation and metal corrosion in Petersen disk fisb tags. *Calif. Fish Game*, **37**: 301—14.

FLEMING, A. M. 1959. The longline fishery at Bonavista, Newfoundland, 1952—1958. ICNAF Annu. Meeting, June 1959, Doc. No. 30, Ser. No. 629 (mimeo).

FORRESTER, C. R. and K. S. KETCHEN. 1955. The resistance to salt water corrosion of various types of metal wire used in the tagging of flatfish. *J. Fish. Res. Bd Can.*, **12**: 134—42.

JENSEN, ALBERT C. 1958. Corrosion resistance of fish tagging pins. *U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish.*, No. 262.

MERRIMAN, DANIEL. 1941. Studies on the striped bass (*Roccus saxatilis*) of the Atlantic coast. *Fish. Bull. U.S.*, **50** (35): 1—77.

POULSEN, ERIK M. 1957. Defects in the recovering of tagged fish. ICNAF Annu. Meeting, May 1957, Doc. No. 4, Ser. No. 439 (mimeo.).

ROUNSEFELL, GEORGE A. 1942. Field experiments in selecting the most efficient tag for use in haddock studies. *Trans. Amer. Fish. Soc.*, **71**: 228—35.

TEMPLEMAN, W. 1959. Canadian Research Report, 1958, Subareas 2 and 3. *ICNAF Annu. Proc.*, **9**: 20—26.

TEMPLEMAN, WILFRED, and A. M. FLEMING. 1962. Cod tagging in the Newfoundland area during 1947 and 1948. *J. Fish Res. Bd Can.*, **19**: 445—87.

TEMPLEMAN, WILFRED, and T. K. PITT. 1962. Comparison of returns of different tags and from differences in tagging methods for cod tagged in the inshore area, St. John's and Fogo, Newfoundland, 1950. (*This Symposium, contr. No.* 47).

46.

Tags and Tagging Techniques for Large Pelagic Fishes

By

FRANK J. MATHER III*

Experiments in marking tunas and other large pelagic species have been in progress at the Woods Hole Oceanographic Institution since 1951, as part of a general study of the biology of these fishes. Small scale markings of large bluefin tuna, *Thunnus thynnus*, by numbering hooks used by sport fishermen in 1951 and 1952, and of very small ones with opercular strap tags in 1953, yielded no returns. Type G dorsal loop tags (Wilson, 1953) were used experimentally in New England waters in 1954 by the author and a few co-operating sport fishermen. We found that bluefin tuna weighing up to about 60 pounds, which had been caught by trolling, could be lifted into a trough, marked, and returned to the water in less than 45 seconds. A tail strap was used to aid in lifting the larger individuals. Nearly all the fish appeared to be in good condition when released, swimming away at high speed. Two reports, including one return, were soon obtained, indicating that at least some of the 54 fish released in July had survived.

While this satisfied us that the dorsal loop tag was practical for use on small bluefin tuna, we felt that a more versatile, simpler, and quicker marking method was needed. In the first place, it was obviously desirable to mark large bluefin tuna, which could not be taken aboard the boat, as well as small ones. Also, lacking the resources to tag fish in sufficient numbers ourselves, we hoped to enlist the co-operation of sport fishermen in marking some of their catches. These men could not be expected to contribute the time and effort required by the dorsal loop method.

Figure 1. Woods Hole Oceanographic Institution type A dart tag with applicator.

Therefore, in the spring of 1954 the author designed the first dart and streamer tag (Figure 1), designated type A. Tags of this general type are referred to as "dart tags" hereafter, as this term is now widely used. A 7 inch plastic streamer, essentially the same as the type G dorsal loop tag, was fastened into the middle of a stainless steel dart about $1^1/_2$ inches long and $^3/_{16}$ of an inch in diameter. In addition to the usual message and serial number on the streamer, the number was also stamped on the dart. This miniature harpoon was set on a stainless steel applicator extending about 2 inches from the end of a wooden pole, to which a rubber band held the streamer (Figure 2). We found that with the boat moving slowly ahead, and the man holding the leader somewhat forward of the tagger, the fish would usually be brought into a position favorable for tagging. The tagger then drove the dart into its flesh (Figure 3), endeavoring to avoid the head, viscera and spinal column. If possible, the dart was driven in at an angle toward the anterior

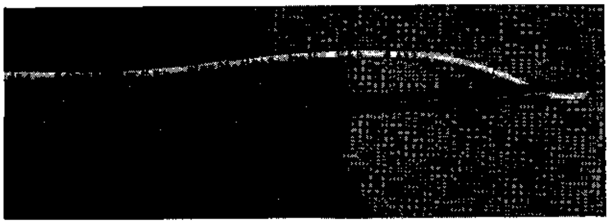


Figure 2. Woods Hole Oceanographic Institution type A dart tag on applicator.

Figure 3. Marking a medium-sized bluefin tuna caught by long line from R/V CRAWFORD with a dart tag.

---

* Woods Hole Oceanographic Institution, Woods Hole, Massachusetts U.S.A. (Contribution No. 1220). Work supported by grants from the National Science Foundation.

portion of the fish so the streamer could lie back alongside the fish as it moved forward. After tagging fish were released by cutting the leader close to the hook. With all types of dart tags, it is most important that the darts and streamers fit loosely on the applicators and handles. Otherwise, they may be partially or completely retracted from the fish when the applicator is withdrawn. As it is not necessary to handle the fish or remove it from the water, giant bluefin tuna and other large fishes can be marked by this method. Smaller tuna, white marlin, *Makaira albida*, and Atlantic sailfish, *Istiophorus albicans*, could also be tagged much more rapidly and easily than with other devices.

Although returns were not immediately forthcoming, field trials and holding experiments with captive fish convinced us of the practicality of the dart tag. The initial model, however, was very expensive (about $ 1.25 each) and we also felt that its dart was so large that it might injure the smaller fishes we wished to mark.

The type B dart tag (Figure 4), made up of mass produced components and with a smaller head, was designed to reduce these limitations. The dart, stamped from stainless steel about 0.023 inches thick, was $^3/_4$-inch long by $^1/_4$-inch wide. Unfortunately, we have found no economical method of numbering the darts. A $4^1/_2$-inch tape, imprinted with message and serial number, was drawn into a 6-inch length of $^1/_8$-inch diameter clear plastic tubing, the ends of which were then heat sealed. The streamer thus formed was clamped to a dart by squeezing a lug provided for this purpose onto its end. The dart was set on the slotted end of the stainless steel applicator, which projected about $1^1/_2$-inches from the end of the pole, and was held on loosely by placing the streamer in a groove in the wood (Figure 5). These tags cost about 11 cents each, and could be set in most of the oceanic game fishes ordinarily caught on hook and line, with little risk of injuring them.

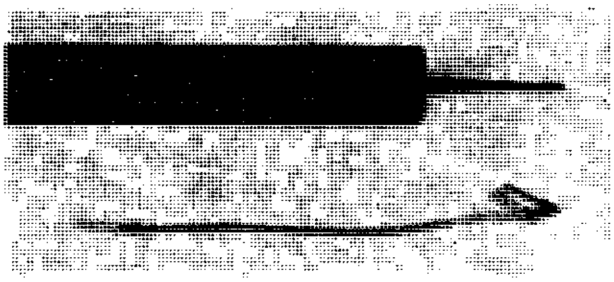


Figure 4. Woods Hole Oceanographic Institution type B dart tag with applicator.

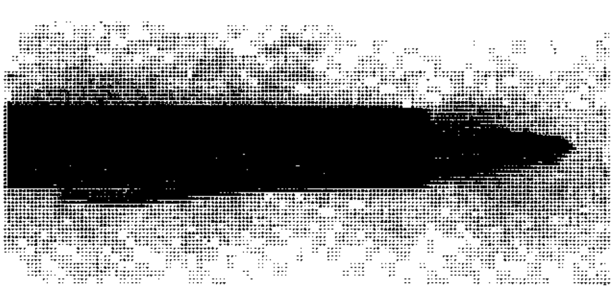


Figure 5. Woods Hole Oceanographic Institution type B dart tag on applicator.

Since the neutral color of the B tag was inconspicuous, we began in 1958 to replace it with our C tag, made up of the same darts with yellow plastic streamers on which the message and number were printed directly. These showed up well in contrast to the dark dorsal surfaces of the fish, and subsequent experiments (Broadhead, 1958) indicated that this color was a good choice. Some of these streamers were coated with liquid plastic to protect the lettering. We received some reports of darts without streamers being found in fish being skinned for mounting. Although we were unable to verify these, we made up several hundred C tags with heavy nylon monofilament glued into the streamers and clamped to the darts to give greater mechanical strength at the connection. This proved to be a mistake, however, as one tag of this construction came apart through failure of the glue when the fish was recaptured after $8^1/_2$ months at large, and in others recovered after shorter periods the monofilament had partially pulled out of the tubing. One dart with the monofilament but no streamer was recovered from a fish which we could determine by elimination had been tagged about 16 months previously. We have therefore reverted to clamping the streamers directly to the dart. As these streamers are more expensive than the B type, partly because legends in other languages were added and the serial number was put on twice, these tags cost about 23 cents each, despite a saving in assembly time.

Higher recovery rates have been obtained with plastic-headed dart tags used in the Pacific (Yamashita and Waldron, 1958) and in the eastern Atlantic (Hamre, 1959) than we have attained with our steel-headed darts. Therefore in 1959 we began using FT-1 nylon-headed dart tags (Figure 6) of the Floy Tag and Manufacturing Co., Seattle, Washington as our D series, along with the C tags. Pacific workers usually confine their tagging to small tunas which are brought aboard the vessel by the live-bait fishing method, and considerable difficulty was experienced in adapting the applicators for these tags to our technique of marking fish in the water. The arrangement shown in Figure 6 was fairly satisfactory. As these tubular applicators often become clogged with fish material, a piece of brass rod is furnished to clean them out.

The author collaborated in the design of the FM-60 tag (Figure 7) of the Floy Tag and Manu-

Figure 6. Floy Tag and Manufacturing Company F T — 1 (Woods Hole Oceanographic Institution series D) dart tag, shown separately and in applicator as used by Woods Hole Oceanographic Institution.

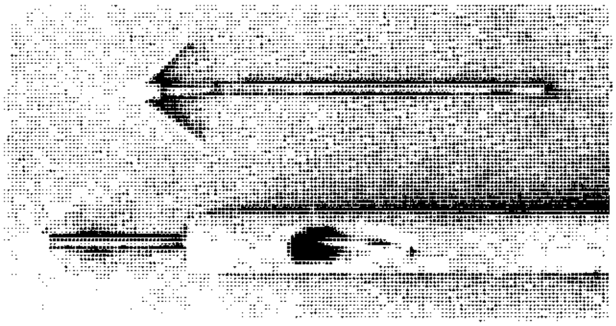


Figure 7. Floy Tag and Manufacturing Company FM — 60 (Woods Hole Oceanographic Institution series E) dart tag, shown separately and in applicator as used by Woods Hole Oceanographic Institution.

facturing Company, which we have used in limited numbers since May, 1960, as our series E. Developed especially for marking large (over 150 pound) fish, these have a large double-barbed nylon dart and a thicker streamer than the earlier dart tags. In some, the message was printed on red plastic and inserted in clear tubing.

From 1 May 1954 through 31 December 1960 3686 fish of 25 species or groups were released, and 22 returns were obtained by 15 April 1961 (Table 1). The returns of interest to our studies include those for bluefin tuna, Atlantic sailfish, white marlin, and greater amberjack, *Seriola dumerili.* Since the return rate for greater amberjack is an order of magnitude higher

Table 1

Releases from 1 May 1954, through 31 December 1960, by years and species (several species which have been released in insignificant numbers are listed as "other fishes"). Returns through 15 April 1961 are shown in numbers and in percent of releases for each category

Species	Releases								Returns	
	1954	1955	1956	1957	1958	1959	1960	Totals	No.	%
Atlantic sailfish	27	16		24	26	109	820	1,022	8	0.8
White marlin	4	144	405	143	40	192	106	1,034	2	0.3
Bluefin tuna	190	231	110	37	38	148	232	986	5	0.5
Greater amberjack						8	30	38	5	13.5
Yellowfin tuna*.................			105	1		1	50	157	0	0.
Pacific sailfish**	3	9		35	8	124	104	283	0	0.
Other fishes	0	12	29	30	13	29	53	166	2***	1.2
Totals	224	412	649	270	125	611	1395	3686	22	0.6

* *Thunnus albacares.*

** *Istiophorus greyi.*

*** One return from 9 releases of striped bass, *Roccus saxatalis*, and 1 return from 1 release of summer flounder *Paralichthys dentatus.*

Table 2

Releases of Atlantic sailfish, white marlin, and bluefin tuna from 1 May 1954, through 31 December 1960, by type of tag, with returns through 15 April 1961, in numbers and in percent of releases

Type of tag	Atlantic sailfish			White marlin			Bluefin tuna			Totals		
	Releases	Returns		Releases	Returns		Releases	Returns		Releases	Returns	
		No.	%		No.	%		No.	%		No.	%
G							155	3	1.9	155	3	1.9
A	42	1	2.4	7	0	0	57	0	0	106	1	0.9
B	150	3	2.0	809	2	0.3	396	1	0.3	1,355	6	0.4
C	376	3	0.8	154	0	0	82	0	0	612	3	0.5
D	454	1	0.2	64	0	0	174	1	0.6	692	2	0.3
E							122	0	0	122	0	0
Totals	1,022	8	0.8	1,034	2	0.3	986	5	0.5	3,042	15	0.5

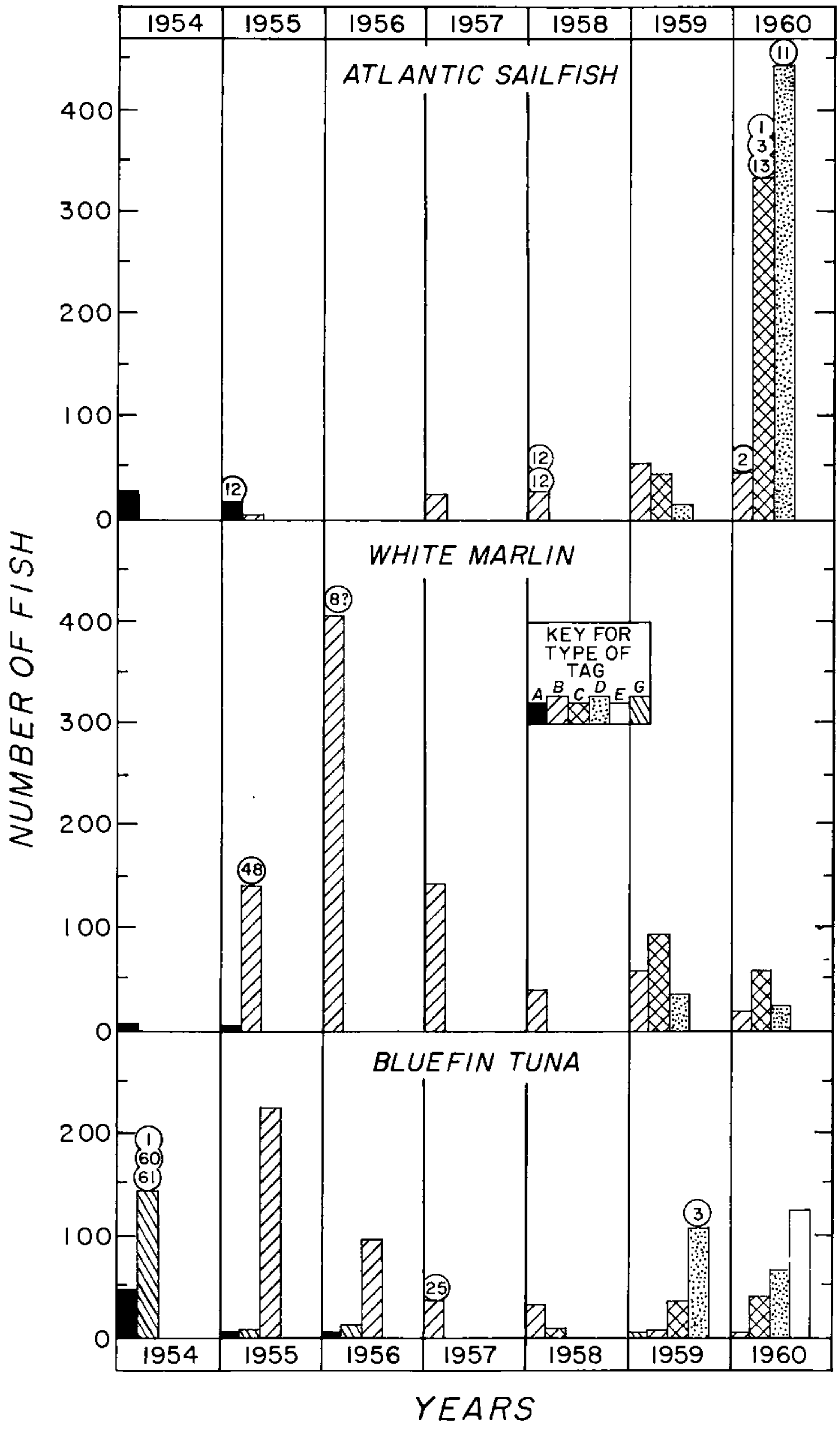


Figure 8. Releases of Atlantic sailfish, white marlin, and bluefin tuna, from 1 May 1954, to 31 December 1960, by types of tag and years. Circled numbers indicate the months at large for each return obtained up to 15 April 1961, from the releases represented below them.

than those for the 3 more truly pelagic species, only the latter will be considered in comparing the performance of the respective types of tags. The high return rate for the greater amberjack, however, shows good possibilities for comparative tests of marking devices for moderately large fish.

The number of releases and returns for each type of tag are listed for Atlantic sailfish, white marlin, and bluefin tuna respectively, in Table 2. A further breakdown, showing the releases for each of these species by type of tag and year, is shown in Figure 8, along with the time at large for each resulting return. The overall return rates for the respective species varied from 0.3% for white marlin to 0.8% for Atlantic sailfish, while those for the types of tags, excepting type E, which has been in use only recently and in small numbers, varied from 0.3% for type D to 1.9% for type G. The A, B, and G tags which were applied in the earlier years have had a somewhat greater chance of being recovered than those used more recently, but in the absence of sufficient statistics on size composition of landings and also of reliable age data for some of the species, this factor cannot be evaluated numerically. Likewise, the relationship of returns to recoveries and recaptures is uncertain. Despite extensive distribution of posters offering a reward of $ 5.00 for returned tags, as well as numerous press releases and some radio and television publicity, most of the returns apparently resulted from the messages on the tags themselves, or from the good offices of other research organizations.

Two of the 5 returns for bluefin tuna resulted from recoveries in canneries, and one of these fish was handled at least 6 times before the tag was recognized. Research workers who fortuitously happened upon fishermen or cannery workers in possession of these 2 marks and one of the others brought about their return. Thus it appears that the efficiency of recovery for this species is poor. That of return probably is also, although we have had only one seemingly reliable report of a recovery which did not result in a return. The low return rate may be due in part to the very small and dispersed commercial fishing effort for tunas in the western North Atlantic. Sailfish and marlin are not utilized commercially in the United States, but they are caught in some numbers by sport fishermen and many of them are mounted. We have received no complete tags from the taxidermists, but have had some as yet unverified reports, as mentioned above, of darts without streamers being found by skinners. One sailfish return was not completed until about 3 years after the recovery and report. There is little indication that recaptures of these fish, when they are actually landed, do not usually result in recoveries. The widespread practice of releasing these species, however, probably reduces the number of recoveries considerably. Releasing of big game fish usually occurs under circumstances of excitement and some confusion, and the leader is often cut or the hook pulled out while the fish is at a considerable distance from the boat. Therefore, it is very probable that many recaptured sailfish and marlin are re-released, with no recovery resulting.

Conclusions

While the dorsal loop tag has produced a distinctly better return rate for bluefin tuna than the dart tags, the latter have furnished useful information on this species and also on istiophorids and amberjack. Returns have been obtained after 5 years at large and about 3000 miles of net travel with 2 type G dorsal loop tags, and after 4 years at large with a type B dart tag (Mather, 1960). The chief advantages of the dart tags are their versatility, which permits the tagging of fish too large to mark by other methods, and the speed with which tagging can be accomplished. The nylon darts have shown no advantage over the stainless steel ones. The former have frequently been broken or jammed in the applicators, while the latter have been quite trouble-free in operation. From detailed descriptions of the condition of skin and flesh around tags in recaptured fish, and examination of a frozen sample (Figure 9), we can find no evidence that the stainless steel causes any unfavorable reaction. It seems likely that the higher return rates obtained from tunas with nylon darts in the Pacific and the eastern Atlantic are due mainly to the much more intensive and more centralized tuna fisheries of those regions. Also, the marking in those areas was done by trained biologists, and the Pacific practice of tagging fish aboard the vessel permits much more accurate and careful placing of tags than our method

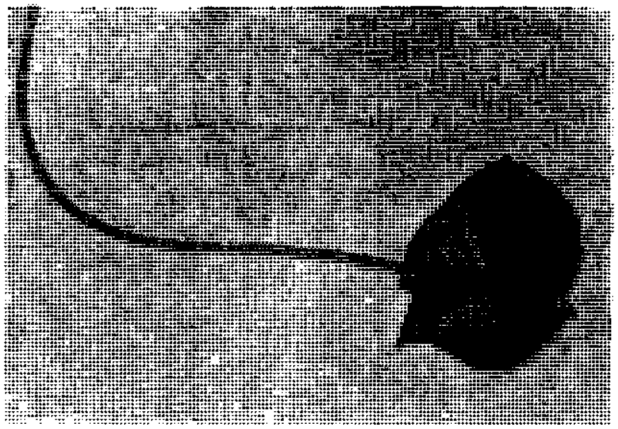


Figure 9. Type C dart tag excised with surrounding flesh and skin from an Atlantic sailfish recaptured after 31 days at large.

of tagging them in the water. Another possibility is that fish caught by the live bait and the purse seine methods may by released in better condition than those caught by rod and reel and by long line.

Acknowledgements

I am indebted to a great many organizations and individuals for making this program possible. It has been financed chiefly by the National Science Foundation, with supplementary assistance from the Associates of the Woods Hole Oceanographic Institution, the Charles W. Brown Jr. Memorial Foundation, and donations from several clubs and individuals. Most of the marking, especially for istiophorids and amberjack, has been accomplished through the co-operation of several hundred sport fishermen, including anglers and captains and mates of sport fishing boats, and many of their organizations. Many additional releases, especially of tunas, have resulted from co-operation with the U.S. Fish and Wildlife Service. Returns which might otherwise have never reached us were secured by scientists of the U. S. Fish and Wildlife Service, the Institut Scientifique et Technique des Pêches Maritimes, Paris, and the Marine Laboratory of the University of Miami, Florida. Holding experiments with tagged fish were conducted at the Lerner Marine Laboratory, Bimini, and the Woods Hole, Massachusetts, laboratory of the U. S. Fish and Wildlife Service. I am most sincerely grateful to all of these individuals and organizations and to the many others who have assisted in this co-operative program.

References

BROADHEAD, GORDON C. 1958. Techniques used in the tagging of yellowfin and skipjack tunas in the Eastern tropical Pacific Ocean during 1955—1957. *Proc. Gulf Caribb. Fish. Inst.*, 11th Ann. Sess.: 91—97.

HAMRE, JOHANNES. 1959. The tuna tagging experiments in Norwegian waters. *I CES Scombriform Fish Committee*, No. 92,: 5 p. (Mimeo).

MATHER, FRANK J., III. 1960. Recaptures of tuna, marlin and sailfish tagged in the western North Atlantic. *Copeia* (2): 149—151.

WILSON, ROBERT C. 1953. Tuna marking, a progress report. *Calif. Fish Game* **39** (4): 429—442.

YAMASHITA, DANIEL T. and KENNETH D. WALDRON. 1958. An all-plastic dart type fish tag. *Calif. Fish Game* **44** (4): 311—317.

47.

Comparision of Returns from Different Tags and Tagging Methods for Cod Tagged in the Inshore Area, St. John's and Fogo, Newfoundland, 1950

By

WILFRED TEMPLEMAN and T. K. PITT*

Introduction

In 1950, over 4,000 cod (*Gadus morhua* L.) were tagged near Fogo, Aug. 2—10, in 13.5—17 fathoms (25—31 m), and near St. John's, Aug. 25-Sept. 29, in 20—40 fathoms (37—73 m). These areas are both in the inshore fishing area of the east coast of Newfoundland and from 0.5 to 1 mile (0.8—1.6 km) offshore. At St. John's the cod were caught in flying sets by linetrawl (longline hauled by hand from a small boat) and at Fogo by linetrawl and bottom gillnet, both set overnight. In the Fogo tagging the cod tagged from linetrawl gave considerably higher returns than those tagged from approximately the same depths from gillnet. Apart from the 2-inch red preopercular tag which was used at St. John's only, the remaining tags were used in both areas and showed approximately the same total percentage returns from the tagging of linetrawled cod in both areas. Consequently for purposes of Table 1 the returns from St. John's area have been combined with those from linetrawled cod, only, from the Fogo tagging. The returns from the gillnet tagging are, however, included in the special experiments discussed under "Additional notes on returns". Only cod 50 cm and over in fork length were tagged. Tagged cod which floated away, unable to swim downward, were not included as successfully tagged fish and were not used for this paper regardless of whether the tags were later returned or not.

Tags and Methods

In these tagging experiments the following tags were compared (Fig. 1): a small bright-pink, flat tag (smolt tag) of laminated cellulose nitrate, $^{25}/_{32}$ inches (20 mm) long, $^{3}/_{16}$ inches (4.8 mm) wide and 0.025 inches (0.6 mm) thick, designed for tagging salmon smolts, and attached, with 0.020-inch (0.4-mm) diameter nickel wire, either through the flesh below the anterior base of the first dorsal fin (dorsal), around the left preopercular bone (preopercular) or around the left maxilla (maxillary); an opercular tag (opercular button) of the bachelor-button type used by Thompson (1943) and consisting of 2 circular concave discs — a bright red disc of laminated cellulose nitrate, 0.7 mm thick and 15.5 mm diameter which was attached by special pliers to the hollow shaft of an aluminium disc 15.7 mm in diameter and 0.5 mm thick. The shaft was 3.0 mm long to the shoulder and the distance between the outer edges of the concave discs was 7 mm. (The tag was applied through the left opercular bone. For further details regarding this tag see Rounsefell and Kask, 1945); a cerise-red flat tag of laminated cellulose nitrate, 2 inches (51 mm) long, $^{3}/_{8}$ inches (9.5 mm) wide and 0.035 inches (0.9 mm) thick, attached either by 0.032-inch (0.8-mm) diameter nickel wire around the left preopercular bone or inserted into the body cavity; and bright-orange, flat tags of laminated vinylite, 2, 3, 4 and 5 inches (51, 76, 102 and 127 mm) long, $^{3}/_{8}$ inches (9.5 mm) wide and 0.035 inches (0.9 mm) thick, used as internal (body-cavity) tags. Tags of each variety were attached individually in rotation to groups of 10 cod.

Rounsefell and Kask (1945) say that the opercular-button tag (bachelor-button tag no. 16) was devised by William C. Herrington for use on haddock. The tag was first used for tagging haddock in the Gulf of Maine in 1932—33 (Rounsefell, 1942) after preliminary live car tests on haddock during 1930—32. This tagging in 1932—33 was of otter-trawled haddock and was unsuccessful. Rounsefell (1942) used the bachelor-button tag for haddock in the Gulf of Maine and found little difference between the returns for this tag and for the Petersen disc in the 1938 tagging, but returns somewhat below those for the Petersen disc in tagging during 1939. In Rounsefell's and presumably the earlier American use of this tag the aluminum half was placed outside the operculum rather than the celluloid half as in our experiments. Thompson (1943) also used the red celluloid disc on the outside, but probably inserted the tag through the subopercular bone.

Rounsefell and Kask (1945) say that the body-cavity tag was tried by Schroeder on cod in Maine in 1931 and 1932 with a return of 21.4%. Also in the United States report to the North American Council on Fishery Investigations (1939) it is stated that a comparison of disc- and belly-tagged cod showed that second- and third-year returns of belly (internal) tags were markedly superior to those from the external disc tags, but returns from both types were low after the first year.

---

* Fisheries Research Board of Canada, Biological Station, St. John's, Nfld., Canada,

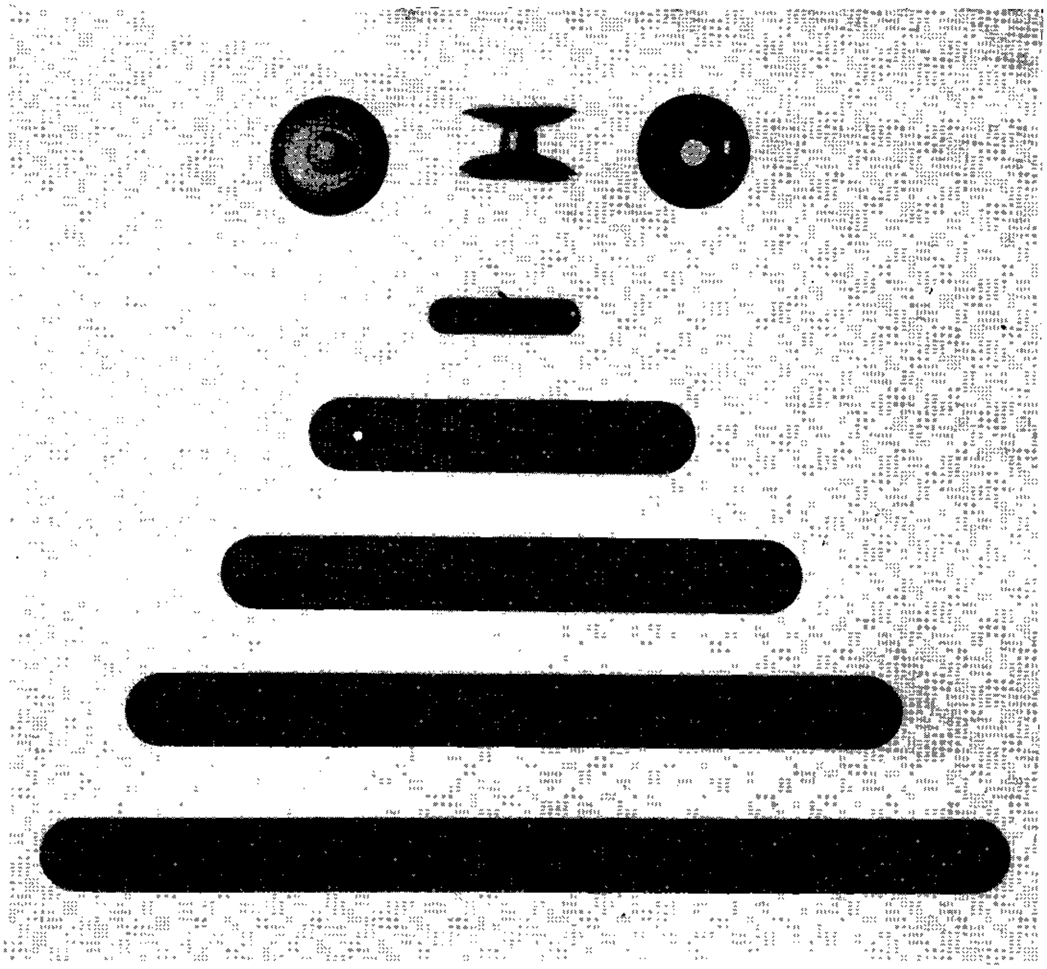


Figure 1. Bachelor-button opercular tag, smolt tag, and 2-, 3-, 4- and 5-inch tags used in the cod tagging experiments. (Tags approximately natural size.)

Complete instructions for the return of the tag, the address of the Biological Station and the information that a one dollar reward would be paid were printed on each tag. On the return of the tag information on the date and place where the fish was originally tagged was sent to the fisherman who caught it.

Some of the tags used and their positions of attachment or insertion are shown in Figs. 2 and 3. The slit in the abdominal wall for the internal tag was made lengthwise instead of vertically as the wound heals better with a longitudinal slit. For the external tags attached by wire the original hole was made by a hypodermic needle (curved for the preopercular insertion). The end of the wire was inserted in the hypodermic and the hypodermic and wire withdrawn through the hole. For additional details regarding methods of attachment and insertion the reader is referred to Templeman and Fleming (1962).

Returns

The information on numbers tagged with various tags and percentages recaptured and returned is shown in Table 1.

Tags giving highest returns

The best tag was the 2-inch red preopercular and the second best tags the 5-inch orange internal and the smolt dorsal. The smolt preopercular, the 3-inch orange internal and the 4-inch orange internal also gave good returns. By far the best long-term tag was the 2-inch red preopercular, but only 109 cod were tagged with this tag.

The probabilities (P) in the following account are from chi-square tests, using 2 × 2 tables under the hypothesis that returns are independent of the type of tag, and with Yates' adjustment for continuity.

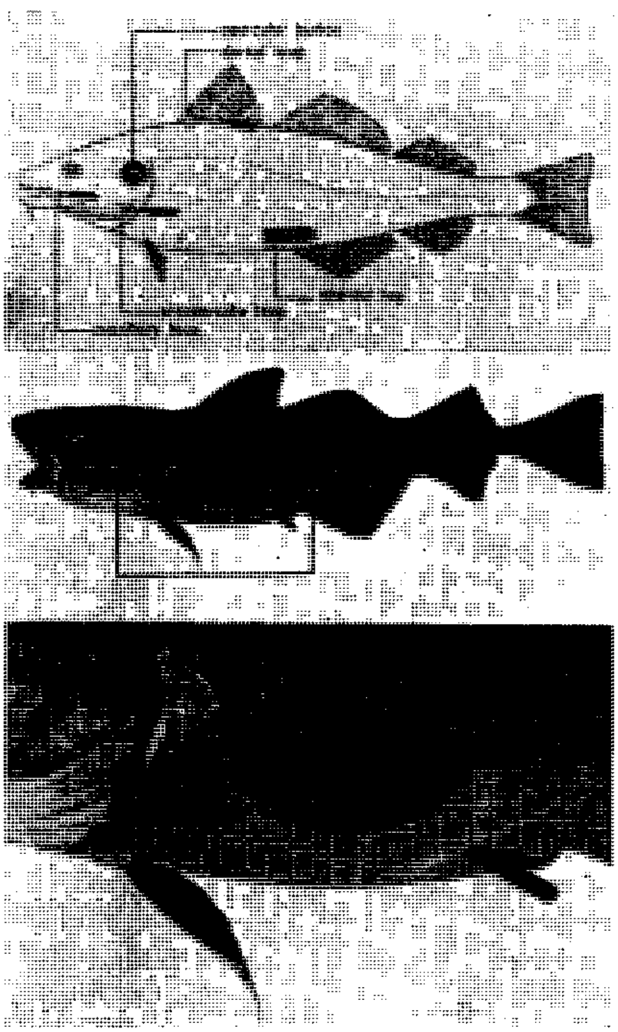


Figure 2. Positions of tag attachment or insertion. (The slit for the internal tag was longitudinal as in the photographs, not vertical as in the diagram.)

Figure 3. Left side of cod's head showing loop attachments around maxillary and preopercular bones and bachelor-button tag attached through opercular bone.

The returns of the 2-inch red preopercular (47.7%) were, however, not significantly different from the 37.2% returns of the smolt dorsal, P = 0.10—0.20; but the difference in the returns of the 2-inch red preopercular and those of the 5-inch internal (38.0%) was closer to significance, P = 0.10—0.05. The difference between the returns of 2-inch red preopercular and of the $^{25}/_{32}$-inch smolt preopercular (33.6%) was significant, P = 0.05—0.02. The returns of the 2-inch red preopercular were highly significantly different from those of the 2-, 3- and 4-inch internal tags. For even the least different, the 3-inch internal (32.8% returns) and the 2-inch preopercular, P = 0.01—0.001.

Smolt tags in various attachment positions

For the $^{25}/_{32}$-inch (smolt) tags the dorsal position was best (37.2% returns), the preopercular only slightly inferior (33.6% returns) and the maxillary position worst (28.9% returns).

These differences can be reasonably explained but are not statistically significant. For the most extreme difference — dorsal and maxillary positions — P = 0.20—0.10. Recoveries after the tagging year — 29% for the dorsal and 18.3% for the maxillary position — are significantly different, P = 0.05.

It is possible that the preopercular position may be best for returns after the first 4 to 5 years, but the numbers are too few for certainty. The preopercular position should offer the firmest attachment, but like the maxillary has doubtless suffered some observation losses from its position on the left side of the head and the immediate discard of the head into the sea when the fish are gutted and headed preliminary to salting.

Internal body-cavity tags

Returns of 2-inch red and 2-inch orange internal tags were very similar (25.6 and 25.8% respectively) and returns of 3-, 4- and 5-inch tags were higher (32.8, 31.0 and 38.0% respectively). The 5-inch tag may lose its superiority after the first few years.

The only 2-inch internal tag which may be compared without reservation with the 3-, 4- and 5-inch internal tags is the 2-inch orange tag inserted anteriorly. (See later discussion) The returns from this tag (29.3%) are significantly lower than those from the 5-inch tag (38.0%), P = 0.02, but not significantly different from those of the 3-inch orange internal (32.8%), P = 0.40—0.30, and similarly, not significantly different from those of 4-inch orange internal.

Since the differences between anterior and posterior insertions (see later discussion) and between returns of red and orange 2-inch internal tags are not significant, the total returns of the 2-inch red + orange internal

Table 1

Percentage returns from St. John's and Fogo cod tagging 1950 (linetrawled cod only)

Type of tag	Cod successfully tagged	Percentage returns of tagged cod											Total 1950 — 1960	Total 1951 — 1960	Total 1952 — 1960	Total 1953 — 1960	Total 1954 — 1960
		1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960					
	no.	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
$^{25}/_{32}$-inch bright pink smolt-dorsal	145	8.3	17.9	5.5	2.8	2.1	0.7	—	—	—	—	—	37.2	29.0	11.0	5.5	2.8
$^{25}/_{32}$-inch bright pink smolt-preopercular	146	10.3	12.3	4.1	2.1	1.4	0.7	2.1	0.7	—	—	—	33.6	23.3	11.0	6.8	4.8
$^{25}/_{32}$-inch bright pink smolt-maxillary	142	10.6	10.6	2.8	3.5	0.7	0.7	—	—	—	—	—	28.9	18.3	7.7	4.9	1.4
2-inch red preopercular	109	7.3	18.3	11.0	4.6	2.8	2.8	0.9	—	—	—	—	47.7	40.4	22.0	11.0	6.4
Opercular button	738	6.2	4.6	0.8	0.3	0.5	0.3	—	—	—	0.1	0.1	13.0	6.8	2.2	1.4	1.1
2-inch red internal-ant.	277	7.2	10.1	3.2	2.2	1.8	0.4	0.7	—	0.4	—	—	26.0	18.8	8.7	5.4	3.2
2-inch red internal-post.	263	5.7	10.6	3.0	2.3	1.1	1.1	0.4	0.8	—	—	—	25.1	19.4	8.7	5.7	3.4
2-inch orange internal-ant.	259	7.3	13.9	3.9	0.8	2.3	—	0.4	0.4	0.4	—	—	29.3	22.0	8.1	4.2	3.5
2-inch orange internal-post	261	4.6	10.7	3.8	1.1	0.8	0.8	—	0.4	—	—	—	22.2	17.6	6.9	3.1	1.9
3-inch orange internal	551	7.4	13.1	6.2	2.7	1.5	0.5	0.9	0.2	—	0.4	—	32.8	25.4	12.3	6.2	3.4
4-inch orange internal	532	7.5	13.0	4.1	2.4	2.1	0.8	0.6	0.4	—	0.2	—	31.0	23.5	10.5	6.4	3.9
5-inch orange internal	550	6.5	20.2	5.6	2.2	1.6	0.7	0.4	0.4	0.4	—	—	38.0	31.5	11.3	5.6	3.5
Total 2-inch red & orange internal-ant.	536	7.3	11.9	3.5	1.5	2.1	0.2	0.6	0.2	0.4	—	—	27.6	20.3	8.4	4.9	3.4
Total 2-inch red & orange internal-post.	524	5.2	10.7	3.4	1.7	1.0	1.0	0.2	0.6	—	—	—	23.7	18.5	7.8	4.4	2.7
Total 2-inch red & orange internal	1,060	6.2	11.3	3.5	1.6	1.5	0.6	0.4	0.4	0.2	—	—	25.7	19.4	8.1	4.6	3.0
Total 3- to 5-inch orange internal	1,633	7.2	15.4	5.3	2.4	1.7	0.7	0.6	0.3	0.1	0.2	—	34.0	26.8	11.4	6.1	3.6
Total 2- to 5-inch internal	2,693	6.8	13.8	4.6	2.1	1.6	0.6	0.5	0.3	0.1	0.1	—	30.7	23.9	10.1	5.5	3.4
Total other than opercular button	3,235	7.2	13.9	4.8	2.3	1.6	0.7	0.6	0.3	0.1	0.1	—	31.6	24.4	10.5	5.7	3.4
Total	3,973	7.0	12.2	4.0	1.9	1.4	0.6	0.5	0.3	0.1	0.1	0.02	28.2	21.1	8.9	4.9	3.0

anterior (27.6%) and the total returns of all the 2-inch internal tags (25.7%) may be compared, with some reservations, with the total returns from 3-, 4- and 5-inch tags (34.0%). The difference between these returns is highly significant, for the former $P = 0.01$—0.001 and for the latter $P < 0.001$.

The difference between the returns of the 5-inch internal (38.0%) and of the 3-inch internal (32.8%) is not significant, $P = 0.10$; but the difference between the returns of the 5-inch internal and of the 4-inch internal (31.0%) is significant, $P = 0.02$.

Opercular button

The opercular button was an unsuccessful tag with a 13.0% return, only about half that of the rather unsuccessful 2-inch internal and about a third to a quarter that of the most successful tags.

This return is approximately the same as that reported for the same opercular-button tag by Thompson (1943) for the Newfoundland area, 11.5%. Thompson reports higher recaptures, up to 34%, from tagging in some coastal areas, but almost all of these were recaptured in the year of tagging, the majority, doubtless, within the first month or two.

The returns of the opercular button tag and those of even the least successful of the remaining tags show highly significant differences: opercular button and smolt maxillary (28.9% returns), $P < 0.001$; opercular button and 2-inch orange internal posterior (22.2% returns), $P < 0.001$.

Our returns of all varieties of tags would have been considerably higher except that, in order to allow for dispersal before recapture, tagging was deliberately carried out after the major inshore fishery was over for the year and hence recoveries were relatively low in the year of tagging.

Additional Notes on Returns

Linetrawl and gillnet

At Fogo, where some cod were captured for tagging by bottom linetrawl and some by bottom cotton gillnet and the tagging from each source was well spread among the different varieties of tags, returns (for every kind of tag) for the linetrawl fish were higher than those for the gillnet fish. For linetrawl fish (using all tags), of 1,221 cod tagged 27.4% were returned and for gillnet fish, of 670 cod tagged, only 17.7% were returned. This difference is highly significant, $P < 0.001$. These were all apparently equally vigorous fish which swam downward and disappeared from view after tagging. The linetrawl tagging depths of 14—17 fathoms (26—31 m) were slightly less favourable than those for gillnet tagging, 13.5 fathoms (25 m).

Internal tags, scraped and unscraped

The 2- to 5-inch tags used internally had the usual rough edges when received from the makers. Half of each size and variety of these tags were scraped to remove the rough edges and half were left rough (unscraped). Of 1,611 scraped 2- to 5-inch tags used internally 28.2% were returned, while of 1,591 unscraped similar tags used internally the returns were 29.0%. There is thus apparently no advantage from scraping. The results from the Fogo tagging were slightly in favour of the unscraped tags and from the St. John's tagging slightly in favour of the scraped tags.

Anterior and posterior insertion

The 2-inch internal tags were inserted through an opening cut in the same position, either by the method used for all the 3- to 5-inch tags, anteriorly toward the main body cavity, or posteriorly into the pocket running backward from the cloaca. Considering the total 2-inch red + orange tags the insertion toward the anterior direction gave better returns, 27.6% from 536 tagged, than that toward the posterior direction, 23.7% from 524 tagged. This difference is not significant, $P = 0.20$—0.10. Even if the most different results are compared — those for the 2-inch orange — returns from the anterior insertion, 29.3% of 259 tagged, were not significantly different from the returns from the posterior insertion, 22.2% of 261 tagged, $P = 0.10$—0.05. The posterior position presumably made the tag less visible, since the tag may occasionally remain in the posterior pocket after the viscera have been removed.

Relation of size of hole to retention of opercular tag

In the St. John's tagging, before the opercular-button tags were attached, a hole was made in the opercular bone using a leather punch to cut openings of 3 different sizes. The No. 4 punch hole was 3.5 mm, that of the No. 5 punch 4.2 mm and that of the No. 6 punch 5.2 mm in diameter. The outside diameter of the aluminum shaft of the opercular-button tag was 5.0 mm. The gradually increasing size of hole in the opercular bone produced increasingly better returns — the No. 4 punch 11.2% returns from 196 tagged, the No. 5 punch 13.1% returns from 160 tagged and the No. 6 punch 18.8% returns from 176 tagged. The difference in total returns from the No. 4 and the No. 6 punch is close to significance, $P = 0.10$—0.05. Even more striking were the differences in the returns subsequent to the year of tagging — 4.6%, 5.0% and 11.9% respectively for the No. 4, No. 5 and No. 6 punch sizes. These returns for the No. 4 and No. 6 punches and also for the No. 5 and No. 6 punches were significantly different, $P = 0.02$ and 0.05—0.02 respectively.

It is thus evident that the small number of returns from the opercular-button tags was very likely due largely to the compression of the opercular area and the consequent destruction of flesh and bone followed by the loss of the tag. We have indeed seen recovered tagged cod and heard of others with a hole in the opercular area large enough for the tag to drop out. Furthermore, aluminum is brittle and there is probably some loss of tags through the fracture of the junction of the aluminum shaft to the celluloid disc. Doubtless an improved opercular-button tag might be designed with suitable materials and different lengths of shaft. (According to Rounsefell and Kask (1945) Herrington used two lengths of shaft for haddock.) By finding the best-sized hole in relation to the diameter of the shaft and by choosing increasingly longer shaft lengths for larger fish better results might be obtained from a tag of this type. This tag and the internal tags can be applied more rapidly than the other tags used in these experiments.

Summary

In 1950 over 4,000 cod (*Gadus morhua* L.) of 50 cm and over (fork length) were tagged in the inshore fishing areas at St. John's and Fogo. Different varieties of tags and tagging methods were used individually in rotation for groups of 10 cod. The most successful tags were a 51-mm bright red tag of cellulose nitrate attached around the preopercular bone on the left side by 0.8-mm diameter nickel wire (48% returns of 109 tagged), a 127-mm orange internal (body-cavity) tag (38% of 550 tagged) and a 20-mm bright pink tag of cellulose nitrate attached with 0.4-mm diameter nickel wire (37% of 145 tagged).

For the 20-mm pink tags, attached by a loop of nickel wire, the attaching position below the anterior end of the first dorsal gave the highest returns (37%). Returns were lower for the preopercular position (34%) and still lower for the maxillary position (29%).

For the internal vinylite tags of the same width, thickness and orange colour the percentage returns for tags 51, 76, 102 and 127 mm long were respectively 26, 33, 31 and 38.

A bright red cellulose nitrate and aluminum bachelor-button tag penetrating the opercular bone on the left side was an unsuccessful tag with only 13% returns.

Cod caught for tagging by longline hauled by hand gave returns of 27%, whereas of cod caught for tagging by gillnet in approximately the same depth and in the same area only 18% were returned.

Internal tags with the rough edges smoothed by scraping showed no advantage in returns over unscraped tags.

For the bachelor-button opercular tag returns varied with the size of the hole punched in the opercular bone — from 11% returns with a 3.5-mm hole to 13% with a 4.2-mm hole and 19% with a 5.2-mm hole.

Acknowledgements

The authors are grateful to the following people who in various ways assisted in these tagging experiments: Mr. F. Brett, Mr. W. R. Hamilton, Mr. W. C. Blackmore, Mr. A. M. Fleming, Mr. V. M. Hodder, Mr. E. L. Rowe, Dr. A. A. Blair, Miss Dolores A. Bursey and Miss Eleanor M. Squires.

References

ROUNSEFELL, GEORGE A. 1942. Field experiments in selecting the most efficient tag for use in haddock studies. *Trans. Amer. Fish. Soc.*, 71: 228—35.

ROUNSEFELL, GEORGE A., and JOHN LAURENCE KASK. 1945. How to mark fish. *Trans. Amer. Fish. Soc.*, 73: 320—63.

TEMPLEMAN, WILFRED, and A. M. FLEMING. 1962. Cod tagging in the Newfoundland area during 1947 and 1948. *J. Fish. Res. Bd Can.* 19: 445—87.

THOMPSON, HAROLD. 1943. A biological and economic study of cod (*Gadus callarias* L.) in the Newfoundland area. *Res. Bull. Div. Fish. Resour. Newfoundland*, No. 14.

United States Research Report. 1939. *Proc. N. Amer. Coun. Fish. Invest.*, 1934—1936, No. 3: 8—16.

48.

Some Notes on the Tagging of Redfish, *Sebastes marinus* (L.), from Deep Water

By

E. J. SANDEMAN and E. I. S. REES*

Introduction

Redfish, *Sebastes marinus* (L.), which normally live in deep water, possess large closed swimbladders and strong body walls. They are usually in a somewhat distressed condition when brought to the surface by otter trawls or other fishing gears. The symptoms of distress are not confined solely to the distension and rupture of the swimbladder resulting in gas in the body cavity. In addition the eyes are usually blown up and frequently the pressure of gas in the body cavity has also caused the stomach to evert through the mouth. Numerous attempts to facilitate the return of fish to the depths by allowing the gas in the body cavity to escape have failed, and the fish have merely floated at the surface when released.

The problem of gas pressure is not so acute in shallow water. U.S. biologists (Anon, 1956 and 1957; Kelly and Barker, 1961), working with a shallow water stock of redfish at Eastport in the Gulf of Maine, have obtained excellent results which show, amongst other things, that redfish may be tagged successfully when the harmful effects of extreme pressure changes are not present. Hansen (1961) has reported the successful tagging of some large *marinus*-type redfish in Godthaab Fjord, West Greenland, and even where the depth was only 20—30 m, it was apparently necessary to release the fish below the surface. This was accomplished by lowering the fish in an inverted metal basket, in most cases only for a few meters before they swam briskly toward the bottom.

The general method of releasing fish below the surface was used by Bertelsen in 1950 for liberating tagged herring at a depth of 20—30 m (Bertelsen, 1955). Release was effected by means of a special tub with a lid which could be opened by a messenger device. This same method was used in whiting tagging operations in 1956 (Bertelsen, MS, 1956) and the recovery of three fish, liberated at a depth of 138 m a month previously, indicated the success of the method, which was subsequently applied to the Danish whiting tagging in 1956.

Kotthaus (1957) used a similar method of sub-surface release in liberating tagged redfish in several areas around Iceland and East Greenland. A steel drum with a messenger-operated detachable lid and reversing device was used, and 163 redfish were tagged and released during April 1957.

Our own attempts at tagging redfish were started in 1956 when some preliminary experiments, in which fish were lowered in a cage and brought to the surface after varying periods of time, indicated that some survival was possible.

Tagging Operations

The tagging experiments described here were conducted in the general area of Hermitage Bay on the south coast of Newfoundland. The small inshore research vessel "Marinus" was used in all these experiments, the fish being caught by otter trawling. On the basis of subsequent knowledge of the occurrence and distribution of *marinus* and *mentella* types in the area, it is likely that the tagged fish were of the North American *mentella* type.

Tagging of redfish was attempted on three separate occasions and on each of these different types of tags were used.

A. In August 1956, in Hermitage Bay, 94 redfish were tagged with $^{25}/_{32} \times {}^{3}/_{16}$ inch (20- × 5-mm) yellow vinylite laminated plastic tags. The tags were attached with 0.025 inch (0.64-mm) diameter stainless steel wire looped through the fleshy part of the nape just anterior to the dorsal fin. These fish, which were caught at depths between 125 and 140 fathoms (229—256 m), were released at a depth of 200 m or greater by means of a tagging cage.

B. In June 1957, in Hermitage Bay, 271 redfish were tagged with Petersen disc tags. The two portions, the one yellow and the other orange, were fastened securely to the fish through the fleshy part of the nape, just anterior to the dorsal fin, by means of 0.032 inch (0.81-mm) diameter stainless steel wire. These fish were caught in depths from 133—147 fathoms (243—269 m) and released at a depth of 200 m.

During the same period, in the adjoining Connaigre Bay, 32 redfish were tagged. These fish were tagged in exactly the same manner as those released in Hermitage Bay, but were caught at the shallower depth of 99—103 fathoms (181—188 m) and released at 150 m. At both these localities the tagging cage was used for the sub-surface release of the tagged fish.

---

* Fisheries Research Board of Canada, Biological Station, St. John's, Nfld., Canada.

C. In July—August 1960, in Hermitage Bay, 54 redfish were tagged with 2 × $^3/_{16}$ inch (51- × 5-mm) yellow vinylite laminated plastic tags, attached to the fish by 0.020 inch (0.51-mm) diameter stainless steel wire inserted through the flesh below the last few dorsal spines and secured on the other side of the fish by means of yellow vinylite plastic discs of diameter 0.5 inches (13 mm). These redfish were caught at 138—146 fathoms (252—267 m) and released at the bottom within the same depth range. In this experiment release was accomplished by means of a canvas cylinder.

Apparatus Used for Sub-surface Release of the Tagged Fish

A. The tagging cage

The tagging cage consisted of a cubical metal frame constructed of angle iron and having an edge dimension of 3 feet. This metal framework was covered with manila netting to form a cage which, when attached to the hydrographic wire, could be lowered in the water (Figs. 1 and 2). Entrance to the cage for loading purposes was provided by a small trap-door situated in the upper surface of the cube, and this was tied securely shut while the cage was lowered. The tagged fish were allowed to escape by means of a second, considerably larger trap-door consisting of almost a complete side of the cage. This escape trap-door was kept closed by means of a spring-loaded line connected to a messenger-operated trip-release mechanism of the type normally used for closing plankton nets. On being tripped, this trap-door, which is hinged at its lower edge, falls open. To allow a more positive action and to ensure that prompt opening occurs even when the cage is tilted, the centre of gravity of the trap-door was moved from above the hinge by means of a short weighted arm affixed at the centre of the upper edge of the trap-door.

During the experiments in which the tagging cage was used the fish were obtained by otter trawling, usually from short tows of about 10—15 minutes duration. In the catch from each tow a few fish can usually be found which appear to be relatively unaffected by gas expansion; the most lively of these were selected for tagging. Selection, transfer to a tub of running sea-water, tagging and transfer to the tagging cage, which was partially immersed alongside the ship, were accomplished as quickly as possible. It was generally possible to tag only some 10—15 fish from each set although occasionally numbers up to 20 were tagged. As soon as the fish had been tagged, the entry trap-door was secured, the trip-release mechanism set, and

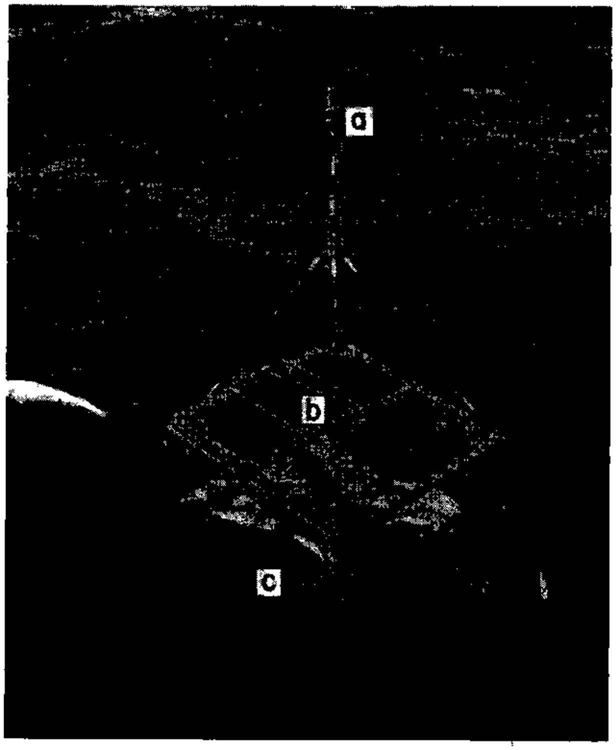


Figure 1. The tagging cage. The tagged fish are in the cage and the cage is ready for lowering. a. Trip-release mechanism. b. Loading trapdoor. c. Escape trapdoor.

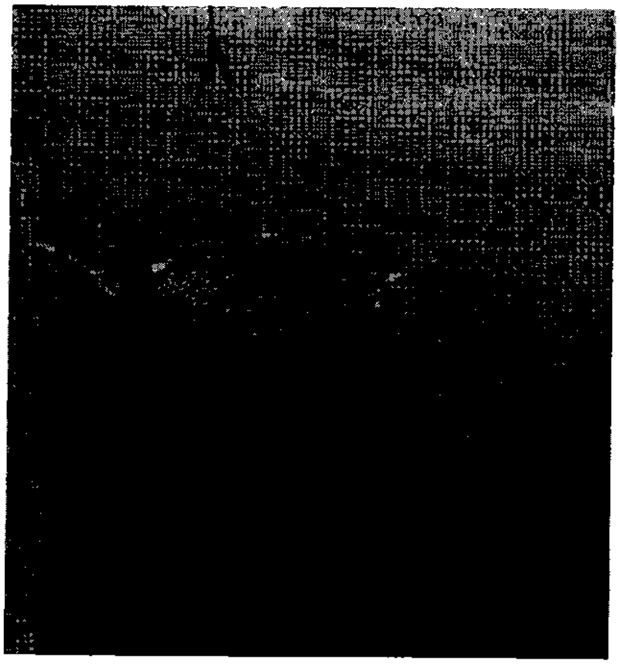


Figure 2. The tagging cage after return to the surface. The escape trapdoor is open (front of photo) and is hanging down below the picture. Also note that one fish did not escape.

the cage lowered rapidly to the depth at which the fish were to be released. The tripping messenger was sent down and some 5—10 minutes later the cage brought to the surface, where any fish which had not escaped were recovered.

B. The canvas cylinder

This consisted of a hollow canvas cylinder 6 feet (1.8 m) in length and having a diameter of about 20 inches (0.5 m) (Fig. 3). The ends of the canvas cylinder were kept in shape by iron rings. To these were attached the bridles, by which it was suspended from the hydrographic wire, and the ropes supporting an 80-pound (36-kg) weight at the lower end. The upper end was closed with netting while the lower end remained open. Canvas was chosen for the construction of this apparatus in preference to either a rigid material or netting, in order to ease the handling and stowage on a small vessel and at the same time keep tangling to a minimum.

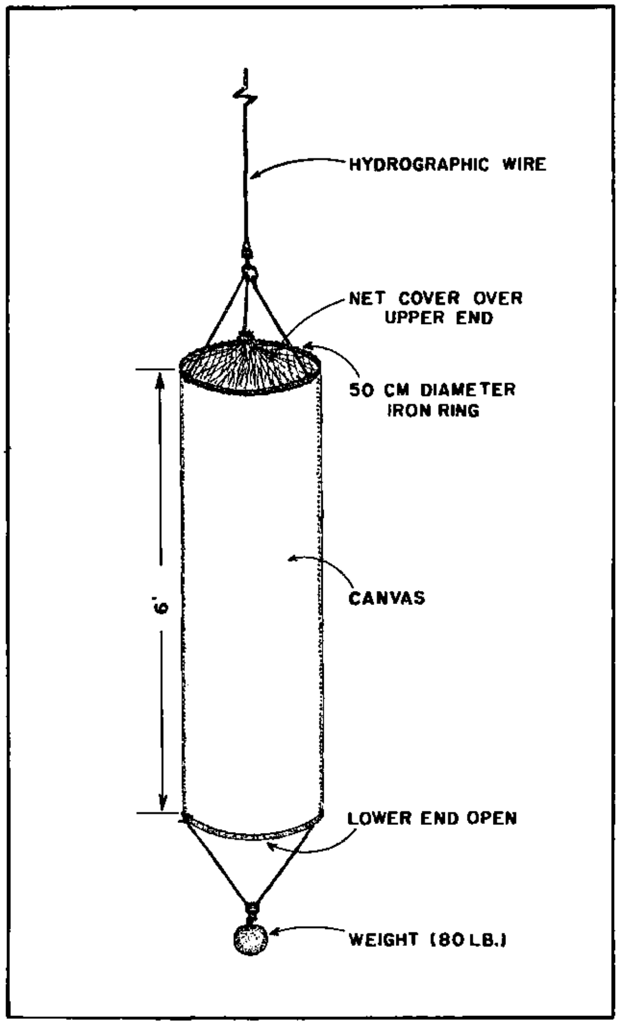


Figure 3. Diagram of the hollow canvas cylinder used for sub-surface release of tagged redfish in 1960.

During the tagging experiments, in which this canvas cylinder was used to secure sub-surface release, the fish for tagging were selected from the catch of one-hour sets. The most lively fish were picked, tagged and transferred to the canvas cylinder as quickly as possible. Loading of the cylinder was accomplished either via the upper end, in which case the netting cover at this end was untied and the lower end immersed in the sea alongside the ship, or via the lower end, in which case the cylinder was bent in a U shape and the weight taken aboard. When loading of the cylinder was completed it was lowered to near the bottom. While being lowered the fish are held against the net at the upper end by their own buoyancy and the force of water streaming through the cylinder. When the apparatus is stopped at or near the bottom the fish can escape. Any that do not escape are washed out immediately the apparatus starts to be hauled up.

Some Considerations regarding the Possible Success or Failure of the Method as applied to Redfish

(1) Tagging returns

The success or failure of a particular tagging method or experiment must, in the final analysis, be judged from tag returns. With this in mind, we regret that we can show but a few rather inconclusive returns and these come from only one of the three experiments described above. The experiments and the returns are tabulated below (Table 1).

Table 1
Summary of tagging and returns

Expt.	Tag used	Depth caught (fathoms)	No. released	Surface temp. °C	No. returned
A	$^{25}/_{32}$″ yellow	125—140	94	14.5*	0
B (i)	Petersen disc	133—147	271	6—10	2
B (ii)	Petersen disc	99—103	32	approx.	3
C	2″ yellow	138—146	54	15—17	0

* Surface temperature taken on only one occasion.

Of the 271 fish tagged in June 1957 in Hermitage Bay (Expt. B (i)) two returns are noted. One was taken, about 3—4 hours after tagging, by the small commercial trawler "Pennyworth", which was fishing alongside the "Marinus". Radio communication with the captain revealed that, in his own words, "the fish was alive and lusty". The other, which was tagged on June 21, was caught by the same vessel a short time afterwards. Unfortunately we have been unable to establish the date of recapture. We can be certain, however, that it was at liberty for at least

24 hours, as the "Pennyworth" was not fishing on the day the fish was tagged. In fact, it is extremely unlikely that the fish was caught before June 27, when the "Marinus" left the area, as the captain of the "Pennyworth" did not report the recovery to us by radio.

Of the 32 fish tagged in the shallower waters of Connaigre Bay three recoveries are noted, one of which must be regarded as a negative recovery. This fish was recaptured by the "Marinus" about 5 hours after tagging. It was in a moribund condition, being lacerated and having the "guts" protruding through the body wall. Another fish, alive and showing no apparent ill-effects, was recovered about 3 hours after tagging. The third fish was not recovered in the normal sense of the word, but the tag and attaching wire were found on a shingle beach about 18 months after tagging and some 40 nautical miles (74 km) from the tagging position. How this non-buoyant tag, to which no fish was attached, arrived at this place is a matter for conjecture.

(2) Survival experiments

Several experiments were conducted, during which fish were lowered to various depths and returned to the surface after varying periods of time. The tagging cage was used in two initial experiments.

In the first, which was conducted prior to all our redfish tagging attempts, 10 fish were lowered to 200 m. Of these, 9 were not only alive but lively when brought to the surface after 2 hours. They were, however, largely denuded of scales, and this can probably be attributed to movements of the cage, resulting from the rolling of the ship. In our desire not to lose the cage we did not allow it to touch bottom. The 9 fish which survived the ordeal were all large, 31 cm and greater, while the remaining fish, which was in obvious rigor, was 24 cm in length. In a second similar experiment, when the cage was recovered after 90 minutes, the result was similar, 9 out of the 10 fish being alive when brought to the surface. During this latter experiment the sea was smooth and no noticeable loss of scales occurred.

During two cruises of the "Marinus" to Hermitage Bay in 1960 some further survival experiments were carried out. In these experiments a 45-gallon oil drum, one end of which had been removed and covered with shrimp netting, was used as a cage. The redfish were caught during sets of one hour's duration at a depth of 138—148 fathoms (252—271 m) and lowered again to the bottom within the same depth range. Seventeen recoveries were made after time intervals ranging from 2 hours 40 minutes to 48 hours.

The essential results of these experiments are summarized in Table 2. Although the experiments were of a preliminary nature and the results based on very few fish, a few tentative conclusions, which may be useful in planning future experiments of this kind, are indicated. It should also be pointed out that both air and sea-surface temperatures were unfavourably high during the latter (July—August) experiments.

It is evident from Table 2 that, whereas at all periods up to 14 hours most redfish remained alive in the cage, at periods of submersion of 15 hours or greater, with one exception (Experiment no. 4), all died. This would not appear to augur too well for successful application of the method of sub-surface release for tagging redfish from deep water. There are, however, some considerations which cast some doubt on the validity of this conclusion.

Table 2

Basic data of survival experiments on redfish in Hermitage Bay, 1960. The data have been arranged according to the length of time the fish were immersed. (N.S.T. = Newfoundland standard time)

Expt. No.	No. of fish lowered	No. of fish recovered alive	Time down (hr.-min.)	Notes	Time of catching N.S.T.
Series performed in May 1960 (Surface temperature 4.6—6.2°C)					
1	4	4	3—25		1045
2	5	4	9—35		0740
3	5	4	14—30		1715
Series performed in July—August 1960 (Surface temperature 14.8—17.0°C)					
13	4	3	2—40		0930
15	5	4	2—45	3 treated M.S.$_{222}$	0910
10	6	6	6—10	3 treated M.S.$_{222}$	0750
8	4	3	6—35		0850
6	4	4	7—20		0740
12	6	6	14	3 treated M.S.$_{222}$	1715
9	6	0	15	4 fish attacked by hagfish (*Myxine glutinosa* L.)	1700
14	5	0	15—45	Attacked by hagfish	1455
16	6	0	16—40	Attacked by hagfish	1530
11	6	0	17	3 treated M.S.$_{222}$	1715
7	6	0	21—55		1720
4	7	7	24		0740
5	9	0	42		1400

In one other experiment, 6 of the 7 fish in experiment (4) were again lowered for a further period of 48 hours during which time they succumbed.

In drawing the tentative conclusion that the survival time in the cages is limited to a period of about 15 hours, two basic assumptions are implied: the experimental conditions, apart from the length of time submerged, were all identical, and the capacity of fish to survive was the same in each experiment. If these assumptions and the conclusions indicated by the experiments are correct, we should expect that when the critical time was approached the physiologically weaker fish would die first and that, particularly over the period immediately before and after the critical time, results showing varying numbers of dead and alive fish would be obtained. This, however, was not so, and in the five experiments with immersion periods between 14 and 17 hours the fish were either all dead or all alive. This same "all or nothing" type of result was also noted in all the other experiments, for when the redfish survived they almost all survived (75% or more) and when they died they usually all died. In view of this and the one exceptional experiment (no. 4) in which all the fish remained alive for a period of 24 hours, it seems likely that in some experiments the fish were subjected to greater stresses than in others, in which case the basic assumptions should be examined.

Were the experimental conditions, apart from the length of time submerged, identical? Apart from one or two procedural details, such as treatment with anaesthetics and force feeding which revealed no differences in survival success within experiments, the most likely of the possible factors which might vary from one experiment to the next are those of temperature and time between being dumped from the otter trawl onto the deck and being lowered to the bottom in the cage. No data are available on this latter point, but since in no experiment were more than 7 fish selected, this period could be considered as relatively constant (about 5 minutes). With regard to variations in temperature to which the fish might be subjected during the period on deck, it is likely that large diurnal variations would occur, and that the fish used in experiments during the early morning would suffer less from exposure to high temperatures than those used in experiments at the mid-day period when they might be exposed to the full force of the sun.

In considering air temperature as a possible variable in this respect, it is immediately apparent that we must consider separately the two series of experiments done in May and July—August. We will consider in detail the July—August series of experiments, which were of sufficient number to provide some preliminary conclusions. No air temperature data are available for Hermitage Bay during this period, but the experiments were conducted during a long spell of fine dry weather when the maximum temperature at St. John's, on the days on which experiments were carried out, ranged from 66—77°F (19—25°C). It is unlikely that the air temperatures in Hermitage Bay were much different from those at St. John's on the days in question, particularly as the wind speeds at the times of these experiments were never more than about 5 m.p.h.

When the survival results are examined in relation to the time of day at which the experiment took place (Table 2), it is apparent that a possible correlation exists between these factors, and that, with one exception (Expt. no. 12), successful survival was only obtained when the experiments were conducted before 10 00 hours. If this correlation is correct, it could also be connected with variation in the second assumption above, namely that the capacity of the fish to survive varied between experiments. In this respect it seems likely that, because of the diurnal habits of redfish in seeking shallower waters at night, fish caught early in the morning would be compensated to shallower depths and thus would not suffer such extreme gas volume changes as fish in hydrostatic equilibrium at the bottom.

(3) Possible differential success in tagging with regard to fish sizes

In designing the cage used in the tagging experiments of 1956—1957, an attempt was made to ensure that only the most active fish would escape. The release trap-door, besides being placed at the side of the cage rather than on the lower surface, was also made smaller than the full size of the side of the cage, being hinged 7—8 inches above the lower surface (Fig. 2). It was hoped that only those fish which actively swam out of the cage would escape.

It was found that the number of fish remaining in the cage when it was returned to the surface was very variable. Whereas on 10 occasions all tagged fish escaped, in the other 16 successful lowerings the number escaping varied from none on one lowering to between 5 and 15%, on seven occasions. The percentage escaping from one experiment to the next appeared to be unrelated to temperature or other factors of technique.

When the lengths and sexes of the escaping and non-escaping fish are examined a possible difference in viability between sizes and sexes can be noted.

Males			Females		
Length	Total lowered	% Not escaped	Length	Total lowered	% Not escaped
20—30 cm	26	42	21—31 cm	12	50
31—40 cm	261	18	32—45 cm	50	30

The preponderance of large males is a characteristic feature of Hermitage Bay and the proportion of large males to large females used for tagging approaches that of the overall length distribution of the fish caught during the trip. The fact that selection of fish for tagging was biased toward large fish does not alter the conclusion that better escapement was obtained from the large fish than the small, and, though not so striking, by males rather than females.

Summary

The main conclusion to be drawn from our experiments on survival and our attempts at tagging redfish from deep water by the method of sub-surface release is that further work is required to reach a decision as to the probability of success or failure of the method. However, the present results indicate a few pointers which might be fruitfully applied to future attempts at tagging redfish and further survival experiments.

In the tagging experiments, 451 redfish were tagged after being caught by otter trawl in depths of 99—147 fathoms (181—269 m). The tagged fish were released at or near the bottom by sub-surface release mechanisms. The results of these attempts at tagging redfish from deep water were disappointing, as only 5 returns were obtained and these provided little or no data on whether or not the majority of tagged fish would be likely to survive their ordeal. The experiments did not, however, take place at a time of year when air and sea temperatures could be considered most favourable for tagging operations.

Survival experiments, in which redfish were confined in a container and lowered to the bottom for varying periods of time before being brought back to the surface for examination, indicate that, if survival is possible at all, very careful attention must be directed towards minimizing the effects of exposure to abnormal conditions of temperature and possibly also light, and to catching the fish during the most favourable phase of their diurnal cycle.

Some evidence exists that the larger fish (> 30 cm) are better able to bear the vicissitudes of a visit to the deck of a trawler.

References

ANON. 1956. Deep-sea redfish now successfully tagged. *Fish. Gaz.* 73 (8): 44.

ANON. 1957. Ocean perch tagged in 1956 recaptured at Eastport, Maine. *Comm. Fish. Rev.*, **19** (7): 14—15.

BERTELSEN, E. 1955. Danish herring tagging in the North Sea 1949—51. *Rapp. Cons. int. Explor. Mer*, **140** (2): 9.

BERTELSEN, E. 1956. Danish whiting taggings in 1956. *Near-Northern Seas Committee, ICES*, 1956. (Mimeo.).

HANSEN, P. 1961. Studies on the growth of the redfish (*Sebastes marinus*) in Godthaab Fjord, Greenland. *Int. Com. NW-Atl. Fish.*, Sp. Publ. No. 3, 258—61.

KELLY, G. F. and A. M. BARKER. 1961. Observations on the behaviour, growth and migration of redfish at Eastport, Maine. *Int. Com. NW-Atl. Fish.*, Sp. Publ. No. 3, 263—75.

KOTTHAUS, A. 1957. Rotbarsch-Markierung. *Fischereiwelt*, **6**: 50—51.

49.

Some Results of Tagging and Recovery of Tropical Tunas 1955—1959

By

MILNER B. SCHAEFER, BRUCE M. CHATWIN and GORDON C. BROADHEAD*

In November 1955, the Inter-American Tropical Tuna Commission commenced tagging of tropical tunas, employing an improved version of the polyvinyl plastic loops (originally employed by Wilson (1953)) and attached through the dorsal muscles. In this paper are summarized some results of tagging and recovery of tunas through December 1959, although continuing tagging experiments are still in progress. During the period considered here, we also employed a few plastic "dart" tags, similar to those described by Yamashita and Waldron (1958). Subsequently, we have found that return rates of dart tags are at least equal to those from loop tags and, since they are more easily applied, we are at present using them exclusively.

Between November 1955 and December 1959, we tagged 20,470 yellowfin tuna and 49,911 skipjack, from which, through the end of 1959, there had been returned 747 yellowfin and 937 skipjack. For experiments for which return data were nearly complete (i.e. for tagging through 1958), return rates for different years of tagging ranged from 4.9 to 8.7 per cent for yellowfin and from 0.8 to 2.8 per cent for skipjack. There were wide variations in return rates between cruises and tagging areas. It was noted that return rates were much lower from tagged fish liberated in the region of warmest water, near the center of the range of these species off Central America, than near the two ends of the range where sea temperatures are lower. Analysis of the relationship between temperature at tagging and return rates *within* regions reveals a striking negative correlation. It is inferred that there is heavy initial mortality of tagged fish, increasing with water temperature, probably due to effects of hyperactivity during capture and tagging. Estimates of initial tagging mortality can be made by comparing tag return rates with the rates that would be expected, on the basis of fishing and natural mortality rates estimated by other means. (However, a correction needs to be made to the rates of tag return for non-return of recaptured tags. Non-return of recaptured tags was estimated from returns of tags placed in the holds of fishing vessels without the knowledge of fishermen or unloaders; it was estimated at about 50% for very early experiments and at about 10% after improvement of tags and recovery techniques). It is estimated that initial tagging mortality may be, under average conditions, 80 per cent, or more.

It appears, from the returns, that both species of tropical tunas in the Eastern Pacific are much less migratory than might have been expected. It seems that they do not migrate, in appreciable numbers at least, to other regions of the Pacific Ocean, since not a single return has been made from any other part of the Pacific. Even within the Eastern Pacific, the fish from different areas apparently do not intermix rapidly; there are, however, certain annual patterns of migrations, which are particularly evident near the northern and southern limits of the range of these species.

During the first several months at liberty, the movement of tagged yellowfin and skipjack tuna often corresponds moderately well to a simple random diffusion model, since a plot of mean-square distance against time at liberty is linear during this period. The "diffusion" coefficients in different regions vary, for yellowfin tuna from 57 miles^2/day to 530 miles^2/day, being lower near the extremes of the distribution range than in the central regions. In general, skipjack evidence more rapid dispersion than yellowfin within the fishing region (which is confined to a strip along the coast of only about 200 miles width, except where there are outlying islands). There is some evidence that, especially at larger sizes, skipjack disperse offshore beyond the fishing area.

Logarithms of numbers of yellowfin tag recoveries decrease linearly with time, which is consistent with a model in which the fish remain within the fishing area and remain equally available to capture. "Survival" rates for tagged yellowfin tuna, estimated from rate of decrease of tag returns with time, are lower than survival rates estimated from age-composition data. Estimates of annual survival rate from tag returns range from 0.032 to 0.169, while from age-composition data Hennemuth (1961) has derived estimates of 0.09 to 0.19, with 0.18 as the "best" value. It seems, therefore, that there is some continuing loss of tagged fish (or at least of tags) from other causes than normal natural mortality or fishing mortality.

Logarithms of tag returns of skipjack plotted against time exhibit a distinctly non-linear relationship. Assuming a model in which the tagged fish are moving away from the point of tagging and offshore out of the fishing area, according to a simple diffusion

---

* Inter-American Tropical Tuna Commission, La Jolla, Calif., U. S. A.

law, we would expect the return of tags R_t at time t to follow the equation

$$R_t = R_o\, e^{-(F+M+Q)t} \cdot \frac{k}{t}$$

where F and M are the fishing and natural mortality coefficients, Q is the coefficient of other continuing losses, and R_o and k are constants. This leads to

$$\log (tR_t) = \log kR_o - (F + M + Q)\, t.$$

Plotting logarithms of tR_t against t for skipjack tag returns yields an approximately linear relationship, and indicates "survival" rates (within the area of fishing) of 0.066 to 0.221.

A more detailed report on these experiments is being published in Volume 5, Number 5 of the Bulletin of the Inter-American Tropical Tuna Commission.

References

HENNEMUTH, R. C. 1961. Year-class abundance, mortality, and yield-per-recruit of yellowfin tuna in the Eastern Pacific Ocean, 1954—1959. *Inter-Amer. Trop. Comm., Bull.*, **6** (1): 1—51.

WILSON, R. C. 1953. Tuna marking, a progress report. *Calif. Fish & Game*, **39**, (4): 429—42.

YAMASHITA, D. T. and K. D. WALDRON. 1958. An all-plastic dart-type fish tag. *Calif. Fish & Game*, **44**, (4): 311—17.

50.

The Use of Blood Group Characteristics in Studying Subpopulations of Fishes

By

JOHN C. MARR* and LUCIAN M. SPRAGUE*

Introduction

"It is one thing to recognize the existence of racial diversity and another to define it in terms of the underlying genetic facts." (Stern, 1960, p. 681).

The necessity of identifying population units** within species of fishes that are the objects of commercial fisheries has long been recognized and has recently been summarized by Mužinić and Marr (1960) as:

"The logical and practical reason for identifying population units is that such units may have their own characteristics of recruitment, growth, natural mortality, migration, behavior, etc., more or less independent of the characteristics of other population units within the same species. The need for studies of population units in a particular situation may arise from two sources: (a) There exist variations in yield and/or heterogeneities in the characteristics of the catch for which the most likely explanation (hypothesis) is the existence of population units. (b) Management decisions have been made empirically for which it is necessary or desirable to provide understanding and thus confidence in the original decisions."

Methods of studying subpopulations have recently been reviewed (Marr, 1957) and may be grouped in four categories, according to the characteristics studied. These include (1) phenotypic qualities, (2) movements as revealed by tagging or marking, (3) vital statistics and (4) genetic characteristics. Studies of phenotypic qualities (meristic and morphometric characteristics) and of movements revealed by tagging are too well known to require examples. The concept of identifying population units on the basis of vital statistics (rates of recruitment, death and growth) has only recently been proposed by Holt (as reported by Mužinić and Marr, 1960). The use of genetic characteristics, especially blood groups, is also a recent innovation.

The use of phenotypic characteristics has a number of limitations. The characteristics used are frequently of the form of overlapping frequency distributions and, even with the more sophisticated techniques recently employed (see Royce, 1957 and MS, for example), show (1) that the samples were not drawn from the identical universe and (2) the maximum possible mixing. Moreover, since the characteristics are susceptible of environmental modifications, the observed differences may relate to environments rather than to subpopulations. Frequently, if not generally, the samples are not drawn from spawning assemblages, so that real mixtures of subpopulations could remain undetected.

Tagging experiments require that fish be tagged and returned. This is not only costly in time and effort, but effectively limits such experiments to areas in which there is an effective recapture mechanism (i.e., a fishery). Again, the tagging experiment is generally not performed on spawning assemblages, so that the question of interest is examined with less than maximum precision.

The use of vital statistics may, in fact, correspond more nearly to a definition of a subpopulation rather than to a tool for studying subpopulations. Their utility as a tool would be increased if they could be applied to spawning assemblages.

The limitations and advantages accruing from the use of blood groups in studying subpopulations are considered in greater detail below. But a minor semantic difficulty must first be noted. The phenotypic characteristics referred to above are genotypic characteristics as modified by the environment; they are plastic. Numbers of vertebrae are an example of such a plastic phenotypic characteristic. Many quantitative genetic traits are subject to such environmental modification. There are also phenotypic characteristics which are not susceptible of environmental modification and bear a direct relationship to the genotype; they are non-plastic. Many qualitative genetic traits have direct, regular genotype-phenotype relationships. Blood group phenotypes belong to the latter, non-plastic category.

Blood Group Systems

Blood groups are studied through the use of the antigen-antibody reaction. A number of compounds on or in the erythrocyte surface, and the soluble-specific substances (A of man, for example), constitute blood group substances. These substances are frequently present in certain individuals and lacking in

---

* U. S. Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 3830, Honolulu 12, Hawaii, U.S.A.

** A population unit may be defined as a fraction of a population that is itself self-sustaining. This is identical with the definition of subpopulation given by Marr (1957). Population unit, subpopulation and interbreeding population are here considered to be exact synonyms and are used interchangeably throughout.

others. The substances are probably polysaccharides and are certainly antigens*.

Erythrocyte antigens and soluble specific substances have been found to be under genetic control in every animal in which this question has been studied. The various antigens which occur separately, or together, in response to the segregation of genetic material at a single locus or genetic site, constitute a blood group system. Thus, antigens which are not genetically related belong to different blood group systems.

Antibodies, a constituent of plasma, occur either naturally or as products of the immune mechanism. Antibodies are reasonably antigen-specific and react in demonstrable ways with the appropriate antigen. The simplest and most common method of observing the reaction of antibody and erythrocyte antigen is the agglutination reaction. Thus, anti-x serum can be used to classify red blood cells according to the presence or absence of x (antigen). Initially, the investigator must acquire a set of antisera or reagents that will identify one or more of the blood groups present in the species of interest. Such reagents may be developed by the introduction of red blood cells of the species being studied into other individuals of the same species, into individuals of other species or, more rarely, they may occur naturally in the same or other species. It has been found (Mäkelä, 1957; Bird, 1959) that extracts of the seeds of many legumes are very useful in this regard. The exact nature of the "antibodies" in the legume seeds is not known, but they are proteins, probably globulins (Boyd et al., 1958).

Exploratory classification of samples of the species under study will proceed, of course, simultaneously with the development of antisera. At some point the investigator will be satisfied that the antisera can identify one or more blood groups and will begin to examine series of samples from appropriate localities. Since erythrocytes are frequently difficult to preserve for any length of time, this may mean quite literally taking the tests to sea.

With this technique, samples of a subpopulation are not ordinarily classified according to the presence or absence of a single characteristic, although this could be the case. In fact, most blood group systems are genetically quite complex, having more than two alleles; 6—9 alleles are not uncommon, and one blood group system in cattle has more than one hundred and fifty**. It follows, then that samples are classified according to the frequency of presence or absence of several characteristics. Thus, in comparing samples, there still exists the problem (which fishery biologists constantly encounter) of making sample-size adequate to enable distinction between observational error and real differences between samples. But it should be borne in mind that the differences, if any, relate to non-plastic rather than plastic phenotypes.

There is a further quality of genetic characteristics which adds great power to the use of this tool. In the presence of random mating***, and assuming no mutation or selection effects, the frequencies of alleles p, q . . . x will occur in proportions according to the expansion of the binomial. This condition will obtain after only one generation of random mating and will persist thereafter. This general concept is known as the Hardy-Weinberg Law. It follows, then, that single samples can be examined to determine whether or not they conform to this law. If a sample does not conform to the Hardy-Weinberg Law, it may be concluded that it was not drawn from an interbreeding population; i.e., it was composed of individuals of two or more interbreeding populations. If a sample does conform to the Hardy-Weinberg Law, the data are consonant with the hypothesis and it may be concluded that the sample was drawn from an interbreeding population.

Some Examples

Examples may be drawn from observed frequencies of the phenotypes (and, in this case, the genotypes) of the M-N blood group system in humans (Stern, 1960). The mode of inheritance is that of two alleles, $\underline{L}^M$ and $\underline{L}^N$, and the phenotypes, M, MN and N can all be identified serologically. Data on the observed frequencies of these phenotypes in seven populations, the computed allele frequencies and the expected phenotype frequencies are given in Table I. The frequency of allele $\underline{L}^M$, $p\underline{L}^M$, is computed from

$$p\underline{L}^M = \frac{\overline{M} + {}^1/_2\,\overline{MN}}{100},$$

and $q\underline{L}^N$ from

$$q\underline{L}^N = 1 - p\underline{L}^M,$$

where $\overline{M}$ and $\overline{MN}$ are the observed relative frequencies (percentages) in the populations.

The samples of the first six populations all conform closely to the Hardy-Weinberg Law and each may be considered to have been drawn from a distinct interbreeding unit or subpopulation. The seventh sample, however, does not conform to the Hardy-Weinberg Law and could not have been drawn from

---

* Certain soluble-specific substances found in the body fluids might be considered to be non-antigenic.

** It should be pointed out that, lacking genetic information, the recognition of a particular blood group system as a 2, 3, 4 or x allele system is an assumption.

*** Random mating refers not to random mating between individuals, but rather to random combinations within a gene system.

a distinct subpopulation ($P < 0.01$). The data were in fact obtained by combining, in equal parts, data from the first (Caucasian) and fourth (Eskimo) samples.

Table 1

Frequencies of M—N blood types in different human populations. Slightly modified from Tables 17 and 18 of Stern (1960)

N	Population		Percentages of Blood Types			Allele Frequencies	
			M	MN	N	pL^M	qL^N
6129	Caucasian (U.S)	obs.	29.16	49.58	21.26	0.540	0.460
		exp.	29.16	49.68	21.16	—	—
278	Negro (U.S.)	obs.	28.42	49.64	21.94	0.532	0.468
		exp.	28.35	49.89	21.86	—	—
205	Indian (U.S.)	obs.	60.00	35.12	4.88	0.776	0.224
		exp.	60.15	34.81	5.04	—	—
569	Eskimo (E. Greenland)	obs.	83.48	15.64	0.88	0.913	0.087
		exp.	83.35	15.89	0.76	—	—
504	Ainu (Japan)	obs.	17.86	50.20	31.94	0.430	0.570
		exp.	18.45	49.01	32.34	—	—
730	Aborigine (Australia)	obs.	3.00	29.6	67.4	0.178	0.882
		exp.	3.17	29.26	67.57	—	—
1000	X	obs.	56	33	11	0.725	0.275
		exp.	52.3	39.9	7.6	—	—

Another example that may represent a two-allele system has been given by Sinderman and Mairs (1959). They were able to classify individual herring in the Gulf of Maine as either C-positive or C-negative. Samples from different localities were characterized according to percent C-positive and those from the northeastern Gulf were found to have a higher percentage (about 98%) of C-positive fish than samples from the southwestern Gulf (about 77%). If this is a regular two-allele system, the genotypes $\underline{CC}$ and $\underline{Cc}$ are classified as C-positive and $\underline{cc}$ as C-negative. Lacking the ability to distinguish between $\underline{CC}$ and $\underline{Cc}$ individuals, it is not possible to determine if these samples conform to the Hardy-Weinberg Law. The possibility exists that this C system is actually a much more complicated system, consisting of $\underline{C_1}$, $\underline{C_2}$, $\underline{C_3}$ ... C_x alleles. If this is so, the genotype $\underline{C_x C_x}$ is identified as being C-negative; the remaining genotypic combinations are C-positive. This is a common genetic problem and its significance is only one of the degree to which phenotypes may be regularly related to allelic combinations.

Similarly, Sprague and Vrooman (MS) have discovered a C system* in the sardine of the northeastern Pacific. Although this is believed to be a multiple allele system and is known to be a multiple antigen system, the individual fish were classified only as C-positive or C-negative. Otherwise, the general remarks about the C system in herring apply here.

A two-allele system, $\underline{A}$-$\underline{a}$, has been reported in sockeye salmon by Ridgway, Cushing and Durall (1958, 1961). It is possible to recognize all three phenotypes. Although the results presented are preliminary (and based upon relatively small samples), the samples from two spawning tributaries of the Columbia River conformed to the Hardy-Weinberg Law, whereas samples from (1) the main Columbia River and (2) rivers from Kodiak Island to the Fraser River (combined) did not. The latter two samples, of course, would be expected, on the basis of other information, to be composed of individuals from several spawning populations. A fifth sample from rivers tributary to Bristol Bay (combined) did conform to the Hardy-Weinberg Law. It would be expected that this sample consisted of individuals from several spawning populations, and Dr. Ridgway has informed us (personal communication) that additional studies indicate the existence of distinct populations within one of the rivers tributary to Bristol Bay. The original conclusion of homegeneity within the rivers tributary to Bristol Bay is thus modified.

A blood group system designated Tg1—Tg2—0 has been found in albacore tuna by Suzuki, Morio and Mimoto (1959). We interpret their data to indicate a blood group system with three alleles, analogous to the human A-B-O blood group system. Suzuki et al. (1959) give data for samples from the Pacific Ocean in the general area southeast of Honshu and from the Indian Ocean largely from the general area southwest of Sunda Strait. The striking differences between samples from these two areas in phenotype frequencies were noted, but the question of whether or not the samples from each area were drawn from an interbreeding population was not examined. It is of interest to do so.

According to the Hardy-Weinberg Law, if the samples were drawn from an interbreeding population, then the following relationship obtains:

$$\underline{Tg1} + \underline{Tg2} + \underline{0} = 1$$

where

$$\underline{Tg1} = 1 - \sqrt{\overline{0} + \overline{Tg2}},$$

$$\underline{Tg2} = 1 - \sqrt{\overline{0} + \overline{Tg1}}$$

and

$$0 = \sqrt{\overline{0}}\,.$$

Substituting the Pacific Ocean data

$$0.04 + 0.71 + 0.27 = 1.02\,.$$

---

* The use of the same letter to designate blood group systems in different species does not indicate, barring a specific statement to the contrary, the existence of the identical or even similar blood group in the different animals. This practice arises because of the small number of letters in the alphabet and the tendency to use the earlier letters of the alphabet.

For the Indian Ocean data, however

$$0.39 + 0.55 + 0.30 = 1.24 .$$

Thus, it may be concluded that the Pacific Ocean samples were drawn from a single interbreeding population, but that the Indian Ocean samples were drawn from a mixture of two or more interbreeding populations. There is, incidentally, other evidence (from tagging experiments, for example) that the albacore of the North Pacific constitute a single interbreeding population. A similar inference (based on much less evidence) is possible about albacore of the South Pacific.

Another three-allele A-B-O analog, termed $\underline{S}_1$-$\underline{S}_2$-$\underline{S}_0$, has been reported in the spiny dogfish in the Gulf of Maine by Sinderman and Mairs (1961)*. Their data conform to the Hardy-Weinberg Law, indicating that their samples were drawn from a single interbreeding population. An interesting aspect of their work was the comparison of the blood group types of pregnant females and their unborn pups. The results of this comparison were consonant with a three-allele system.

A final example is that of the sardine B system (Sprague and Vrooman, MS), which by detailed serological analysis suggests a system in which at least four alleles are segregating. In practice, it was possible to recognize only three phenotypes and one of them occurred so rarely (0.001) as to be negligible. This particular system affords a good example of the difficulties which may be encountered in working with complicated blood group systems. The work of Sprague and Vrooman (MS) is also of interest in that the C system (see above) and the B system were shown to be independent.

We have not considered the statistical methodology pertinent to these problems. Reference to three previous works may be helpful. Applications of χ^2 have been given by Race and Sanger (1958). An introduction to the methods of gene frequency calculations and the application of χ^2 has been presented by Mourant (1954). In cases where χ^2 is not pertinent, the Z test for the significance of the difference between proportions and the t test for the significance of the difference between means are useful (see, for example, Freund et al., 1960).

Application to Fishery Problems

On a practical basis, the general "subpopulation problem" in fishery biology involves (1) the definition and recognition of the interbreeding unit and (2) the delineation of its geographic range, including its spawning range and its total range.

This general problem is usually encountered in more specific form, and hypothetical examples of three common situations will be considered. (While the examples given above on the occurrence of blood group systems in fishes are pertinent, data on human blood group systems will be used illustratively only because they are much more extensive and not because of any inherent superiority.)

First, are the fish at Area A (which is, say, the area of a fishery) from a single subpopulation or from more than one? Each of the first six samples in Table 1 may be considered to be analogous to fish samples drawn from six Area A's. On the basis of the MN blood group, it may be said that each of these samples represents an interbreeding population. The seventh sample, however, does not conform to Mendelian expectations and must represent individuals from two or more subpopulations. This examination of the data will not indicate how many populations are involved, although it may be recalled that these particular data were made by equal contributions from two of the other groups in the table.

In the case where heterogeneity is found, the subsequent steps taken to determine exactly how many populations are involved and their distributions are difficult to generalize, since they will be determined by the real situation obtaining and how much the investigator knows about it.

Second, are the fish from discrete Areas B and C, which are both fishery areas, of the same population or of distinct subpopulations? As an example, consider the data of Table 1 for Eskimo and Aborigine. These have each been demonstrated to represent an interbreeding population. They are so different it is obvious that they represent two distinct populations, rather than two samples of a single population.

But suppose that, instead of Eskimo and Aborigine, samples from the two areas were represented by Caucasian and Negro. It is obviously impossible to distinguish between these two population units on the basis of the M-N blood group system. However, an additional set of allele frequency estimates (Table 2) for a genetically independent blood group system, the A-B-O system, demonstrates that these two samples are, in fact, from distinct population units ($P < 0.01$). (If these A-B-O data were pooled, representing a single sample drawn from a single area, as in the first hypothetical example, it would only have been possible to conclude that two or more subpopulations were present. The exact number could not have been specified without additional data.)

This particular example emphasizes the obvious: The greater the number of genetically independent

---

* The use of subscripts in the designation of the antigens of the spiny dogfish and of the albacore is probably unfortunate, since there is a conflict in this terminology with the accepted notation for regular subtyping relationships such as are found in the A_1, A_2 series of the A-B-O blood group.

blood group systems by which the organisms may be classified, the more powerful will be the method.

Third, if fish from discrete Areas D and E, which are nonfishery areas, are known to be separate subpopulations and if fish from these separate areas (subpopulations) mingle in Area F, which is a fishery area, what is the relative contribution of each subpopulation to the fishery area? An example is found in Table 1, if the Caucasian data are considered to represent Area D, the Eskimo data Area E and the X data Area F. This is a straightforward problem, since there is a unique combination of the observed blood group frequencies in Areas D and E which will yield those observed in Area F.

Table 2

Frequencies of A—B—O blood groups in two human populations comparable to those represented in Table 1. From Boyd (1939)

N	Population	Percentage of blood types				Allele frequencies		
		O	A	B	AB	${}_pI^A$	${}_qI^B$	${}_rI^O$
500	Negro (U.S.)	47.0	28.0	20.0	5.0	0.181	0.133	0.686
1708	Caucasian (U.S.)	44.0	37.9	13.2	4.5	0.240	0.094	0.668

Advantages and Disadvantages

The advantages and disadvantages of the use of blood group systems in the study of subpopulations of fishes may be summarized. Advantages:

1. The characteristics studied are genetic.

2. Not only can samples be compared, but single samples can be examined with respect to whether or not they were drawn from a single subpopulation.

3. The statistical procedures involved are simple.

4. Recaptures are not required (i.e. there need not be a fishery).

Disadvantages:

1. Blood preservation may be a problem. If it is, the method must be taken to sea.

2. Developing reagents may be difficult and time-consuming.

3. For the full power of the technique to be realized, blood group systems must be identified and it must be possible to recognize one more phenotype than the number of recognized alleles. (This provides the degree of freedom necessary for Hardy-Weinberg analysis.)

It is apparent to us, and, we hope, to others that the use of blood group systems in fishes constitutes an extremely useful and powerful tool in the solution of problems involving the definition and recognition of interbreeding populations. Examples of such problems have been given above. It also seems to us that, in the long run, the use of this tool will lead to more important results in the understanding of populations of fishes in nature, especially in three areas; (1) the genetics (in the classical sense) of fishes; (2) the interaction of fish and environment leading to isolation of population units and the nature of these isolating mechanisms; and (3) population genetics.

Summary

The necessity for studying population units of fishes, the desirability of using genetic characteristics in such studies, and the nature of blood group systems are briefly reviewed.

Examples are drawn from M-N and A-B-O blood groups in man. Examples are given of blood group systems recently found in several bony fishes, including western Atlantic herring, northeastern Pacific sardine, sockeye salmon, albacore tuna, and also in one elasmobranch, the spiny dogfish.

Illustrations are given of how data on blood group systems are useful in attacking the kinds of problems encountered by fishery biologists. It is suggested that such data will also contribute to the solution of broader problems.

References

BIRD, G. W. G. 1959. Haemaglutinins in seeds. *Brit. med. Bull.* **15** (2): 165—168.

BOYD, W. C. 1939. Blood groups. *Tabul. biol.*, Hague, **17**: 113—240.

BOYD, W. C., D. L. EVERHART and M. H. McMASTER 1958. The anti-N lectin of *Bauhinia purpurea*. *J. Immunol.*, 81 (5): 414—420.

FREUND, J. E., PAUL LIVERMORE and IRWIN MILLER 1960. *Manual of experimental statistics*. Prentice-Hall Inc., Englewood Cliffs., N. J., p. viii + 132.

MÄKELÄ, O. 1957. Studies in haemaglutinins of Leguminosae seeds. Thesis supplement no. II. *Ann. Med. exp. Fenn.*, 35, 133 p.

MARR, JOHN C. 1957. The problem of defining and recognizing subpopulations of fishes. pp. 1—6 *In* Contributions to the study of subpopulations of fishes. *Spec. sci. Rep. U. S. Fish Wildl. Serv.* 208, 129 p.

MOURANT, A. E. 1954. *The distribution of the human blood groups*. Blackwell Scientific Publications, Oxford, p. xxi + 437.

MUŽINIĆ, R., and J. C. MARR 1960. Population identification. Rep. Sect. 1. *In FAO, Proc. World Sci. Meet. Biology Sardines & Relat. Species*. Vol. 1.

RACE, R. R., and L. R. SANGER 1958. *Blood groups in man*. 3rd ed. Blackwell Scientific Publications, Oxford, p. xix + 377.

RIDGWAY, G. J., J. E. CUSHING and G. L. DURALL 1958. Serological differentiation of populations of sockeye salmon, *Oncorhynchus nerka*. *Spec. sci. Rep., U.S. Fish Wildl. Serv.* 257, 9 p.

RIDGWAY, G. J., J. E. CUSHING and G. L. DURALL 1961. Serological differentiation of populations of sockeye salmon, *Oncorhynchus nerka*. *Intern. N. Pacif. Fish. Comm. Bull.* no. 3, p. 5—10.

ROYCE, WILLIAM F. 1957. Statistical comparison of morphological data. p. 7—28 *In* Contributions to the study of subpopulations of fishes. *Spec. sci. Rep. Fish., U. S. Fish Wildl. Serv.* 208, 129 p.

ROYCE, WILLIAM F. (MS). A morphometric study of yellowfin tuna, *Thunnus albacares* (Bonnaterre).

SINDERMAN, CARL J., and DONALD F. MAIRS 1959. A major blood group system in Atlantic sea herring. *Copeia*, no. 3, 228—232.

SINDERMAN, CARL J., and DONALD F. MAIRS 1961. A blood group system for spiny dogfish, *Squalus acanthias*. *Biol. Bull., Woods Hole*, 120 (3): 401—410.

SPRAGUE, LUCIAN M., and ANDREW M. VROOMAN (MS). A racial analysis of the Pacific sardine (*Sardinops caerulca*) based on studies of erythrocyte antigens.

STERN, CURT 1960. *Principles of human genetics*. 2nd ed. W. H. Freeman & Co., San Francisco, p. x × 753.

SUZUKI, AKIMI, TADAO MORIO and KOICHI MIMOTO 1959. Serological studies of the races of tuna. II. Blood group frequencies of the albacore in Tg-system. Part I. Comparison of the Indian and the northwestern Pacific Ocean. *Rept. Nankai Reg. Fish. Res. Lab.* no. 11: 17—23.

51.

Methods of Fish Tagging in the USSR. Experiments on Using Different Types of Tags and Methods of Attachment.

By

N. E. ASLANOVA*

Introduction

Experiments on commercial fish tagging are of great importance in studying migrations, distribution and behaviour of fish, as well as for investigating different aspects of fish biology under conditions of artificial rearing. Results of tagging experiments are particularly effective when tagging is systematical and conducted on a large scale.

Types of Tag

In mass tagging an important role is played by the choice of material for tags, types of tags, and methods of attachment. Types of tags and methods of attachment as well as tagging methods have been constantly improved, depending on the objects of tagging, the conditions under which it is carried out and the tasks set.

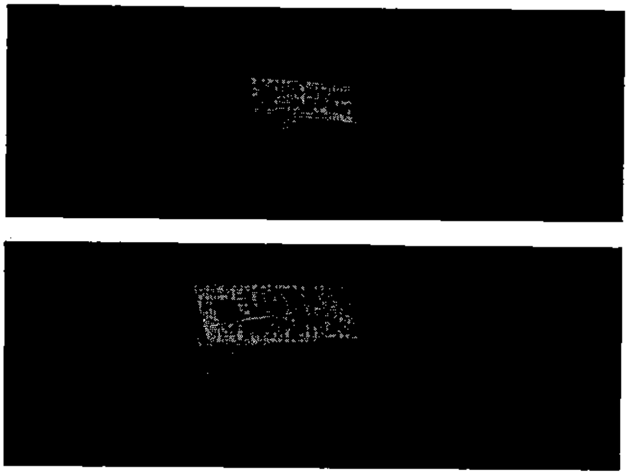


Figure 1. Metal clip-type tags.

For many years the main types of tags used in the USSR for tagging commercial fish have been metal clip type tags (Fig. 1) and suspended strips of coloured celluloid (Fig. 2). The celluloid plates are numbered and lettered and have the name of the country on them. Numbers and letters are stamped or written in black ink, after which the plate is covered with transparent celluloid lacquer.

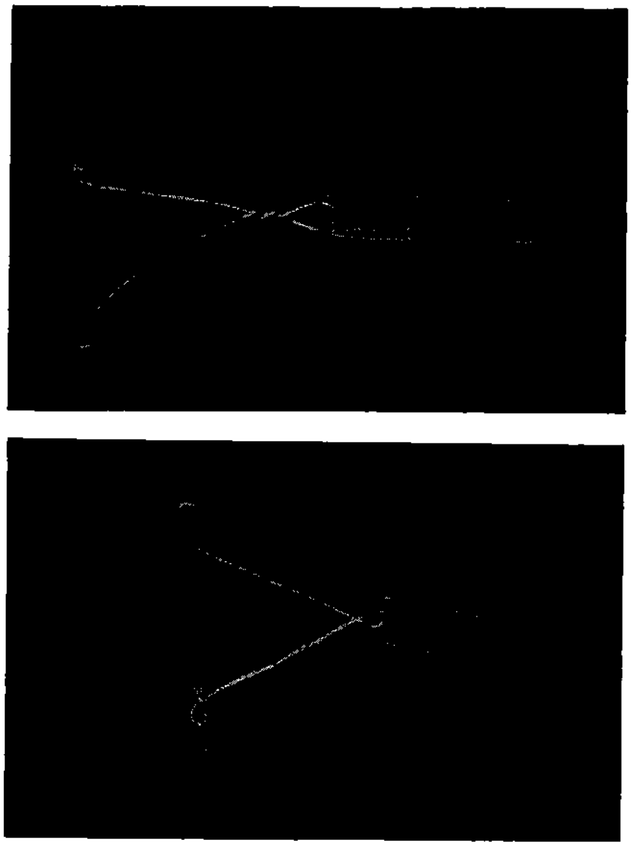


Figure 2. Celluloid plate-type tags

Since 1958 tags of tubular celluloid and polyethylene ("ampoule" type, Fig. 3) and polyethylene film ("envelope" type, Fig. 4) have been used. These tags are hermetically sealed ampoules or envelopes with letters inside containing the address of the tagging agency and instructions as to what is to be done with the tagged fish on recapture. One end of the "ampoule" type tag made of tubular polyethylene is spherical and the other is flat, while in the tag used for tagging flatfish and crabs both ends are flat and rounded with eyelets in them (Fig. 5).

A special type of tag was designed for tagging young or small fish. This is a photocopy of a letter hermetically sealed in transparent polyethylene (Fig. 6).

---

* Senior research worker, Oceanic Fisheries Laboratory, (VNIRO), Moscow, USSR.

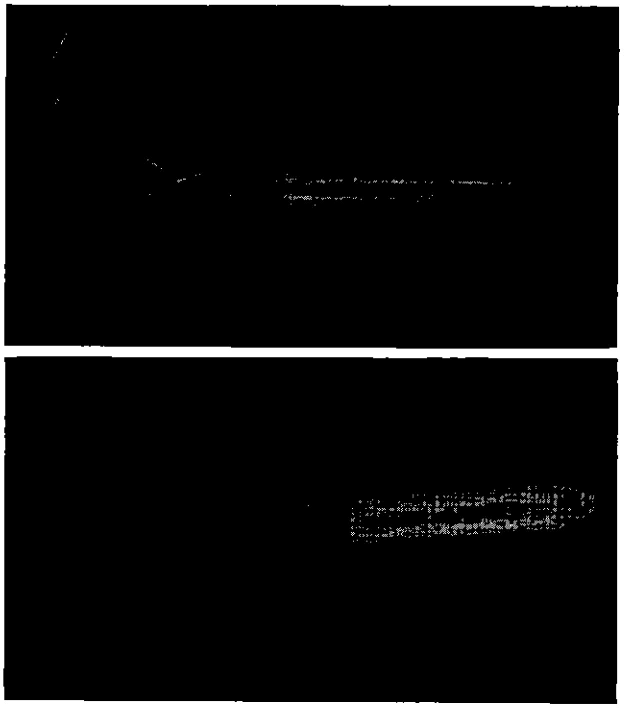


Figure 3. "Ampoule"-type tags of tubular celluloid or polyethylene.

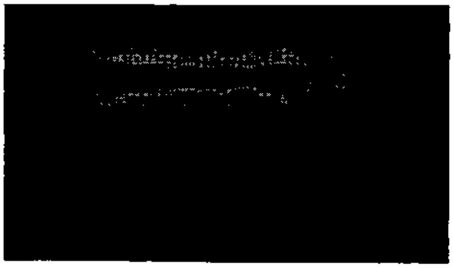


Figure 4. "Envelope"-type tag of polyethylene film.

Table 1

Returns of different types of tags in the course of the first year after tagging

Species	Return of different types of tags as a percentage of the numbers released	
	tags with letter	tags without letter
Clupea harengus pallasii Val.	13.5	1.0
Alosa brashnikovi maeotica Gr.	6.5	1.5
Alosa kessleri pontica Eichw.		
Trachurus mediterraneus (Steindachner)	4.0	0.5
Mugil auratus Risso	7.0	1.5
Lucioperca lucioperca L.	19.0	2.0
Abramis brama (L.)	21.0	3.0
Cyprinus carpio L.	10.3	0.3

Table 1 gives tag return data from tagging commercial fish with different types of tags.

All the above- mentioned tags are attached to fish by means of rustproof wire (monel metal, steel or nichrome) 0.3 to 0.6 mm in diameter, or by kapron or polyethylene thread 0.2 to 0.8 mm in diameter, with the exception of the photocopy type tag which may be either suspended or used as the button type one.

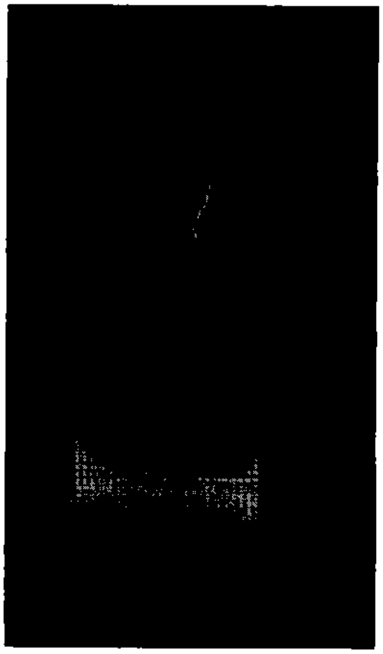


Figure 5. Tubular polyethylene tag for tagging flatfish and crabs.

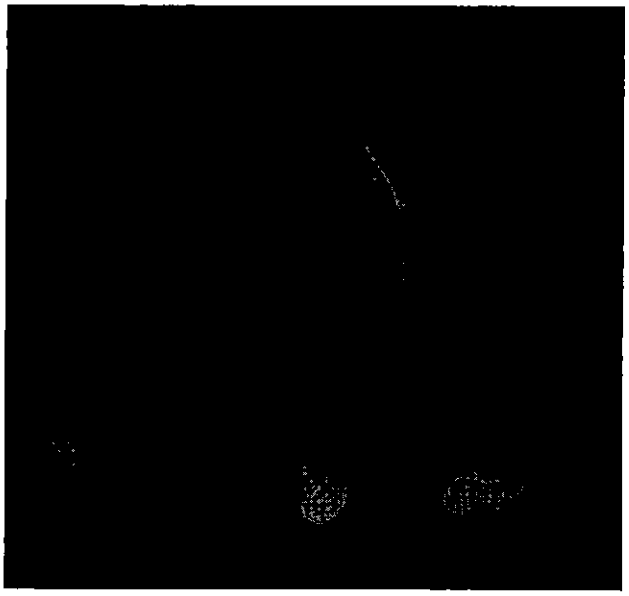


Figure 6. Photocopy-in-polyethylene tag for tagging small or young fish.

Experiments on tagging commercial species carried out in various water bodies show that tags with detailed letters proved the most effective.

Table 2

Returns of the "ampoule" type tags attached with different materials in the course of the first year after tagging as a percentage of the numbers released

Species	kapron thread 0.3 to 0.8 mm in diameter	polyethylene thread 0.3 to 0.6 mm in diameter	wire 0.3 to 0.6 mm in diameter
Alosa brashnikovi maeotica Gr.	1.0	5.0	9.0
Abramis brama L.	6.0	23.0	34.0
Trachurus mediterraneus (Steindachner)	1.0	7.0	7.0
Lucioperca lucioperca L.	2.0	—	36.0

Attachment

Experiments on fish tagging showed that besides the importance of the choice of the most effective types of tags a great deal depends on the choice of material for attaching them. Experiments conducted in aquaria and at sea show that the healing of tagging wounds depends on the material with which the tag is attached. Healing is more rapid when the tag is attached with kapron or polyethylene threads. Therefore kapron or polyethylene threads 0.3 to 0.8 mm in diameter (depending on the species and sizes of fish) may be recommended for attaching suspended tags made of tubular polyethylene and tags consisting of photocopies of a letter sealed in polyethylene. However, preliminary experiments with freshwater fish (*Cyprinus carpio* L.; *Leucaspius delineatus*) (Heck.) in aquaria and with different species (*Alosa brashnicovi maeotica* Gr., *Trachurus mediterraneus* (Steindachner), *Abramis brama* L., *Cyprinus carpio* L., *Acipenser güldenstädtii* Brandt, *Lucioperca lucioperca* L.) under sea conditions show that the tag is more easily lost from fish when it is attached with twisted kapron thread; the ends of the thread seem to untwist easily, the knot becomes loose and finally the tag is lost.

Suspended tags attached with soft rustproof wire remained attached to fish (*Clupea harengus pallasii* Val., *Clupea harengus harengus* L., *Abramis brama* L., *Lucioperca lucioperca* L.) for over 2—4 years.

It was also observed that tagging wounds healed up more rapidly during the period of higher activity in fish (spring and summer) than during the period of lower activity (late autumn and winter), which seems to indicate a connection with metabolism in different seasons.

Handling of Fish

Success of tagging experiments is very much dependent on the proper selection of fish for tagging. About 150 to 200 of the most viable fish are selected for tagging from purse-seine, beach-seine and fixed-seine catches. Marine bottom fish are selected from trawl catches, with the duration of trawling not exceeding 10—15 minutes when the catch is good and 20—25 minutes when the catch is poor.

In exceptional cases fish are selected from fixed net and drift net catches. Fish are disentangled very carefully and, if need arises, the meshes in which a fish has become entangled are cut open.

To keep the fish in a viable condition they are carefully removed with the help of a dip-net (made of fine meshed netting for large fish and of silk gauze for small or young fish) from the gear to tanks, ponds or boats filled with water.

Live-fish tanks are made of various materials. If tagging is conducted on board the ship tanks are usually made of watertight canvas or any other rubberized cloth, and are 1.5 × 1. 5 × 0.6 m in size for large fish and 1 × 1 × 0.5 m for small fish. Tagged fish are released from a tank 0.4 to 0.6 m in diameter and 0.4 to 0.7 m in height which is suspended from the ship's boom and lowered to the sea. Sometimes the tagged fish are liberated by hand; in this case they are put in a bucket or a smaller tank. Usually live-fish tanks have a running water supply or, if not, water is changed often, particularly in hot weather.

In the course of the tagging experiment the fish are either removed from the tank with the aid of a dip-net or the inside of the tank is lined with a piece of net, with the edges of the net fastened to the sides of the tank. By pulling up the net to the surface of the water the fish are removed for tagging.

When tagging is conducted at coastal or river stations it is preferable to put fish into a boat filled with water or into a net pond. Fastened to the side of the boat there is a special net or wooden cage with a side lid to provide for a simultaneous release of a school of fish. Experiments show that it is advisable to release schooling fish in shoals consisting of 25—50 fish (depending on the species and size).

In arranging gear for a tagging experiment care should be taken to have everything handy including a register for writing down information on the fish tagged, tags with attaching wire or thread, needles, scale envelopes and a special cradle for measuring and keeping fish while the tag is being attached.

The tagging process should be a speedy one. During it the fish should be kept in water; therefore a special cradle is used which is made of organic glass and has a measurement scale on the bottom. Different sizes of cradles are used — from 30 × 12 × 9 cm to 80 × 30 × 20 cm — depending on the species and sizes of fish; very large fish (over 75 cm long) are measured with a centimetre tape and the tag is attached without removing fish from the pond.

Tags are attached 1 to 1.50 cm (for large fish) or 0.5 to 0.8 cm (for small fish) ahead or behind the dorsal fin, and 0.5 to 0.8 cm (for large fish) or 0.15 to 0.2 cm (for small or young fish) below the edge of the fish's body. It is very important to observe this rule, for the attachment of the tag nearer to the fin prevents its normal vibration, while its attachment further below is not conducive to a rapid healing of the wound and sometimes disturbs co-ordination of movements in fish.

To attach the tag the dorsal muscles are pierced with a hypodermic needle, after which the thread or the wire is inserted into the sharp tip of the needle and the needle is pulled back leaving the thread or the wire in the pierced hole. The ends of the wire are twisted together and the ends of the thread are double knotted.

A photocopy-in-polyethylene tag is attached with a polyethylene thread in the same way as the button-type tag; the thread is held over a burning match, a cigarette lighter or soldering iron.

Attachment with a kapron thread is made with the help of either a medical needle with an open eyelet or a common needle (using a special device for threading it).

If metal wire 0.5 mm to 0.6 mm in diameter is used the muscles of the fish are pierced with the wire itself. To sharpen the end it is cut obliquely.

Apart from the application of this or that method the success of the tagging experiment depends on the general arrangements and the available information. To encourage the people in sending the recovered tags back explanatory work is conducted by means of press, radio, posters and lectures on the aims and results of tagging fish.

In order to work out methods of tagging commercial fish and new types of tags, as well as with the purpose of exchanging information, all fishery research institutions co-ordinate their programs of work.

The following are the main targets of future work:

1) to extend tagging experiments, with the aim of estimating the size of fish stocks and their utilization by the fishery as well as with the aim of settling problems connected with fish culture; 2) to improve methods of tagging commercial fish and to work out designs of effective fish tags and means of their attachment.

Summary

Various types of tags are used in the USSR for tagging commercial fish and their young (Figs. 1—6).

Tagging experiments with *Clupea harengus pallasii* Val., *Alosa brashnikovi maeotica* Gr., *Alosa kessleri pontica* Eichw., *Trachurus mediterraneus* (Steindachner), *Mugil auratus* Risso, *Lucioperca lucioperca* L., *Abramis brama* (L.), *Cyprinus carpio* L. showed that the return was much higher when fish carried tags with a detailed letter rather than numbered tags with only the name of the country and the tagging agency (Table 1).

Tags were attached by means of wire made of monel metal, steel or nichrome 0.3 to 0.6 mm in diameter, or with kapron or polyethylene threads 0.3 to 0.8 mm in diameter, in a position 1 to 1.5 cm (for large fish) or 0.5 to 0.8 cm (for small fish) ahead or behind the dorsal fin, and 0.5 to 0.8 (for large fish) or 0.15 to 0.2 cm (for small fish) below the dorsal edge of the fish's body. It is very important to observe this rule, for the attachment of the tag nearer to the fin prevented its normal vibration, while its attachment further below was not conducive to a rapid healing of the wound and sometimes disturbed co-ordination of movements in fish.

The wound healed up more rapidly when the tag was attached with a kapron or polyethylene thread.

It was also noticed that the wound healed up more rapidly during the period of higher activity in fish (in spring and summer) and less rapidly during the period of lower activity (in late autumn and winter). This may be connected with metabolism in different seasons.

It should be mentioned, however, that the tag attached with twisted kapron thread was lost more often than that attached with polyethylene thread or wire.

In the first year after tagging, under equal conditions the return of the "ampoule" type tags attached with wire was higher than that of tags attached with kapron thread (Table 2).

52.

Distribution of *Lernaeocera branchialis* (L.) on Cod as an Indicator of Cod Movements in the Newfoundland Area

By

WILFRED TEMPLEMAN and A. M. FLEMING*

Introduction

From 1947—53 most of the samples of cod processed by the St. John's Station for length, sex, sexual maturity and otolith removal were checked for *Lernaeocera branchialis* (L.) by turning each cod on its back and spreading the operculum and gills wide so that adult *Lernaeocera* could be observed in their usual position at the ventral anterior apex of the gills. This examination was not detailed enough to detect the smaller 'Pennella' stages.

Preliminary brief reports on some of the results of these investigations of the distribution and amount of *Lernaeocera* infestation of cod have been given in: Templeman, Fleming and Squires (MS, 1950); Biological Station, St. John's, Nfld. (1951); and Templeman (1953).

In these data cod infested with *Lernaeocera* ranged in fork length from 21—30 to 81—90 cm. Eighty-seven per cent of the inshore cod examined and included in Figs. 1 and 2 were between 41 and 80 cm and 94% between 21 and 90 cm.

Most of these samples were collected between June and September, but samples from all months of the year are included.

Length of Life of *Lernaeocera*

In different samples of generally over 100 cod there were the following high percentages (over 9%) of the cod infested by living adult *Lernaeocera*: for January 10.9; February 13.1, 17.5; March 9.3, 9.4; May 13.3; June 9.2, 10.0, 18.2, 18.9, 28.4; July 11.8, 11.8, 18.6; August 10.9; September 10.4; and for December 14.8, 23.0, 26.1. Additionally in 3 different samples taken in November 5.8, 6.4 and 6.4% of the cod were infested with *Lernaeocera*.

Thus, large numbers of adult *Lernaeocera* may be present on cod at any time during the year. The cod examined were random samples which mainly contained fish of commercial size. Although, therefore, the matter of percentage infestation needs further examination in relation to size of fish in different areas and to season, as a first approximation the percentages of cod infested with *Lernaeocera* may be considered without regard to season and size of fish.

Percentage Infestation by *Lernaeocera*

Figure 1 shows the numbers of cod examined for *Lernaeocera* and Fig. 2 the percentages of these cod infested with living adult *Lernaeocera* in the years 1947—53 in various 1-degree longitude, $^1/_2$-degree latitude rectangles. Most of the samples contained more than 100 fish.

Infestation with *Lernaeocera* had a high relationship to the inshore area, all infestation rates of 10% and over being close to shore. In the area east and southeast of Newfoundland the amount of infestation decreased approximately in proportion to distance from shore. In the Grand Bank-St. Pierre Bank area and the neighbouring Avalon Peninsula and Burin Peninsula inshore areas, for example, there were some high rates of infestation near shore, 10.3—18.3% near the Burin Peninsula and 5.1—10.4% in some rectangles near the Avalon Peninsula. On St. Pierre Bank infestation decreased rapidly southward from the coast and on the Grand Bank rapidly eastward and southward from the coastal area, with no infestation noted on Flemish Cap and only a trace at the southeastern tip of the Grand Bank. On the northern and northeastern Grand Bank there were occasional rectangles with infestation rates as high as 4.1—4.2%, although most samples in these areas had low rates of infestation.

Similarly the Gulf of St. Lawrence offshore infestation rates were low compared with infestation rates on the west coast of Newfoundland and in the Strait of Belle Isle.

Off Labrador, inshore infestation rates were lower than off Newfoundland and no higher than in the offshore area which in this region is relatively close to shore.

The highest infestation rates in the inshore area were in the warmer rather than in the colder parts of the Newfoundland area — in the region from the Burin Peninsula west to the southern half of the west coast of Newfoundland. Intermediate rates of infestation were observed on the colder northeast coast of Newfoundland, and infestation in the coldest area, Labrador, was low.

Discussion and Conclusions

In order to use the adult *Lernaeocera* as a natural tag it is essential that (a) infestation of the cod by

---

* Fisheries Research Board of Canada, Biological Station, St. John's, Nfld., Canada.

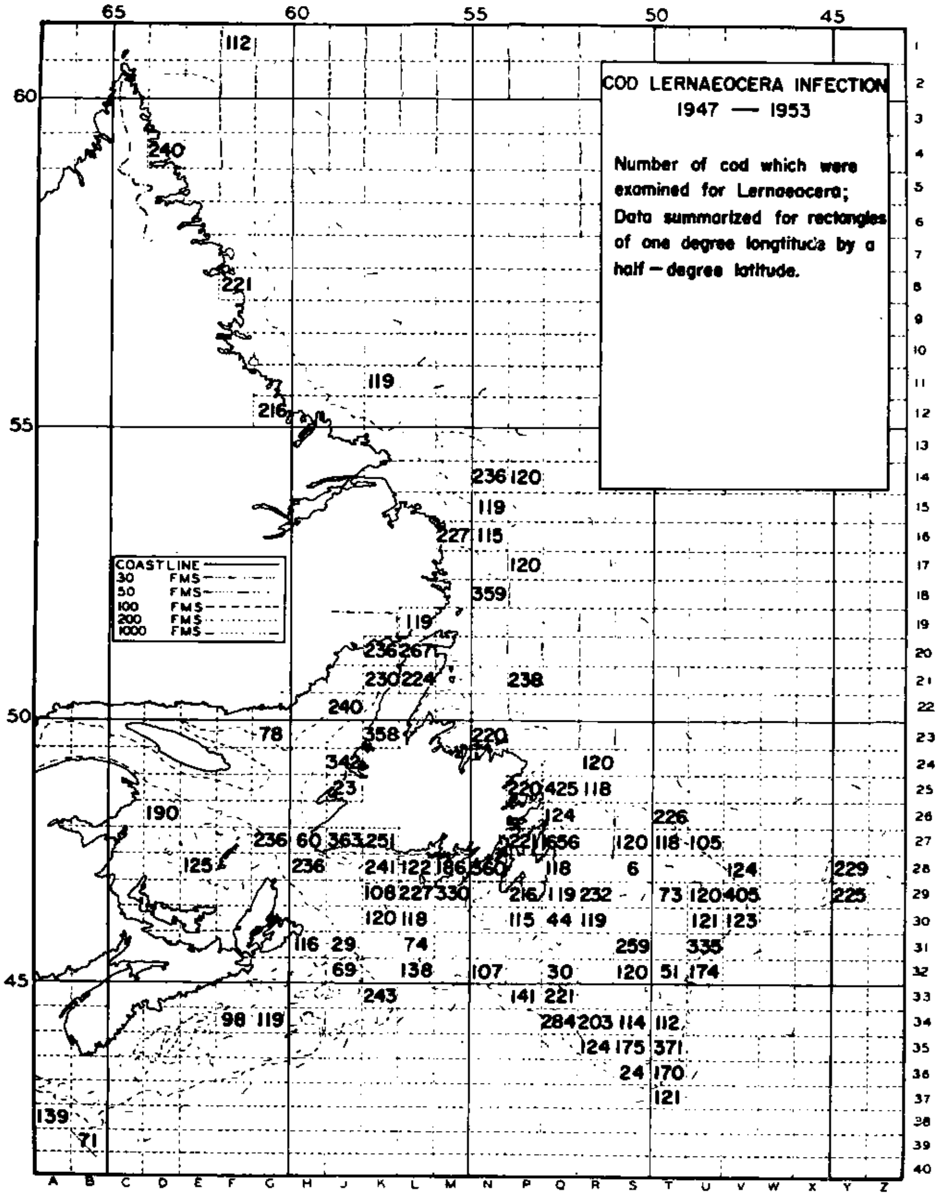


Figure 1. Number of cod in each 1°-longitude, $^1/_2$°-latitude rectangle examined for infestation by *Lernaeocera branchialis*, 1947—53.

the larval parasite should not be uniform over the whole area; (b) the infesting larva should have only a small planktonic range between the intermediate and final hosts: (c) the intermediate host, in this case the lumpfish, should not, during the presence of the late stage *Lernaeocera* larva on its gills, have a widespread dispersal over the whole area; and (d) the adult phase must not be a transitory one but should last at least a year and preferably longer.

The *Lernaeocera* larva is rather unwieldy for a purely planktonic existence at the time when it liberates itself from the lumpfish gill and, although complete evidence is lacking, most students of the larval stages (Stekhoven and Punt, 1937; Sproston and Hartley, 1941; Capart, 1947, 1948; Kabata, 1958) agree that the planktonic existence of the fertilized female must be a very short one, at the most a few days. Since in the Newfoundland and

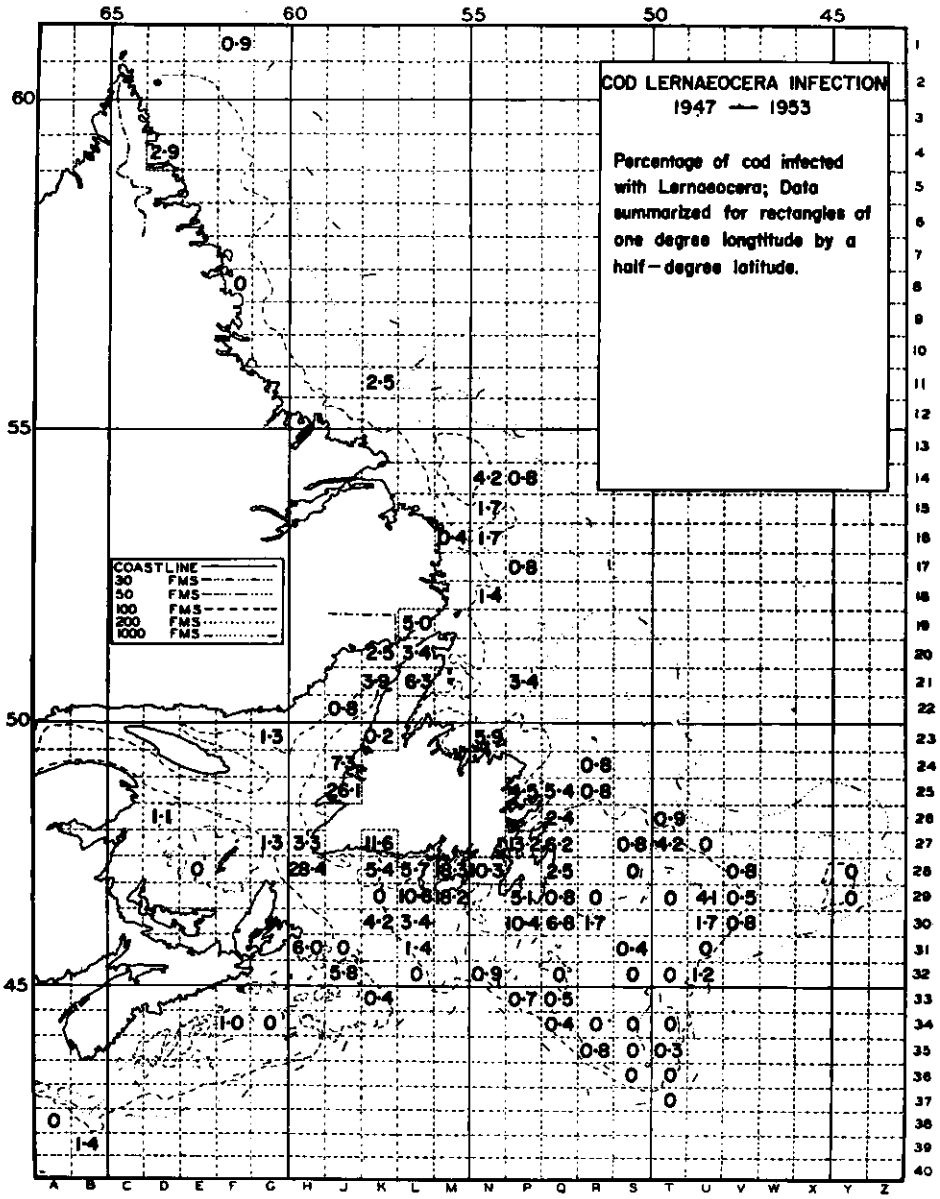


Figure 2. Percentage infestation of cod (of Figure 1) by adult *Lernaeocera*, 1947—53.

Labrador areas this liberation is generally likely to be near the coasts (see later discussion) and the coastal currents have an onshore trend, these larvae should infest cod mainly near the coast.

Lumpfish with gills highly infested with *Lernaeocera* larvae have been found only near the shore. Although proof of the length of life of individual *Lernaeocera* is not available, we have found (see introduction) high percentages of cod carrying adult *Lernaeocera* throughout almost all months of the year and, indeed, since cod are absent from the immediate inshore shallow waters of the area in the winter time, in order to carry out the life cycle in the shallow inshore area with the lumpfish, the minimum life cycle of the parasite on the cod must be almost a year in length.

Stekhoven (1936) and Stekhoven and Punt (1937), from studies at Helder, Holland, on a small number of cod, conclude that there is an annual cycle of infestation, with the highest intensity occuring in mid-summer.

Sproston and Hartley (1941) produce evidence that, at Plymouth, generations of *Lernaeocera branchialis* larvae are being produced continuously all year round on the flounder, *Pleuronectes flesus* (L.).

Capart (1947, 1948) is of the opinion, but without offering adequate evidence, that the attaching phase is only on very young cod in the immediate inshore region, and since these parasites are still to be found on cod up to 10 or more years of age the adult parasite must live for a number of years.

Heegaard (1947) kept adult females of *L. branchialis*, removed from the host, for up to 2 months without nourishment, in sea water in a plunger jar at temperatures of 6 to 8° C. The specimens were alive after 2 months when the experiments were interrupted. During this period a female spawned twice and hatched its eggs. Thus in the *Lernaeocera* attached to its cod host there can presumably be a number of egg extrusions and spawnings, and this increases the probability of a relatively long life for the adult *Lernaeocera*.

Kabata (1958) presents evidence that the life of the closely related *Lernaeocera obtusa* on haddock of the North Sea area is about $1^1/_2$ years and the adult reproductive phase about a year.

The only intermediate host found for *Lernaeocera branchialis* in the Newfoundland area up to the present time is the lumpfish, *Cyclopterus lumpus* L. (Fleming and Templeman, MS, 1951; Biological Station, St. John's, Nfld., 1952; also for the New England region — Sherman and Wise, 1961). Lumpfish are common in inshore Newfoundland waters for spawning and egg-incubation purposes in May-July, and by the latter part of June and especially by July a small proportion of the *Lernaeocera* larvae on the lumpfish gills in the inshore waters of the east coast of Newfoundland were in the final or 7th stage. In the inshore waters of the west coast of Newfoundland by July almost all the *Lernaeocera* larvae on the lumpfish gills were in the 7th stage. August samples of lumpfish gills are lacking in our records, but by September the few lumpfish obtained from the east coast inshore area had comparatively few *Lernaeocera* remaining on their gills. These larvae were usually extremely scarce or absent on the gills of lumpfish taken offshore.

Lernaeocera larvae in their period of transfer from lumpfish to cod apparently have only a brief free-swimming period. Thus, from present evidence, cod infestation apparently occurs mainly inshore from mid-summer to early autumn on the east coast of Newfoundland, but a month or more earlier on the west coast of the island.

The cod of the southeastern Grand Bank and of the Flemish Cap are the most distant from the Newfoundland coastal areas and have the lowest infestation with *Lernaeocera*. The very low infestation on the southeastern Grand Bank indicates some, but very little, mixing with the coastal areas and this is also indicated by the results from tagging experiments (Templeman and Fleming, MS, 1961 and unpublished data). Relatively distinct coastal and southeastern Grand Bank cod stocks are also indicated from distinct differences in vertebral averages (Templeman, 1953; Fleming, 1958). No *Lernaeocera* infestation has been found in the cod of Flemish Cap, although moderate infestation rates exist in the neighbouring northeastern Grand Bank areas. No cod-tagging results are available for Flemish Cap, but vertebral averages on Flemish Cap are consistently lower than those of the neighbouring deep-water areas of the northeastern Grand Bank, and spawning is in February-March on the Flemish Cap and in May—June on the northeastern Grand Bank. Thus the cod stocks in the two areas are presumably distinct, as is indicated by the data on *Lernaeocera* infestation.

Assuming that infestation with the parasite occurs chiefly in the inshore area, the moderate (4.2%) infestation by *Lernaeocera* in the northern Grand Bank rectangle 27T and the generally higher infestation rates in this area are indicative of migration of inshore cod from the east coast of Newfoundland to these northern Grand Bank areas. This agrees with the known distribution (from the unpublished tagging returns of the St. John's Station) of some cod from the east coast of Newfoundland, especially in spring (and presumably in winter), to the northern edge of the Grand Bank, and also with the existence, around the northern edge of the Grand Bank, of cod having high vertebral counts similar to those of cod from the east coast of Newfoundland. Reasoning from the locations of recapture of cod tagged inshore, the cod with the 4.1% infestation in 29U and with the lower infestation rates of 0.5—1.7% in neighbouring rectangles on the northeastern corner of the Grand Bank are on the outer fringe of coastal cod migration. They are, however included within the high vertebral count stock typical of cod of the east coast of Newfoundland.

The low rates of infestation of inshore cod in Labrador and the intermediate infestation rates on the east coast of Newfoundland compared with the higher rates on the south coast and on the southern part of the west coast of Newfoundland may have some relationship to the lower inshore temperatures in the two former regions. However, it is unlikely that this is more than a partial explanation since the Greenland cod, *Gadus ogac* Richardson, which, in Labrador, lives still closer to the shore than the Atlantic cod, may be very highly infested, e.g., 44% infested with *Lernaeocera* in a sample of 25 Greenland cod from Nutak in August 1948 and 79% infested in a sample of 19 Greenland cod from Domino, July 1948.

Because the free-swimming larval period of the 7th stage *Lernaeocera* is so short, explanations of infestation rates in inshore areas will need to take account of the times and places of lumpfish location and spawning and the relation of the abundance of different sizes of cod to the location of lumpfish infested with the final stage larvae. The remaining part of the cycle from adult infestation on the cod to larval infestation on the lumpfish gills must also be considered. The present data, while extensive, are not adequate to answer all these questions. The complete data on adult *Lernaeocera* infestation by size of cod and on the infestation of the lumpfish gills by larval *Lernaeocera* will, however, be published later in the Journal of the Fisheries Research Board of Canada.

Summary

Researches on the infestation of cod of the Newfoundland and neighbouring areas with adult *Lernaeocera branchialis* (L.) were carried out from 1947—53.

Infestation with *Lernaeocera* was highly related to the inshore area, all rates of 10% and over being close to shore and infestation declining approximately in proportion to distance from shore, with none on Flemish Cap and very little on the southeastern parts of the Grand Bank.

The interrelationships of cod stocks in the eastern and southeastern Newfoundland coastal areas to those of the neighbouring offshore bank areas, as deduced from the amounts of *Lernaeocera* infestation, are similar to those indicated by tagging and meristic studies.

References

Biological Station, St. John's, Nfld. 1951. In *Rep. Fish. Res. Bd Can.*, 1950: 26—38.

Biological Station, St. John's, Nfld. 1952. *Ibid.* 1951: 43—65.

CAPART, ANDRÉ. 1947. Le *Lernaeocera branchialis* (L.), copépode parasite des gadides. *J. Cons. int. Explor. Mer*, 15: 69—76.

CAPART, ANDRÉ. 1948. Le *Lernaeocera branchialis* (Linné 1767). *Cellule*, 52: 159—212.

FLEMING, A. M. 1958. Differentiation of cod groups in the Newfoundland and Labrador region. *ICNAF, Spec. Publ.* No. 1: 331.

FLEMING, A. M., and W. TEMPLEMAN. 1951. Discovery of larval forms of *Lernaeocera branchialis* on lumpfish. *Rep. Fish. Res. Bd Can. Biol. Sta., St. John's, Nfld.*, 1951 (mimeo.). App. No. 11: 19—20.

HEEGAARD, POUL. 1947. Contribution to the phylogeny of the arthropods. *Copepoda. Spolia zool. Mus. Hauniensis* 8: 1—229.

KABATA, Z. 1958. *Lernaeocera obtusa* n. sp. — its biology and its effects on the haddock. *Scot. Home Dep., Mar. Res.*, No. 3.

SHERMAN, KENNETH, and JOHN P. WISE. 1961. Incidence of the cod parasite *Lernaeocera branchialis* L. in the New England area and its possible use as an indicator of cod populations. *Limnol. Oceanogr.*, 6: 61—67.

SPROSTON, N. G., and P. H. T. HARTLEY. 1941. The ecology of some parasitic copepods of gadoids and other fishes. *J. mar. biol. Ass. U.K.*, 25: 361—92.

STEKHOVEN, J. H. SCHUURMANS. 1936. Beobachtungen zur Morphologie und Physiologie der *Lernaeocera branchialis* L. und der *Lernaeocera lusci* Bassett-Smith (Crustacea parasitica). *Z. Parasitenk.*, 8: 659—96.

STEKHOVEN, J. H. SCHUURMANS, and A. PUNT. 1937. Weitere Beiträge zur Morphologie und Physiologie der *Lernaeocera branchialis* L. *Z. Parasitenk.*, 9: 648—68.

TEMPLEMAN, WILFRED. 1953. Knowledge of stocks of cod, haddock, redfish and American plaice in Subareas 3 and 2 of the Northwest Atlantic Convention area. *ICNAF Annu. Proc.*, 3: 62—66.

TEMPLEMAN, WILFRED, and A. M. FLEMING. 1962. Cod tagging in the Newfoundland area during 1947 and 1948. *J. Fish. Res. Bd Can.* 19: 445 — 81

TEMPLEMAN, W., A. M. FLEMING and H. J. SQUIRES. 1950. Studies of *Lernaeocera branchialis* in the Newfoundland area. *Rep. Fish. Res. Bd Can. Biol. Sta., St. John's, Nfld.*, 1950 (mimeo.). App. No. 8: 9—11.

53.

Herring Tagging in the North Sea and Eastern English Channel

("President-Théodore-Tissier", November 1957)

By

J. ANCELLIN*

Introduction

Herrings were tagged in co-operation with foreign scientists in November, 1957 in the southern part of the North Sea and the eastern part of the English Channel, with the purpose of evaluating the extent to which the stocks of herring are exploited by the fishery and the possibility of an overfishing of these stocks.

The present report considers only the techniques of tagging and the conditions for recovery of tagged fish. The results obtained have been the object of a complete analysis published elsewhere (Ancellin and Nédèlec, 1959).

Methods

1. Tags and tagging gear used

All the French tags used were external. The majority were yellow, red or black celluloid discs bearing the letters "RF" followed by a serial number. These tags, provided with a notch, were attached to the back of the herring with nylon string which was passed through the tissues of the back by means of a Reverdin-needle (Ancellin, 1955). A total of 9,897 herring were tagged with this type of tag. Other types of tags were used by the scientists of other countries participating in the experiments, as follows: —

English tags: Three different types were used, all fixed to the fish by means of the Scottish "toggle attachment" (Wood, Parrish and McPherson, 1955). A total of 565 fish were tagged with these types: —

a. yellow button with a white disc (un-numbered) and a violet cotton string (Bolster tag).
b. an orange rubber cup with a white disc and a numbered steel disc (Bolster tag).
c. a flap of transparent plastic (Hodgson tag).

Danish and Norwegian tags: Lea tags, a hydrostatic yellow or blue tag containing a roll of paper with information, attached by means of a metal pin protected by a layer of plastic. A total of 501 Danish and Norwegian tags were used.

Scottish tags: A label in a container of transparent plastic attached by means of a metal safety pin. Of these tags, 683 were used.

2. The tagging operation

All fish tagged were caught by trawl. The otter trawl used had, based on various trials, a head rope of 31.15 m, a ground rope of 50.60 m, and wings measuring 15 m; it was provided with two lifting kites. During the first part of the experiment a trawl of this type with exclusively manila netting was used; during the second part exclusively nylon netting was used.

The duration of the hauls was in the main determined after thorough observations of the echo soundings. The most advantageous operation was a haul of only ten minutes over a stretch where the concentration was found to be dense but not too far from the bottom (between the bottom and 7—8 m); such a haul yielded fish in good condition with only little loss of scales. When brought on deck the herring were strong alive; they were immediately transferred to the tanks. The maximum number tagged from such a haul was 957.

The herring were tagged on the deck in two tanks in which there was continuous circulation of sea water. The tagged fish were returned to the sea in containers of water lowered into the sea alongside the vessel, when this was stopped or only moving slowly.

After the first week of the operation, the fish tagged were divided into the following three categories:

Category A: fish which had lost less than one-third of the scales;
Category B: fish which had lost from one-third to two-thirds of the scales;
Category C: fish which had lost over two-thirds of the scales;

and the category letter was recorded for each fish tagged.

3. Places and dates of tagging

Details of the tagging experiments are given in Table 1; all took place in areas where the trawlers were fishing, except for one or two at the border of the fished area.

Study of the Various Factors thought to Influence the Number of Recaptures

From a total of 11,648 tagged herring 367 or 3.15% were returned during the first fourteen months following the tagging, the large majority in the first three weeks after liberation.

---

* Institut Scientifique et Technique des Pêches Maritimes, Boulogne, France.

Table 1
Places, dates and numbers of tagged fish released

Region	Mean Position	Dates	Number of tagged fish	Fishing Activity
A	SANDETTIE 51°12′N, 1°54′E	5—12 November 1957	1,529	c 100 trawlers
B	off CAP BLANC NEZ 51°04′N, 1°38′E	13—18 November 1957	1,934	80—100 trawlers
C	VERGOYER 50°38′N, 1°17′E	19—21 November 1957 26—28 November 1957	5,833	20—90 trawlers
D—E	AILLY D: 50°19′N, 0°38′E E: 49°58′N, 0°18′E	22—25 November 1957 29 November 1957	2,352	36—140 trawlers

Numerous factors may influence the percentage of recaptures: the condition of the fish caught and the mortality due to the tagging procedure; the type of tag used (internal or external, the method of attachment, colour of tags, etc); the behaviour of the herring schools; the smaller or greater dispersion of fish from the tagging place; and the conditions for the fishery (weather, etc).

The analysis of the data obtained gives some information on the various factors, which will be considered in the following pages.

1. Condition of fish

As mentioned above the herring tagged were classified in three categories depending on the degree of damage to the scales. The percentages of returns from the French tagging experiments for the first ten months after liberation are: category A — 3.95%, B — 2.28%, and C — 1.91%.

It is apparent that the condition of the fish affects the percentage of returns, which are considerably lower for the weakest fish (category C). This is shown in the following table: —

Category	Numbers		Percentage returned
	Released	Returned	
A	1822	72	3.95
B	2943	67	2.28
C	2045	39	1.91

The results confirm those obtained by Jensen (1955) from herring tagging in the Danish straits, for which a range of between 4 and 25% was observed for returns of fish of different quality.

A summary of the mortality rate in relation to the condition of the fish when tagged is presented in Figure 1. It appears that the recaptures of category C fish, and to a minor degree of B, are spread over a

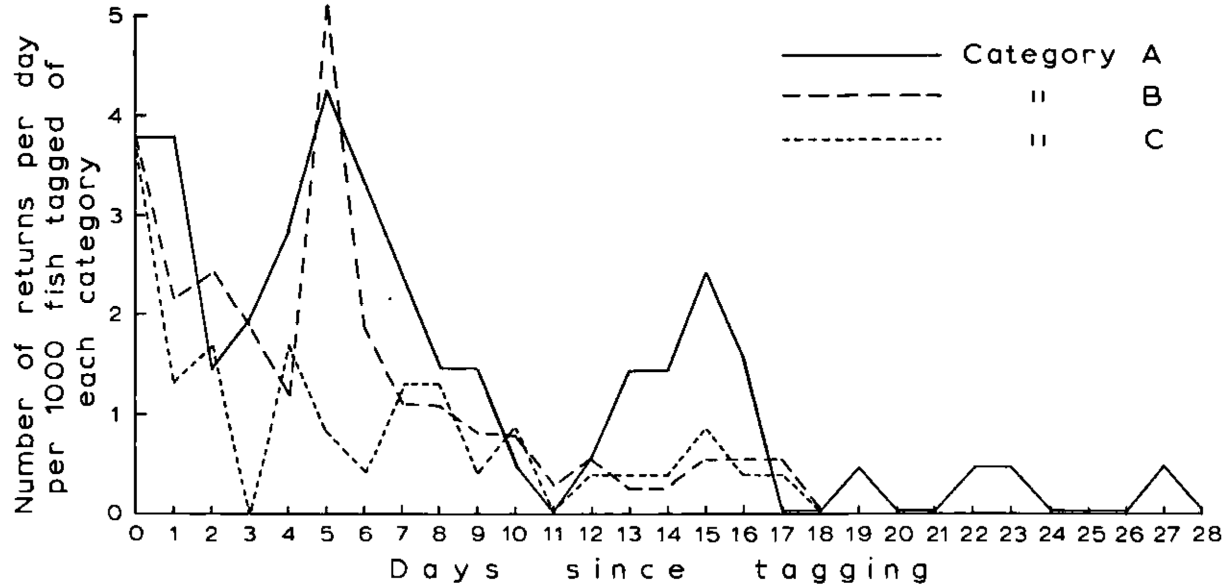


Figure 1. Rates of return of tagged herring each day after tagging.

shorter period than those of category A. The numbers of recaptures decrease much more rapidly with increasing time at liberty for the categories B and C than for A. This difference is probably in the main due to the higher mortality during the days following the tagging for fish with moderate or large losses of scales. It is more difficult to estimate the mortality of category A fish; it appears, however, that it can be regarded as fairly small, at least during the first period, because the fish used were in good condition and caught in rather shallow water (Aasen, 1954; Wood et al., 1955).

The small number of recaptures of fish of category A after the first three weeks is probably due to other causes and especially to the fact that the shoals leave the fishing grounds, as described later in this paper.

2. Types of tags used

Certain types of tags yield higher percentages of returns than others, all other conditions being the same. Table 2 shows for five types of tags the percentages of returns observed in experiments with fish tagged in the same places and under the same conditions.

It is apparent that the percentage of returns is highest for the Lea tags, three to four times as high as for the French tags, under the same conditions, including category of fish. This fact once more confirms previous observations by other scientists (especially Jensen, 1955; Höglund, 1955; Wood et al., 1955). The high efficiency of the Lea tag is probably due, in the main, to the greater attention they gain from presenting a tube containing a letter and to their conspicuous yellow and blue colours. The high rate of returns for the Lea tag is also in part due to the fact that the Danish scientists only included in category A herrings which had retained practically all their scales.

The French tag appears to have about the same efficiency as the English and Scottish. Possibly the slightly lower percentage of returns for the French tag compared to the two others is due to the fact that the French tagging comprised proportionately fewer fish of category A than did the English and Scottish experiments. For the French tags differences in percentages of returns according to the colour of the tags were: red — 2.0%, yellow — 2.7%, black — 3.2%. One advantage of the English and Scottish tags is that these tags can be attached by one single operator. On the other hand the French tag has the advantage of being less expensive. It could be used in combination with the Scottish method of attachment i.e., the "toggle attachment" or the clasp-safety-pin.

The method of attachment can also influence the efficiency of the tags. It is established beyond doubt that tags attached by means of a nylon string, especially when the string is non-twisted, do — after the elapse of some time — tend to work themselves free by cutting the tissues of the fish. This has been confirmed in tank experiments (Wood et al., 1955); however, in these experiments the loosening of the tags only began two to three months after the tagging. On the other hand, it is to be noted that the metal clasps used, e.g. with the Lea tags, in the long run assure a better attachment of the tags (Wood et al., 1955; Jensen, 1955).

However, it appears that these variations in the efficiency of the attachment of the tags could have no influence on our tagging experiments, in which almost all recaptures were made within one month after liberation.

3. The behaviour and dispersion of the shoals over the fishing grounds

A. Seasonal dispersion

At present it cannot be explained why the recaptures from certain places remain high and from

Table 2
Percentage returns of various types of tags

Stations	French tags			Danish (Lea) tags			Scottish tags	English tags (Bolster)	English tags (Hodgson)
	A	B	C	A	B	C			
527, 532, 533 541, 543, 546	3.40	2.65	1.42	14.00	7.88	6.25			
532, 533, 541, 543 546, 556, 557, 558	All categories 3.25						All categories 3.51		
527, 532, 541 546, 556, 557	All categories 4.08							All categories 4.96	
527, 543, 546	All categories 2.31								All categories 3.45

others low. (A similar phenomenon has been noted by McPherson in tagging experiments carried out in Scottish waters during the summer season.) An example of such a difference is observed, e. g., when comparing station 515 (low percentages of returns) with 541 and 517 (high percentages)*; but for the latter station it should be noted that the herring tagged were in an exceptionally good condition. However, the same difference is very conspicuous for station 532 (tagging 20 November, high %) compared with stations 541, 542, 543 (21 November — low %); the conditions of the fish were almost the same for all four stations. Finally, the differences are also very clear between stations 546 and 548, where the conditions of the fish and for the fishery were the same.

It appears in these cases as if the taggings have been done partly on shoals of fish remaining concentrated on the spawning grounds for the duration of the fishery (high percentages of recaptures), and partly on shoals leaving or about to leave the fishing grounds (low percentages).

In this respect two stations are significant and can offer some explanation concerning the irregularities in number of recaptures. These stations are 546 and 548 (already mentioned), the first (22 November at l'Ailly) with 5.01% of recaptures, the second (24 November at l'Ailly) with only 0.33%. Further, station 546 is four miles west of the fishing ground of l'Ailly and station 548 east of this ground.

If, from the annual trend of the fishery, it is assumed that the spent herring on the whole migrate coastwards, i.e. toward the east, then herring coming from the west would concentrate on their spawning grounds, thus sustaining the maximum exploitation by the fishery. On the other hand, the herring concentrated to the east of the fishing ground would be about completing their spawning and following this would disperse quickly, thus avoiding capture by the trawlers.

This is obviously only a tentative explanation (it is to be noted especially that no difference as to stage of maturity is observed for herrings from stations 546 and 548) and the observations ought to be confirmed by other experiments. But for the present we can consider the tagging experiments as carried out partly on shoals about to leave the fishing grounds (short period of recaptures), and partly on shoals just arriving on the grounds (long period of recaptures).

B. Dispersion over the fishing ground

The dispersion of the herring over the fishing ground, on the contrary, does not need consideration when estimating the removal from the stock by the fishing activity. In effect the tagging experiments were carried out in numerous places within the area where the fish were concentrated, while these concentrations were very limited (within an area of 3—4 miles). Finally, from the movements of the recovered herring one can assume that the majority of the recaptures occurred in the area of tagging (the area of tagging is considered to be the area within a radius of 3—4 miles in which the experiment took place and where the fishery was carried out).

It is further possible to assume — at any rate for the shoals which have revealed a certain stability — that the dispersion of tagged fish from any one of the numerous localities of tagging, themselves divided between the various grounds, would be sufficiently homogeneous so as not to cause great differences in the vulnerability of the fish through the applied fishing effort. This is the reason why no factor for correction has been used.

Summary

Herring tagging experiments were made in November 1957 in the southern North Sea and the eastern part of the English Channel in order to estimate the quantities removed by the fisheries from the herring stocks of these waters, where for several years over-exploitation has been assumed to occur.

Various types of tags were used: Danish, English, French, Norwegian and Scottish.

In order to facilitate the analysis of the results the herring to be tagged were divided into three categories according to the extent of loss of scales. It appeared that a considerable mortality occurred for the fish in bad or less good conditions.

The hydrostatic Norwegian Lea tag appeared as the most efficient, with 15% recaptures for the fish which had suffered the least loss of scales.

The percentages of recaptures varied according to the behaviour of the shoals and their dispersion over and away from the fishing grounds.

References

AASEN, O. 1954. Estimation of stock strength of the Norwegian winter herring. *J. Cons. int. Explor. Mer*, **24**: 95—110.

ANCELLIN, J. 1955. Note sur le marquage des poissons au moyen de l'aiguille chirurgicale de Reverdin. *Rapp. Cons. Explor. Mer*, **140** (2): 7—8.

ANCELLIN, J. & NÉDÈLEC C. 1959. Marquage de harengs en Mer du Nord et en Manche orientale. *Rev. Trav. Inst. Pêches marit.*, **23**: 177—201.

HÖGLUND, H. 1955. Swedish herring tagging experiments. *Rapp. Cons. Explor. Mer*, 140 (2): 19—29.

JENSEN, Å. J. C. 1955. Danish herring tagging inside the Scaw, 1945—1952. *Rapp. Cons. Explor. Mer*, **140** (2): 30—32.

WOOD, H., PARRISH, B. B. & McPHERSON, G. 1955. Review of Scottish herring tagging experiments, 1948—53. *Rapp. Cons. Explor. Mer*, **140** (2): 35—54.

---

* These data are given in Ancellin and Nédèlec, 1959. (Ed.)

54.

A Note on the Tagging of Long-finned Tunny in the Bay of Biscay

By

R. LETACONNOUX[*]

In 1960 four hundred long-finned tunny (*Germo alalunga* Gmel.) were tagged in the Bay of Biscay by the Institut Scientifique et Technique des Pêches Maritimes, on board the vessel "Roselys".

The tunny were caught by live bait and then, as soon as caught, held in a trough of soft rubber where they were tagged. The tags were of the 'spaghetti' type, consisting of a transparent plastic tube, 2.5 mm in diameter and 31 cm long, and containing inside a second yellow plastic tube 9 cm long, with the number of the tag and the address to which it should be returned. When attaching the tag, one end of the tube was threaded into the eye of a large, curved needle and thus passed through the upper part of the back a little in front of the second dorsal. The free ends of the tag were then tied together.

The places and dates of tagging, and the numbers of the tags used, were as follows: —

Date	Latitude N	Longitude W	Tag Numbers
24 July 1960	45°00′	3°00′	RF 401—494
27 July 1960	45°17′	3°03′	RF 1—100 RF 201—275
28 July 1960	45°07′	3°02′	RF 276—300
17—19 August 1960	45°14′	3°14′	RF 101—199

Up to mid 1961 only one tag, number 414, has been returned. This was recaptured one month after release, on 22 August, 115 miles west of the point of release.

---

[*] Institut Scientifique et Technique des Pêches Maritimes, Paris, France.

55.

A Preliminary Study of the Efficiency of some Tagging Experiments in New Zealand

By

K. RADWAY ALLEN*

The tagging experiments on marine fish in New Zealand described earlier in this symposium have been undertaken primarily to obtain data on the movements and growth of the fish concerned. Little attention has so far been given to the planning of experiments to yield data on fishing mortality. The data which are available have however been examined to determine how far they can be used to provide preliminary assessments which can be of value in planning future work.

The two fisheries on which most work has been done are those for the snapper of the Hauraki Gulf area and for the tarakihi of the Gisborne-East Cape region. For these the principal data available are —

1. The total mortality rate as estimated from the age composition of the population.
2. The proportion of tags ultimately returned.
3. The relation between frequency of returns and time interval between liberation and recapture.

The age compositions have been plotted on log-natural scales, and values of total mortality rate (Z) have been obtained from the slopes of lines fitted by eye to the right hand limbs of the curves. These values are considered to be sufficiently reliable for a preliminary assessment, since there are no significant indications of major fluctuations in the strength of year-classes, or of variation in mortality rate with age; owing to the restrictive licensing system in force there has been little change in effort during the period of the observations. Age determinations have been made by scale reading.

The instantaneous rate of disappearance of tagged fish (B) has been estimated from the slopes of the lines fitted visually to the data on the relation between frequency of recoveries and time, plotted similarly. To obtain sufficient data it has been necessary to pool all available returns by plotting the number of returns obtained in each time interval after release, without regard for the actual date of release.

The proportion of tagged fish ultimately returned (R) is determined directly from the data.

With these data three categories of loss of tagged fish may be distinguished:

Natural mortality	M
Fishing mortality	F
Other losses (including loss of tags and emigration)	A

Since $Z = M + F$ and $A = B - Z$, A can be estimated from the available data.

If the effective numbers of tagged fish which had been added to the population were known it would also be possible to estimate M and F and hence the proportion of fish ultimately caught (E). The effective number of releases is however less than the actual number, due to type I losses; a major component of these is deaths and tag losses occurring soon after release, but they also include failures to return recaptured fish, since the proportion not returned may be assumed constant and is, in effect, deducted from the number of tagged fish available in the population.

Although it is not possible to estimate M, F and E without knowledge of the type I losses it is possible to examine the relation between them. If P is the proportion of fish surviving type I losses, then the effective number of releases is NP, when N is the actual number.

Since M is the parameter which is least subject to local conditions it seems most useful to express the other unknowns in terms of M. We then get

$$P = \frac{BR}{Z - M},\ E = 1 - \frac{M}{Z},\ \text{and } F = Z - M.$$

For snapper $Z = 0.35$, $B = 2.23$, $R = 0.0147$.

Therefore $P = \dfrac{0.0328}{0.35 - M}$, $E = 1 - 2.86\ M$, and

$F = 0.35 - M$.

For tarakihi $Z = 0.72$, $B = 1.51$, $R = 0.0226$.

Therefore $F = \dfrac{0.0341}{0.72 - M}$, $E = 1 - 1.39\ M$, and

$F = 0.72 - M$.

The curves for P and E are plotted in Figure 1 and it is striking that the value of P varies relatively little over quite a wide range of the more probable values of M. It is also apparent that the tarakihi either is subject to a much higher natural mortality rate than

---

* Director of Research, Fisheries Laboratory, Wellington, New Zealand.

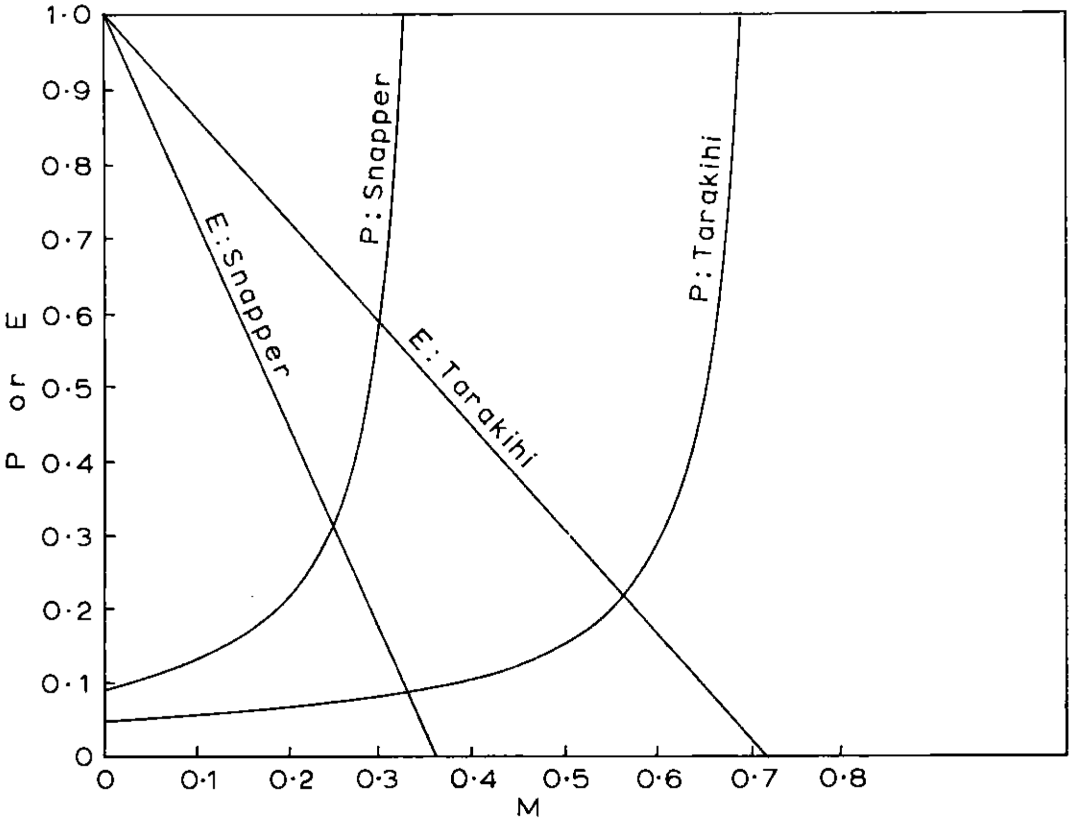


Figure 1. Proportion of fish surviving type I losses (P) and ultimately caught (E), as a function of the natural mortality, M.

the snapper, or is both more heavily fished and subject to greater type I losses. The values of the other parameters corresponding to values of M commonly found in other fish are

	Snapper			Tarakihi		
M	P	E	F	P	E	F
0.1	0.13	0.71	0.25	0.06	0.86	0.62
0.2	0.22	0.43	0.15	0.07	0.72	0.52
0.3	0.66	0.14	0.05	0.08	0.58	0.42

The minimum possible values of E would occur when P = 1, and these are 0.094 and 0.047 for snapper and tarakihi respectively. The data suggest that both species are in fact much more heavily fished, with perhaps 50 per cent of the fish being ultimately caught; they also indicate that type I losses are heavy and that measures aimed at reducing these would be desirable in subsequent work.

Summary

Comparison of the rate of natural mortality with the rate of disappearance of tagged fish and the proportion of tags recovered has been used to determine the magnitude of type I losses and of fishing intensity for various natural mortality rates in two fisheries. The values corresponding to probable natural mortality rates indicate that both type I losses and fishing intensity are high.

56.

Maximum Likelihood Estimation of a Sequence of Annual Survival Rates from a Capture-Recapture Series*

By

D. S. ROBSON**

A homogeneous group of individuals such as a single year-class in a fish population is sampled at successive points in time to determine the survival rate (or death rate) during each successive time interval. Survival rate for any time interval is simply defined to be the ratio of final to initial population size for that interval. With no loss of generality, we shall assume the intervals to be of equal length and shall refer to the survival rate s_k for the k'th interval as an annual survival rate. The problem of estimating population size and survival rate from this type of experiment is covered extensively in the literature (see, for example, Bailey (1951), Hammersley (1953)), but with the assumption of a constant annual survival rate. The present approach to the problem was also taken by Darroch (1958, 1959) who was concerned principally with estimating population size.

Sampling Procedure

The sampling procedure at each anniversary consists of selecting a random sample from the existing population, tagging all untagged individuals (individuals not previously "captured") and noting the year of tagging on each tagged individual ("recaptured" individual) in the sample. At the start of this procedure the population contains no tagged individuals; the first step then consists of capturing, tagging and releasing, say M_1 individuals. After one year a sample is taken from the surviving population and contains, in a notation analogous to Ricker's (1958), R_{12} recaptures along with M_2 untagged individuals. These M_2 individuals are tagged and released along with the R_{12} recaptures. At the next anniversary the sample may contain tags from both the previous releases, as well as untagged individuals; the number of recaptures from the first year's release will be denoted here by R_{13} and the number from the second year by R_{23}, with M_3 new individuals being tagged and released. Continuation of this annual capture-recapture procedure then produces the recapture data shown in Table 1.

Table 1

Tag recaptures classified according to year of tagging and year of recovery

Year of tagging	Number tagged	Year of recapture					Total recaptures
		2	3	4	...	n + 1	
1	M_1	R_{12}	R_{13}	R_{14}	...	$R_{1,n+1}$	R_1
2	M_2		R_{23}	R_{24}	...	$R_{2,n+1}$	R_2
3	M_3			R_{34}	...	$R_{3,n+1}$	R_3
.	.				.	.	.
.	.				.	.	.
.	.				.	.	.
n	M_n					$R_{n,n+1}$	R_n
Total recaptures		C_2	C_3	C_4	...	C_{n+1}	

The Parametric Model

The survival rate s_k from year k to year k + 1 is assumed to be the same for all individuals in this homogeneous population; that is, an individual's probability of survival is s_k, regardless of his tagging history. In year k + 1 the expected number of survivors among the M_1 individuals tagged in year 1 is therefore $s_1 s_2 \ldots s_k M_1$; the expected number of survivors among the M_2 individuals tagged in year 2 is $s_2 \ldots s_k M_2$. In general, among the M_i individuals tagged in year i, the expected number of survivors in year k + 1 is $s_i s_{i+1} \ldots s_k M_i$, and the probability of exactly $X_{i,k+1}$ survivors is a binomial probability

$$\binom{M_i}{X_{i,k+1}} (s_i s_{i+1} \ldots s_k)^{X_{i,k+1}} (1 - s_i s_{i+1} \ldots s_k)^{M_i - X_{i,k+1}}$$

If f_{k+1} is the *catch rate* in year k + 1; that is, f_{k+1} is the probability of capture for each individual in the population in year k + 1, then the probability of recapture of exactly $R_{i,k+1}$ individuals of $X_{i,k+1}$ survivors is also binomial,

$$\begin{aligned} P(R_{i,k+1}) &= \sum_{X_{i,k+1}} P(X_{i,k+1}) P(R_{i,k+1} \mid X_{i,k+1}) \\ &= \binom{M_i}{R_{i,k+1}} (f_{k+1}\, s_i \ldots s_k)^{R_{i,k+1}} \\ &\qquad (1 - f_{k+1}\, s_i \ldots s_k)^{M_i - R_{i,k+1}} \end{aligned}$$

Since catch rate is small, however, we shall approximate this binomial function by the Poisson function with parameter $f_{k+1} s_i \ldots s_k M_i$. The f_k parameters may then be eliminated from consideration by employing

---

* This note is an expansion of an appendix from the paper under this title by Forney, Eipper and Robson.

** Biometrics Unit, Plant Breeding Department, Cornell University, New York, U.S.A.

only the conditional distribution of recaptures for fixed total yearly recaptures; thus,

$$P(R_{i,k+1}, \ldots, R_{k,k+1} \mid C_{k+1}) =$$

$$= \frac{C_{k+1}!}{\prod_{i=1}^{k} R_{i,k+1}!} \prod_{l=i}^{k} \left(\frac{f_{k+1}\, s_i \ldots s_k\, M_i}{\sum_{i=1}^{k} f_{k+1}\, s_i \ldots s_k\, M_i} \right)^{R_{i,k+1}} \qquad (1)$$

Notice that both f_{k+1} and s_k cancel out of this expression.

The joint conditional distribution for the entire sample of R's is a product of distributions of form (1), if catches in successive years are statistically independent, so the log-likelihood function L takes the form

$$L = \text{constant} + (R_1 - C_2) \log s_1 + (R_1 + R_2 - C_2 - C_3) \log s_2 + \ldots + (R_1 + \ldots + R_{n-1} - C_2 - \ldots - C_n) \log s_{n-1} - C_3 \log (s_1 M_1 + M_2) - C_4 \log (s_1\, s_2\, M_1 + s_2\, M_2 + M_3) - \ldots - C_{n+1} \log (s_1 \ldots s_{n-1} M_1 + s_2 \ldots s_{n-1} M_2 + \ldots + M_n)$$

or, letting

$$T_i = (R_1 + \ldots + R_i) - (C_2 + \ldots + C_i)$$
$$b_k = (s_1 \ldots s_{k-1} M_1 + s_2 \ldots s_{k-1} M_2 + \ldots + M_k)\, s_k\, s_{k+1} \ldots s_{n-1}$$

then

$$L = \text{constant} + \sum_{k=1}^{n-1} (T_{k+1} - R_{k+1}) \log s_k - \sum_{k=1}^{n-1} C_{k+2} \log \frac{b_{k+1}}{s_{k+1} \ldots s_{n-1}}.$$

In this notation the maximum likelihood equations become

$$\frac{\delta L}{\delta s_k} = \frac{T_{k+1} - R_{k+1}}{s_k} - C_{k+2} \frac{\delta}{\delta s_k} \log \frac{b_{k+1}}{s_{k+1} \ldots s_{n-1}} - \ldots - C_{n+1} \frac{\delta b_n}{\delta s_k} = 0$$

or, since

$$\frac{\delta}{\delta s_k} \log b_{k+j} = \frac{(s_1 \ldots s_{k+j-1} M_1 + \ldots + s_k \ldots s_{k+j-1} M_k)\, s_{k+j} \ldots s_{n-1}}{s_k\, b_{k+j}} = \frac{b_k}{s_k\, b_{k+j}}$$

then

$$\frac{\delta L}{\delta s_k} = \frac{T_{k+1} - R_{k+1}}{s_k} - \frac{b_k}{s_k} \left[\frac{C_{k+2}}{b_{k+1}} + \ldots + \frac{C_{n+1}}{b_n} \right] = 0. \qquad \textbf{(2)}$$

Multiplying both sides of equation (2) by s_k gives a recurrence relation for B_k, the maximum likelihood estimate of b_k, which may be written in the form

$$B_k = \frac{T_{k+1} - R_{k+1}}{\dfrac{C_{k+2}}{B_{k+1}} + \dfrac{C_{k+3}}{B_{k+2}} + \ldots + \dfrac{C_{n+1}}{B_n}} = \frac{T_{k+1} - R_{k+1}}{\dfrac{C_{k+2}}{B_{k+1}} + \dfrac{T_{k+2} - R_{k+2}}{B_{k+1}}}$$

or, since $C_{k+2} = T_{k+1} - (T_{k+2} - R_{k+2})$,

$$B_k = \frac{T_{k+1} - R_{k+1}}{T_{k+1}} B_{k+1}\, . \qquad (3)$$

The boundary condition on this system is $B_n = B_{n-1} + M_n$, or

$$B_n = \frac{M_n T_n}{R_n}$$

and, of course, $B_0 = 0$. Finally, we observe that

$$\frac{B_k - B_{k-1}}{M_k} = S_k\, S_{k+1} \ldots S_{n-1}$$

so the maximum likelihood estimate S_k of the survival rate s_k is

$$S_k = \frac{M_{k+1}}{M_k} \frac{B_k - B_{k-1}}{B_{k+1} - B_k} = \frac{M_{k+1}}{M_k} \frac{B_k}{B_{k+1}} \frac{\left(1 - \dfrac{B_{k-1}}{B_k}\right)}{\left(1 - \dfrac{B_k}{B_{k+1}}\right)}$$

which, from (3), reduces to

$$S_k = \frac{M_{k+1}}{M_k} \cdot \frac{T_{k+1} - R_{k+1}}{R_{k+1}} \cdot \frac{R_k}{T_k}\, .$$

The inverse of the variance-covariance matrix of the asymptotic joint distribution of the statistics $S_1, \ldots, S_{n-1}$ is then given by the negative expectation of the second partial derivatives of the likelihood L as

$$\sigma^{k,k} = -E \frac{\delta^2 L}{\delta s_k^2} = E \left(\frac{T_{k+1} - R_{k+1}}{s_k^2} \right) + \frac{b_k}{s_k} \frac{\delta}{\delta s_k} \left[\frac{C_{k+2}}{b_{k+1}} + \ldots + \frac{C_{n+1}}{b_n} \right]$$

$$= \frac{b_k}{s_k^2} \left[\frac{C_{k+2}}{b_{k+1}} + \ldots + \frac{C_{n+1}}{b_n} \right] - \frac{b_k^2}{s_k^2} \left[\frac{C_{k+2}}{b_{k+1}^2} + \ldots + \frac{C_{n+1}}{b_n^2} \right]$$

$$= \frac{b_k}{s_k^2} \left[\frac{C_{k+2}}{b_{k+1}} \left(1 - \frac{b_k}{b_{k+1}} \right) + \ldots \right.$$

$$\left. + \frac{C_{n+1}}{b_n}\left(1 - \frac{b_k}{b_n}\right)\right]$$

$$= \frac{b_k}{s_k^2}\, a_k \text{ (say)}$$

and

$$\sigma^{k-j,\,k} = -E\frac{\delta^2 L}{\delta s_{k-j}\,\delta s_k} = -\frac{\delta}{\delta s_{k-j}}\frac{b_k}{s_k}\left[\frac{C_{k+2}}{b_{k+1}} + \dots + \frac{C_{n+1}}{b_n}\right]$$

$$= \frac{b_{k-j}}{s_{k-j}\,s_k}\left[\frac{C_{k+2}}{b_{k+1}}\left(1 - \frac{b_k}{b_{k+1}}\right) + \dots + \frac{C_{n+1}}{b_n}\left(1 - \frac{b_k}{b_n}\right)\right]$$

$$= \frac{b_{k-j}}{s_{k-j}s_k}\, a_k\, .$$

This symmetric matrix

$$[\sigma^{i\,j}] = \begin{pmatrix} \frac{b_1a_1}{s_1^2} & \frac{b_1a_2}{s_1s_2} & \frac{b_1a_3}{s_1s_3} & \dots & \frac{b_1a_{n-1}}{s_1\,s_{n-1}} \\ \frac{b_1a_2}{s_1s_2} & \frac{b_2a_2}{s_2^2} & \frac{b_2a_3}{s_2s_3} & \dots & \frac{b_2a_{n-1}}{s_2\,s_{n-1}} \\ \frac{b_1a_3}{s_1s_3} & \frac{b_2a_3}{s_2s_3} & \frac{b_3a_3}{s_3^2} & \dots & \frac{b_3a_{n-1}}{s_3\,s_{n-1}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{b_1a_{n-1}}{s_1\,s_{n-1}} & \frac{b_2a_{n-1}}{s_2s_{n-1}} & \frac{b_3a_{n-1}}{s_3\,s_{n-1}} & \dots & \frac{b_{n-1}a_{n-1}}{s_{n-1}^2} \end{pmatrix}$$

can be diagonalized by multiplying row $k + 1$ by $b_ks_{k+1}/b_{k+1}s_k$ and subtracting from row k, $k = 1, \dots, n-2$, to give

$$\begin{pmatrix} \frac{b_1}{s_1^2}\left(\frac{b_2a_1 - b_1a_2}{b_2}\right) & 0 & 0 & \dots & 0 \\ \frac{b_1}{s_1s_2}\left(\frac{b_3a_2 - b_2a_3}{b_3}\right) & \frac{b_2}{s_2^2}\left(\frac{b_3a_2 - b_2a_3}{b_3}\right) & 0 & \dots & 0 \\ \frac{b_1}{s_1s_3}\left(\frac{b_4a_3 - b_3a_4}{b_4}\right) & \frac{b_2}{s_2s_3}\left(\frac{b_4a_3 - b_3a_4}{b_4}\right) & \frac{b_3}{s_3^2}\left(\frac{b_4a_3 - b_3a_4}{b_4}\right) & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{b_1a_{n-1}}{s_1\,s_{n-1}} & \frac{b_2a_{n-1}}{s_2\,s_{n-1}} & \frac{b_3a_{n-1}}{s_3\,s_{n-1}} & \dots & \frac{b_{n-1}a_{n-1}}{s_{n-1}^2} \end{pmatrix}$$

and then repeating this operation on the columns to give as the determinant of $[\sigma^{ij}]$

$$D = \begin{vmatrix} \frac{b_1}{s_1^2}\left(\frac{b_2a_1 - b_1a_2}{b_2}\right) & 0 & 0 & \dots & 0 \\ 0 & \frac{b_2}{s_2^2}\left(\frac{b_3a_2 - b_2a_3}{b_3}\right) & 0 & \dots & 0 \\ 0 & 0 & \frac{b_3}{s_3^2}\left(\frac{b_4a_3 - b_3a_4}{b_4}\right) & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \frac{b_{n-1}a_{n-1}}{s_{n-1}^2} \end{vmatrix}$$

The variance $\sigma_{k,k}$ of S_k is then $D_{k,k}/D$, and the cofactor D_{kk} of σ^{kk} may, likewise, be evaluated by performing these same operations on the rows and columns of D_{kk} ; for example,

$$
D_{33} = \begin{bmatrix}
\frac{b_1}{s_1^2}\left(\frac{b_2a_1 - b_1a_2}{b_2}\right) & 0 & 0 & \dots & 0 \\
0 & \frac{b_2}{s_2^2}\left(\frac{b_4a_2 - b_2a_4}{b_4}\right) & 0 & \dots & 0 \\
0 & 0 & \frac{b_4}{s_4^2}\left(\frac{b_5a_4 - b_4a_5}{b_5}\right) & \dots & 0 \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
0 & 0 & 0 & \dots & \frac{b_{n-1}a_{n-1}}{s_{n-1}^2}
\end{bmatrix}
$$

Thus,

$$
D_{33} = \frac{\dfrac{b_4a_2 - b_2a_4}{b_4}}{\left(\dfrac{b_3a_2 - b_2a_3}{b_3}\right) \dfrac{b_3}{s_3^2} \left(\dfrac{b_4a_3 - b_3a_4}{b_4}\right)} D
$$

or, in general,

$$
\sigma_{kk} = \frac{D_{kk}}{D} = s_k^2 \left[\frac{b_{k+1}a_{k-1} - b_{k-1}a_{k+1}}{(b_ka_{k-1} - b_{k-1}a_k)\ (b_{k+1}a_k - b_ka_{k+1})} \right]
$$

$$
= \frac{s_k^2}{b_k} \left[\frac{b_{k+1}}{b_{k+1}a_k - b_ka_{k+1}} + \frac{b_{k-1}}{b_ka_{k-1} - b_{k-1}a_k} \right]
$$

In like manner, we find the covariance of S_k and S_{k+1} to be

$$
\sigma_{k,k+1} = - \frac{s_k s_{k+1}}{b_{k+1}a_k - b_ka_{k+1}}
$$

and all other covariances are 0; that is, only the survival rate estimates of adjacent periods are asymptotically correlated.

Upon substituting for s_k, b_k and a_k their maximum likelihood estimates S_k, B_k and A_k we find

$$
B_kA_{k-1} - B_{k-1}A_k = B_k \left[\frac{C_{k+1}}{B_k}\left(1 - \frac{B_{k-1}}{B_k}\right) + \dots + \frac{C_{n+1}}{B_n}\left(1 - \frac{B_{k-1}}{B_n}\right) \right]
$$

$$
- B_{k-1} \left[\frac{C_{k+2}}{B_{k+1}}\left(1 - \frac{B_k}{B_{k+1}}\right) + \dots + \frac{C_{n+1}}{B_n}\left(1 - \frac{B_k}{B_n}\right) \right]
$$

$$
= B_{k-1} \left[\frac{C_{k+1}}{B_k} + \dots + \frac{C_{n+1}}{B_n} \right] \left(\frac{B_n}{B_{k-1}} - 1\right)
$$

which, from (2) and (3), reduces to

$$
B_kA_{k-1} - B_{k-1}A_k = R_k .
$$

Consequently, the maximum likelihood estimators of the variances and covariances are simply

$$
\hat{\sigma}_{k,k} = S_k^2 \left[\frac{T_{k+1}}{R_{k+1}(T_{k+1} - R_{k+1})} + \frac{T_k - R_k}{R_kT_k} \right]
$$

for $k = 1, \dots, n-1$ and

$$
\hat{\sigma}_{k,k+1} = \frac{S_kS_{k+1}}{R_{k+1}}
$$

for $k = 1, \dots, n-2$ with all other covariances being 0.

Pooling the Individual Survival Rate Estimates

If the survival rate is constant throughout the experiment, $s_1 = s_2 = \dots = s_n = s$, then the maximum likelihood principle leads to an iterative procedure of overwhelming complexity for estimating the common survival rate s. A number of alternatives to the maximum likelihood estimator might be considered in this case; since we now know the form of the maximum likelihood estimators of $s_1, \dots, s_{n-1}$ a natural procedure to follow is the pooling of these individual estimates in the form of a weighted average, $\hat{s} = \sum_{i=1}^{n-1} w_i S_i$. The weights w_i should add to unity and, subject to this restriction, should then be chosen so as to minimize the variance of s. As is well known, the solution to this minimization problem is to choose w_i proportional to $W_i = \sum_{j=1}^{n-1} \sigma^{ij}$, where σ^{ij} are the elements of the inverse of the variance-covariance matrix of $S_1, \dots, S_{n-1}$.

The inverse matrix $[\sigma^{ij}]$ is exhibited in the preceding section for the case of unequal survival rates, and in the notation employed there we now see that with equal survival rates, σ^{ij} is proportional to b_ia_j

for $i \leq j$ and $a_i\, b_j$ for $i > j$. These constants b_i and a_j, however, depend upon the unknown survival rate s,

$$b_k = s^{n-k} \left(s^{k-1} M_1 + s^{k-2} M_2 + \ldots + M_k\right)$$

$$a_k = \frac{C_{k+2}}{b_{k+1}} \left(1 - \frac{b_k}{b_{k+1}}\right) + \ldots + \frac{C_{n+1}}{b_n} \left(1 - \frac{b_k}{b_n}\right)$$

so the optimal weights are also unknown. In the face of this difficulty we propose that the weighting coefficients be estimated from the proportional relation $\hat{\sigma}^{ij} \sim B_i A_j$ which holds for the case of unequal survival rates, where

$$B_k = \frac{T_{k+1} - R_{k+1}}{T_{k+1}}\, B_{k+1} \ (1 \leq k < n),\ B_n = \frac{M_n T_n}{R_n}$$

and

$$A_k = \frac{R_{k+1}}{B_{k+1}} + \frac{T_{k+1} - R_{k+1}}{T_{k+1}} A_{k+1} \,(1 \leq k < n), A_n = 0$$

The computing formula for the pooled estimate then becomes

$$\hat{s} = \sum_{i=1}^{n-1} w_i\, S_i = \sum_{i=1}^{n-1} W_i\, S_i \,/\, \sum_{i=1}^{n-1} W_i$$

where

$$W_i = A_i\,(B_1 + B_2 + \ldots + B_i) + B_i\,(A_{i+1} + \ldots + A_{n-1})$$

Numerical Example

An artificial set of data shown in Table 2 was constructed to illustrate the computational procedure in this method of estimation. Using the arbitrary numbers of annual tag releases shown in Table 2, we constructed the recapture data by assuming a constant 50% annual mortality rate and fishing rate of $f_2 = 1/100$, $f_3 = 1/50$, $f_4 = 1/100$, $f_5 = 1/200$, and $f_6 = 1/150$. For example, then, $R_{14} = f_4\, s_1\, s_2\, s_3\, M_1 = (1/100)\,(1/2)^3\,(5000) = 6.25$, which was then rounded to $R_{14} = 6$ recaptures in year 4 of fish that were marked in year 1.

The computational procedure, shown in Table 3, is carried out in two stages to give estimates of the survival rate (9), and of the sampling variances (13) and covariances (14). The deviations of the estimates (9) from the assumed value $s = 0.5$ which was used to construct these data are due to rounding errors, both in rounding the recapture data to integers and in rounding the further computations of Table 3. The estimates of variance and covariance, of course, are also subject to this type of rounding error.

A third stage in the computational procedure of Table 3 illustrates our method of combining the several estimates of survival rate into a single, pooled estimate. The weighted estimate $\hat{s} = 0.5047$ is essentially the same as the simple arithmetic average

$$s^* = \frac{S_1 + S_2 + S_3 + S_4}{4} = 0.5031$$

in this case, so the latter could be used. The variance of the estimate s* is, for this example,

$$\begin{aligned} \text{var}\,(s^*) &= \frac{1}{(4)^2}\,[\text{var}\,(S_1) + \ldots + \text{var}\,(S_4)] + \\ &\quad + \frac{2}{(4)^2}\,[\text{cov}\,(S_1, S_2) + \text{cov}\,(S_3, S_4)] \\ &= \frac{1}{16}\,[0.1083] - \frac{2}{16}\,[0.0250] \\ &= 0.0036. \end{aligned}$$

Table 2

Numerical example of tag recaptures classified according to year of tagging and year of recovery

Year of tagging	Number tagged	Year of recapture 2	3	4	5	6	Total recaptures
1	5000	25	25	6	2	1	59
2	3000		30	8	2	1	41
3	6000			30	7	5	42
4	5000				12	8	20
5	4000					13	13
Total recaptures		25	55	44	23	28	175

Summary

If the members of a homogeneous population such as a single year-class are sampled, marked and released at successive points in time, then an estimate of the survival rate for the period between the k'th and (k + 1)'th sample is

$$S_k = \frac{M_{k+1}}{M_k} \cdot \frac{T_{k+1} - R_{k+1}}{R_{k+1}} \cdot \frac{R_k}{T_k}$$

where

M_k = number of individuals appearing in the k'th sample that were not previously marked

R_k = total number of times that individuals first marked in the k'th sample are observed again in some subsequent sample (an individual is counted more than once if recaptured more than once)

T_k = total number of times that individuals first marked on or before the k'th sample are observed again after the k'th sample.

The assumptions underlying this estimation procedure are (i) each individual has the same probability of surviving the period in question, regardless of his tagging or marking history, (ii) tags or marks are never lost and (iii) all recaptures are reported.

Table 3
A computational procedure

I. Estimation of annual survival rates

Computation	k = 1	k = 2	k = 3	k = 4	k = m = 5	Key
M_k	5000	3000	6000	5000	4000	(1)
R_k	59	41	42	20	13	(2)
T_k	59	75	62	38	28	(3)*
$\alpha_k = R_k/T_k$	1	0.5467	0.6774	0.5263	0.4643	(4) = (2)/(3)
α_k/α_{k+1}	1.829	0.8071	1.287	1.134	—	(5)
M_{k+1}/M_k	0.6000	2.000	0.8333	0.8000	—	(6)
$r_k = \alpha_k M_{k+1}/\alpha_{k+1} M_k$	1.097	1.614	1.073	0.9072	—	(7) = (5) (6)
$\beta_k = 1 - \alpha_k$	0	0.4533	0.3226	0.4737	0.5357	(8)
$S_k = r_k \beta_{k+1}$	0.4973	0.5207	0.5083	0.4860	—	(9) = Estimate

II. Estimation of variance

$\gamma_k = \beta_k/R_k$	0	0.0111	0.0077	0.0187	0.0412	(10) = (8)/(2)
$\delta_k = 1/\beta_{k+1} R_{k+1}$	0.0538	0.0738	0.1056	0.1436	—	(11) = $[(8)\ (2)]^{-1}$
$\gamma_k + \delta_k$	0.0538	0.0849	0.1133	0.1623	—	(12) = (10) + (11)
$S_k^2 (\gamma_k + \delta_k)$	0.0133	0.0230	0.0293	0.0383	—	(13) = Var (S_k)
$- S_k S_{k+1} / R_{k+1}$	—0.0063	—0.0063	—0.0124	—	—	(14) = Cov (S_k, S_{k+1})

III. Weighted average survival rate

$B_k = \beta_{k+1} B_{k+1}$	319.7	705.2	2186	4615	8615	(15)**
$t_k = R_k/B_k$	0.1845	0.0581	0.0192	0.0043	0.0015	(16) = (2)/(15)
$A_k = t_{k+1} + \beta_{k+1} A_{k+1}$	0.0675	0.0208	0.0050	0.0015	0	(17)***
$B_1 + \dots + B_k$	319.7	1024.9	3210.9	7825.9	16440.9	(18)
$A_k (B_1 + \dots + B_k) = U_k$	21.5798	21.3179	16.0545	11.7388	0	(19) = (17) (18)
$A_{k+1} + \dots + A_{n-1}$	0.0273	0.0065	0.0015	0	0	(20)
$B_k (A_{k+1} + \dots + A_{n-1}) = V_k$	8.7278	4.5838	3.2790	0	0	(21) = (15) (20)
$W_k = U_k + V_k$	30.3076	25.9017	19.3335	11.7388	0	(22) = (19) + (21)
$w_k = W_k / (W_1 + \dots + W_{n-1})$	0.3472	0.2968	0.2215	0.1345	—	(23)

Pooled estimate $= w_1S_1 + w_2S_2 + w_3S_3 + w_4S_4 = 0.5052$ (24)

* $T_1 = R_1$, $T_k = T_{k-1} + R_k - C_k$; ** $B_n = M_nT_n/R_n$; *** $A_n = 0$.

References

BAILEY, N. T. J. 1951. On estimating the size of mobile populations from recapture data. *Biometrika*, **38**: 293—306.

DARROCH, J. N. 1958. The multiple-recapture census. I. Estimation of a closed population. *Biometrika*, **45**: 343—59.

DARROCH, J. N. 1959. The multiple-recapture census. II. Estimation when there is immigration or death. *Biometrika*, **46**: 336—51.

HAMMERSLEY, J. M. 1953. Capture-recapture analysis. *Biometrika*, **40**: 137—69.

RICKER, W. E. (1958). Handbook of computations for biological statistics of fish populations. *Bull. Fish. Res. Bd Can.*, 119. 300 p.

57.

Notes on External Tagging Methods in European Herring Research

By

B. B. PARRISH & G. McPHERSON*

Introduction

Despite its early establishment as an important technique in fishery research, tagging was not used in European herring investigations until the second world war**. The principal reasons for this were the firm long-standing opinions of many herring workers that: (1) herring are too delicate to withstand the tagging operation; (2) their flesh is too soft to "hold" tags of the types used for other species up to that time; (3) the customary methods of mass handling of the herring catch make the detection of recaptured tagged fish difficult.

However, events since the war have shown that, with the right kind of tags, catching, handling and tagging techniques, the method can be applied successfully with herring, as with other species, and as a result of its application, major advances in the understanding of important features of the movements of and inter-relations between herring groups have been made, (e. g. Fridriksson and Aasen, 1950).

Success in the application of the method followed intensive post-war experimental work, stimulated by the pioneer investigations of Einar Lea in Norway, into the design of tags and their attachments and methods of handling fish for tagging. The purpose of this paper is to summarise and review some of the results of this work, in so far as they may be relevant to the choice of tags and tagging methods for other species.

Factors Governing the "Efficiency" of Tagging Methods

For a fish stock subject to a given fishing intensity, the "efficiency" of a tagging experiment, measured as the number of returns per unit number of fish caught for tagging, is governed by one or more of the following groups of factors:—

(i) methods of capture and handling prior to tagging
(ii) handling methods during the tagging operation
(iii) characteristics of the tags and their attachments
(iv) the methods of recapture and reporting of tags.

The importance of some of these groups of factors, as judged from the results of European herring tagging experiments since the war, is discussed below.

Capture and Handling prior to and during Tagging

The methods of capture used in European herring tagging experiments have included purse seines, land seines and ring-nets (Norway; Iceland; I.C.E.S. international experiments; Scotland); pound nets (Sweden; Denmark); gill nets (drift) England; Iceland; Scotland) and herring trawls (France, Sweden, Scotland, I.C.E.S. international experiments).

The results of experiments undertaken in these countries have shown that the greatest "efficiency", measured in terms of percentage return and length of time after liberation over which recaptures have been obtained, has been closely related to the method of capture adopted. The best gears are undoubtedly the encircling (purse-seine, land seine, ring-net) and fixed (pound net) gears, and the least successful, the towed (trawl) gears. For example, Swedish external tagging experiments, using fish caught by pound net off the Bohuslän coast (Höglund, 1955), gave recaptures between 12 and 17 per cent from a wide range of localities for periods of up to four years after liberation, while experiments by the same workers with the same tag and meticulous tagging technique, using carefully selected trawl-caught fish, in the open North Sea, not only gave much smaller percentage recaptures, but also the length of time after liberation over which recaptures were obtained was much shorter. Similar differences were experienced between the recoveries of internal tags from fish tagged from purse seine and trawl hauls in the international tagging experiments, sponsored by I.C.E.S. on adolescent herring in the south-eastern North Sea in 1957 and 1958 (Aasen et al., 1961). Whereas the total recovery of tags from all purse seine liberations in 1957 was 3.5 per cent, those from trawl-caught fish amounted to only 0.3 per cent. In Scottish experiments in the North Sea between 1949—1955, using fish caught by drift net and trawl, no satisfactory results were obtained with trawl-caught fish, despite care in handling the catch and in the selection of fish for tagging. The most successful results from trawl liberations were obtained in a French experiment in the English Channel in 1957 (Ancellin and Nédelèc, 1959), but here again, the returns were mostly confined to a relatively short time interval (less than a month) after liberation.

It is evident therefore that the method of capture is a factor of major importance in herring tagging. It determines the "condition" of the fish, and con-

---

* Marine Laboratory, Aberdeen, Scotland.

** Herring tagging was, however, successfully undertaken before the war off the Pacific coasts of the U.S.A. and Canada on the closely related species *Clupea pallasii*, using the now well known internal tagging method (Dahlgren, 1936; Hart et al., 1937—46; Stevenson, 1955).

tributes to the short and longer term "tagging" mortality after liberation.

Apart from the more obvious types of damage such as torn gill covers, abrasion, cuts and pressure effects, which can often be detected by eye inspection at capture, so that the fish can be discarded, one of the factors which might affect the survival of tagged fish after liberation is the degree of scaling of the fish on capture. Its effects have been investigated by a number of workers. In Danish experiments inside the Scaw (Jensen, 1955), the tagged herring were placed by eye inspection into four "scale" categories. The releases and subsequent returns of the four categories with two different types of tag are given in Table 1.

Table 1

	Tag Type	"Scale" Category* A	B	C	D
Numbers released	1	852	324	178	68
	2	474	183	43	2
Percentage returned	1	25	17	11	2
	2	24	21	5	0

---

* The categories were as follows:—
A less than about 1/10th scale loss
B up to about 1/3 scale loss
C up to about 1/2 scale loss.
D up to about 2/3 scale loss.

These results show progressively lower percentage recaptures with increase in scale loss with both types of tag. The data also indicate that the method of capture — pound net — used in these experiments gave a high proportion of fish in relatively good condition. Over 60% of all fish tagged were in scale category A.

Categorization into "scale" groups was also made in the French experiment, using trawl-caught fish in the English Channel in 1957 (Ancellin and Nédelèc, 1959). Here a broader grouping, into the following three categories, was made:—

A fish with less than $^1/_3$ scale loss
B fish with $^1/_3$—$^2/_3$ scale loss
C fish with more than $^2/_3$ scale loss.

The releases and percentage returns of fish in each category, for the principal tag type used in these experiments, are given in Table 2.

Table 2

	"Scale" Category A	B	C
Number released	1822	2943	2045
Percentage returned ..	4.0	2.3	1.9

Again, the percentage returned decreased progressively with increase in scale loss, category "A"

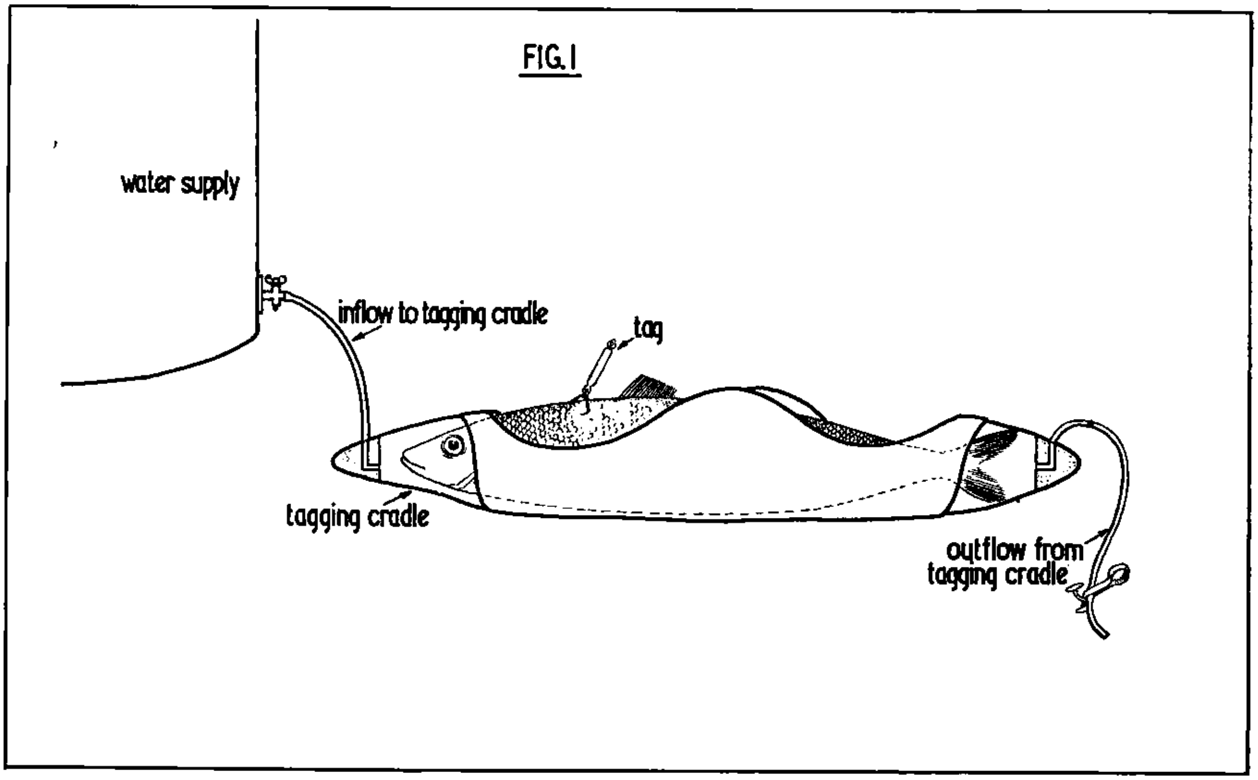


Figure 1. Method of holding herring while being tagged.

giving a significantly greater return percentage than the other two. It is also evident that the fish caught by trawl in this experiment had suffered a higher incidence of scale loss than those caught by pound net in the Danish experiment. The French results also showed that the period of time over which recaptures were obtained was greater for the category "A" fish than for those in categories "B" and "C".

These examples indicate that for a species such as herring, the severity of scale loss at capture is an important factor governing tagging "efficiency", due, most likely, to lower survival of the liberated fish. In Scottish experiments, heavily scaled fish have proved initially as viable and lively as lightly scaled ones caught by the same, or another, method, but over longer periods (exceeding 12—14 hours) in captivity they have suffered a higher mortality rate. Parrish, Blaxter and Holliday (1958) and Blaxter and Holliday (1961) have shown that this is probably mostly due to osmotic stresses caused by the loss of scales. Loss of scales may however also be an indicator of other damaging effects causing death of tagged fish.

It is probable that the poor results obtained hitherto with herring caught by trawl can be attributed mostly to this factor. Scale loss in trawl-caught herring is usually very high, even when the gear and catch are handled carefully. The degree of scaling is usually much less with the encircling or stationary gears. However, it is evident from the French experiments that, providing a careful selection of fish with respect to scale loss is made, satisfactory results can still be obtained with trawl-caught fish, at least for short-term recaptures.

Scale loss and other sources of damage affecting "condition" are not only encountered at capture; they may also result from handling processes before, during and after tagging. It is evident from observation on different handling techniques that scale loss is sometimes substantial when the fish are taken from the tagging tank in coarse nets or by hand. Consequently, meticulous operating techniques have been devised by some European herring workers to minimise the amount of direct handling by the tagging operators. In the techniques adopted in some countries, e.g. Sweden, the fish are untouched by hand between capture and liberation; they are held in a special cradle, with a running water supply, during the tagging operation. The general plan is shown diagrammatically in Figure 1. Similarly, a device which avoids handling the fish during the tagging process has been used in Norwegian internal and external tagging experiments (Aasen, 1954).

Characteristics of Tags and Their Attachments

Several different types and colour of external tags and modes of attachment to the fish have been used in European herring tagging work. The principal types are illustrated in Figure 2. Some of these are also described in contributions to the Special Scientific Meeting on Herring Tagging (Rapp. Cons. Explor. Mer, Vol. 140, 1955). Although no single controlled comparative test has been made of the particular merits and relative efficiencies of all of them, sets of comparisons have been made between two or more of them during the course of the post-war tagging experiments. In some instances these have been between different tags or colours of tag, having the same attachment and method of tagging; in others they have been between different types of tag and attachment, but with the same tagging method, and in others different tag attachments and tagging methods have been compared. The available results from these experiments are summarised in Tables 3 and 4. Table 3 refers to experiments with different types of tag and/or attachments, and Table 4 to comparisons between different colours of the same tag.

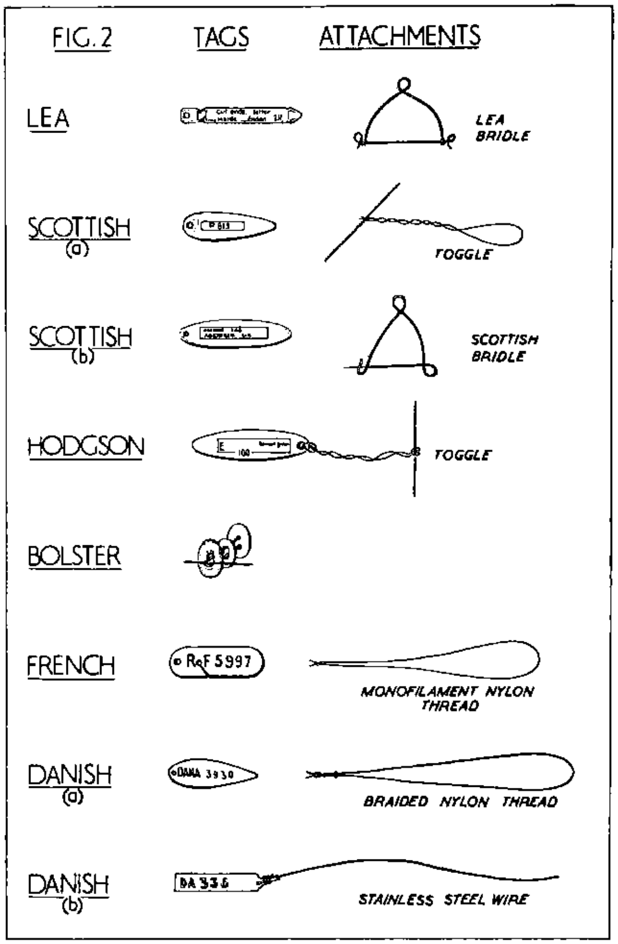


Figure 2. Types of tag and attachment used for herring.

Table 3

Comparisons of tag types and attachments

Each group of fish was released at the same tagging station

Source	Area	Tag Type	Attachment	No. Released	No. Returned	Percentage Returned	Time at liberty (Days)	Remarks
Ancellin and Nédelèc (1959)	English Channel	Lea Hydrostatic	Lea Bridle	418	39	9.3	—	Releases and returns of "scale" categories. A & B fish only. Different operators.
		French plastic tag (yellow)	Nylon thread	1309	55	4.2	—	
,,	,,	Lea Hydrostatic	Lea Bridle	350	34	9.7	—	A& B categories only. Different operators.
		Scottish Hydrostatic	Scottish one-man bridle	354	18	5.1	—	
Wood, Parrish & McPherson (1955)	Northern North Sea	Lea Hydrostatic	Scottish one-man toggle	863	34	3.9	1—399	Same tagging method for both tags. Scottish data include all colours of tag. See Table 4.
		Scottish Hydrostatic	,, ,,	4310	126	2.9	1—397	
Jensen (1955)	Skagerak-Kattegat	Lea Hydrostatic	Lea Bridle	595	(185)	31.3	up to 365	The results for the Danish tag include various types of nylon thread attachment. See text. Same operators.
		Danish plastic tag (Blue)	Nylon thread	723	(173)	23.9	up to c. 280	
Höglund (1955)	Skagerak	Lea Hydrostatic	Lea Bridle	237	49	20.7	up to 800	Scottish data include all colours of tag (see Table 4). Different tagging methods and operators.
		Scottish Hydrostatic	Scottish toggle	238	18	7.6	up to 250	
Wood, Parrish & McPherson (1955)	Northern North Sea	Scottish Hydrostatic	Scottish one-man bridle	199	5	2.5	1—203	Same tagging method and operators.
		,, ,,	Toggle	100	0	0	—	
	Minch	Scottish Hydrostatic	Scottish one-man bridle	120	2	1.7	79—193	Same tagging method and operators.
		,, ,,	Toggle	60	0	0	—	
	Moray Firth	Lea Hydrostatic	Scottish one-man bridle	251	6	2.4	caught on day of liberation	Same tagging method and operators.
		,, ,,	Toggle	130	2	1.5	5—67	
Unpublished Scottish data	Moray Firth	Lea Hydrostatic	Toggle	315	11	3.5	up to 127	Same tagging method and operators
		Scottish Hydrostatic	,,	314	4	1.3	up to 13	
		Lea Hydrostatic	One-man bridle	315	7	2.2	up to 25	
		Scottish Hydrostatic	,, ,, ,,	314	3	1.0	8—145	

In most of these comparisons of tag types there were differences in the attachment and/or method of tagging, as well as in the type of tag. Therefore a complete analysis of the factors governing their relative efficiencies cannot be made. However, the results indicate that of the tags used the "Lea" hydrostatic tag has proved the most "efficient", as judged by return percentages, especially when used with its bridle attachment. Not only has it usually given the higher total percentage returns, but in most of the experiments it has also given the longer-term returns. However, the results from the few experiments in which the "Lea" tag has been used with other attachments, (e.g. the Scottish toggle) suggest that its greater apparent "efficiency" is due in large measure to the properties of its bridle, rather than to the tag itself. This is also indicated by the results of tank experiments at the Marine Laboratory, Aberdeen, which showed that shedding of tags with a toggle attachment, due to cutting of the flesh by movements of the nylon thread, was greater than with a bridle attachment. It is also suggested by results reported by Jensen (1955) on the returns of Danish plastic tags when used with different types of nylon thread attachment. He found that with stiff, twined nylon thread, the returns of fish tended to be higher than of those to which it was attached with soft or untwined thread, which was less rigid and might be expected to cut through the flesh of the fish more readily. It is interesting to note that a number

Table 4
Comparisons of tags of different colours

Each group of fish was released at the same tagging station

Author	Year	Area	Method of capture	Tag Type	Attachment	Colour	No. of fish released	No. of fish returned	Percentage returned	Remarks
Wood, Parrish & McPherson (1955)	1952	North Sea	Drift net	Scottish Hydrostatic	Toggle	1) Yellow	861	28	3.25	Same tagging method and operators.
						2) Amber	862	15	1.74	
						3) Red	864	24	2.78	
						4) Red/Yellow*	861	35	4.07	
						5) Blue/Yellow*	862	24	2.78	
		Skagerak	Pound net	Scottish Hydrostatic	Toggle	1) Yellow	57	6	10.53	Same tagging method and operators.
						2) Amber	57	3	5.26	
						3) Red	56	3	5.36	
						4) Red/Yellow*	57	11	19.30	
						5) Blue/Yellow*	57	4	7.00	
Jensen (1955)	1949—1952	Inside the Scaw	Pound net	Danish Plastic Tag	Braided Nylon thread	1) Blue	234	—	20	Same tagging method and operator.
						2) Red	124	—	25	
Ancellin & Nédèlec (1959)	1957	Channel	Trawl	French Plastic Tag	Monofilament Nylon thread	1) Yellow	1454	27	1.9	Same tagging method and operators. Comparison confined to releases at the same tagging station.
						2) Red	1261	27	2.1	
				French Plastic Tag		1) Yellow	199	10	5.0	Comparison confined to releases at the same tagging station.
						2) Black	752	30	4.0	

* One half of the tag coloured yellow, the other red or blue respectively.

of Scottish hydrostatic tags with the toggle attachment have been recovered from shore strandings, away from herring fishing areas. It is likely that these have been carried by water currents after being shed from the fish.

Thus, for herring, it seems that shedding may be a critical factor governing the "efficiency" of a tag, and that this is principally a function of the type of attachment used and the care taken in applying it. However, it is likely that, in addition to this factor, the "Lea" tag itself has features which probably contribute to its relatively high efficiency. Amongst these are:—

(i) its hydrostatic and low drag properties
(ii) the detailed instructions contained in it
(iii) its conspicuousness amongst the mass of recaptured fish.

As shown in Table 4, the colour of tag also appears to contribute to its overall "efficiency". In the experiments reported in Table 4 percentage returns tended to be highest for tags having yellow or red colour components. Yellow is also a colour component of the "Lea" tag. It is not clear whether this colour effect is due to lesser conspicuousness to predators of herring, or higher conspicuousness amongst the fish on recapture. However, both colours (especially yellow) contrast sharply with the natural colours of the fish, so it is probable that conspicuousness at recapture is the principal factor involved. This is supported by the relatively poor returns obtained with the least conspicuous amber tag in the Scottish experiments in the North Sea and Skagerak.

Discussion

The results reviewed above point to the importance of two factors which contribute substantially to the "efficiency" of herring tagging operations. These are (1) the "condition" of the fish, which largely governs tagging mortality, and (2) the shedding properties of the tag. However, a third major factor, not dealt with above, is the effectiveness of tag recovery after recapture. Unfortunately no data are available concerning the magnitude of this factor for external herring tags; however it is evident from information on the sources from which recovered tags have been received that, for a species such as herring, which are often handled in bulk and untouched by hand after capture, the effectiveness of recovery is often low. It is likely that in the complex North Sea herring fisheries which are undertaken by different countries and gears, and in which part of the catch is treated in bulk for processing and part handled for human consumption, this factor is likely to be the largest contributor to the total "efficiency" of each tagging experiment. In the more confined, local fisheries, e.g. in local Danish waters inside the Skaw, where the bulk of the catch is utilised in the same way and local interest in the tagging scheme can be maintained, the effectiveness of recovery is probably much greater. In some European herring fisheries, the major part of the catch is bulk handled for processing (e.g. Norwegian fishery; Danish and German industrial fisheries). In these situations, the recovery rates of external tags are very low, and this method of tagging is quite unsatisfactory; instead, in these fisheries the internal tagging method, using numbered metal tags which are recovered by magnets in the processing plants, has been very successful. Attempts have also been made to develop "combination" external tags, suitable for recovery from processing plants, for the part of the catch which is bulk handled individually for human consumption (Bertelsen, 1955). In the Scottish "combination" tag (Fig. 2) a strip of mild steel 21 × 3 mm is sealed into a slot in the polythene tag. Pilot trials with this tag in Scottish processing plants have given recovery rates between 42 and 67%. In Norway, double tagging with internal and external tags has been used for meeting the different requirements for these two main catch utilisations.

Many of the tagging techniques which have been designed to minimise the damage to herring during the catching and tagging operations can be employed only by a team working on board a research vessel, or a chartered fishing vessel. These facilities are relatively costly, and if, as may often be the case, the effectiveness of recovery is overwhelmingly the largest factor governing the "efficiency" of the experiments, it may be desirable to forego the most efficient capture and tagging methods in favour of larger scale and less costly "bulk" tagging from commercial fishing vessels. This is especially so when the objectives of the tagging experiment are of a biological (e.g. general movement and growth studies) rather than quantitative (e.g. mortality and mixing rate estimation) nature. The one-man tagging technique used for herring by British workers (Wood, Parrish and McPherson, 1955; Bolster, 1955) has proved successful for these former purposes.

Summary

This paper reviews the factors affecting the "efficiency" of the tagging techniques used in European herring research. These factors are —

1) methods of capture and handling prior to tagging
2) handling methods during tagging
3) characteristics of the tags and their attachments
4) methods of recapture and reporting of tags.

It is shown that the encircling types of gear yield fish in better condition for tagging than the gill nets or towed gears and that this is due largely to fewer scales being lost. Scale loss is also important during the tagging operation.

A summary is given of experiments in which different types of tag and attachments have been used together. This indicates that the "Lea" tag is the most efficient, especially when used with its bridle attachment. It is suggested that the attachment may be as important as the tag, since shedding of tags due to cutting the flesh can be important. Tags having a yellow or red component gave better results than tags of other colours.

In some fisheries the effectiveness of tag-recovery is a factor of major importance in governing "efficiency". This is particularly so in fisheries where a substantial part of the catch is handled and processed in bulk. In these circumstances it may be preferable to dispense with a relatively costly meticulous tagging technique and adopt a faster and cheaper tagging method. The one-man tagging technique, used on board commercial fishing vessels, has been applied with some success in these circumstances.

References

AASEN, O. 1954. Tagging Experiments. *Ann. biol., Copenhague*, **10**: 148—49.

AASEN, O. et al. 1961. I.C.E.S. herring tagging experiments in 1957 and 1958. *Rapp. Cons. Explor. Mer*, **152**.

ANCELLIN, J. & NEDELEC, C. 1959. Marquage de harengs en Mer du Nord et en Manche Orientale. *Rev. Trav. Inst. Pêches marit.*, **23**: 177—201.

BERTELSEN, E. 1955. Danish herring tagging in the North Sea 1949—1951. *Rapp. Cons. Explor. Mer*, **140** (2): 9—10.

BOLSTER, G. C. 1955. English tagging experiments. *Rapp. Cons. Explor. Mer*, **140** (2): 11—14.

BLAXTER, J. H. S. & HOLLIDAY, F. G. T. 1961. The effects of salinity on herring after metamorphosis. *J. mar. biol. Ass. U.K.*, **41**: 37—48.

DAHLGREN, E. H. 1936. Further developments in the tagging of the Pacific herring. *J. Cons. int. Explor. Mer*, **11**: 229—47.

FRIDRIKSSON, A. and AASEN, O. 1950. The Norwegian-Icelandic herring tagging experiments Rep. No. 1. *Fiskeridir. Skr. Havundersók.*, 9 (11).

HART, J. L. et al. 1937—46. The tagging of herring (*Clupea pallasii*) in British Columbia; methods, apparatus, insertions, and recoveries during 1936—37 to 1945—46: *Rep. Fish. Dep. B. C.* (1936—45), 1937—1946.

HÖGLUND, H. 1955. Swedish herring tagging experiments, 1949—1953. *Rapp. Cons. Explor. Mer*, **140** (2): 19—29.

JENSEN, Å. J. C. 1955. Danish herring tagging experiments inside the Scaw. *Rapp. Cons. Explor. Mer*, **140** (2): 30—32.

PARRISH, B. B., BLAXTER, J. H. S. & HOLLIDAY, F. G. T. Herring (*Clupea harengus* L.) in aquaria. I) Establishment: *Mar. Res. Scot.* 1958, No. 5.

STEVENSON, J. C. 1955. The movement of herring in British Columbia waters as determined by tagging. *Rapp. Cons. Explor. Mer*, **140** (2): 33—34.

WOOD, H. PARRISH, B. B. & McPHERSON, G. 1955. Review of Scottish herring tagging experiments, 1948—1953. *Rapp. Cons. Explor. Mer*, **140** (2): 35—54.

58.

The Design and Analysis of Capture-Recapture Experiments

By

J. A. POPE*

Uses of Capture-Recapture Experiments

A capture-recapture experiment consists of taking a set of one or more samples from a population, returning the selected members to the population after marking them in a distinctive manner, and recording the number of marked individuals recaptured in a second set of one or more samples in order to estimate population parameters. This paper reviews some of the ways in which this may be done, the methods of analysing the results of such experiments and the assumptions underlying them. The large number of papers written on this subject in the past twenty-five years (and especially since the end of the second World War) unfortunately cannot all be reviewed here.

Capture-recapture experiments are generally carried out on animal populations for one or more of the following purposes:

(a) to estimate the total population size
(b) to estimate the vital parameters of the population (growth, recruitment, mortality, emigration and immigration)
(c) to estimate the rate and extent of the movement of the members of the population.

The sampling schemes and methods of analysis adopted depend on the population parameters to be estimated. Three types of design will be reviewed here. They are:

Group I: Estimation of population size. Closed population. No natural mortality or recruitment.
Group II: Estimation of mortality. Closed population. No recruitment.
Group III: Estimation of recruitment. Closed population. No natural mortality.

Group I Designs

The simplest experimental design for estimating the total size of a closed population with no deaths or recruitment is that in which one sample is taken for marking purposes and a second for recapturing. The marked members may all be liberated at one point, but they should become distributed in such a way that when the second sample is taken the probability of recapturing a marked individual is proportional to the frequency of marked members in the population.

If N = total population size
M = number taken in first sample, marked and returned to the population
n = number taken in second sample
m = number of marked individuals recaptured in second sample

then, intuitively, we have

$$\frac{m}{n} = \frac{M}{N}$$

so that N is estimated from

$$\hat{N} = M . \frac{n}{m} . \qquad (1)$$

The estimate given by (1) is also the maximum likelihood estimate if binomial sampling is assumed. Since m may take the value zero, (1) has infinite expectation. In the situations in which this type of design is likely to be employed (e.g. sampling inland waters with relatively small total populations and M/N not too small) the value m = 0 will rarely occur. If the value m = 0 is excluded the bias in (1) may be evaluated. An adjusted estimate with smaller bias, suggested by Bailey (1951), is

$$\check{N} = M . \frac{n+1}{m+1} . \qquad (2)$$

A nearly unbiased estimate of the variance of this adjusted estimate is given by

$$\text{var}\,(\check{N}) = \frac{M^2(n+1)\,(n-m)}{(m+1)^2(m+2)} \qquad (3)$$

provided n is not too small.

The validity of this method of estimating N, besides depending on the random distribution in the population of the marked individuals or on the random sampling for recaptures, requires that the marked specimens be as likely to be captured as the unmarked, that marks are not lost and that all recaptures be recorded. The loss of marks or the failure to record marked fish will result in smaller values of m and overestimation of N.

If either m/n or 1 — m/n is small and n not large it is better to obtain limits for $\hat{N}$ or $\check{N}$ from limits to m/n appropriate to binomial sampling rather than by assuming large sample theory using (3). Limits to the estimated proportion of marked individuals in the population, m/n, may be obtained from charts prepared by Clopper & Pearson (1934). The method appears to have been first employed to

---

* Marine Laboratory, Aberdeen, Scotland.

estimate fish populations by Petersen (1896) and is sometimes referred to as the "Petersen method", although the method is older than this.

When sampling large populations the number of marked individuals will usually form a very small part of the total population; that is, M/N will be very small. If n is sufficiently large the number of recaptures will follow a Poisson distribution with mean nM/N. In this case the maximum likelihood estimate of N is again given by (1) and like (1) it has infinite expectation. In this case, however, if m is replaced by m + 1 the average value of the estimate so obtained is

$$E\left(\frac{nM}{m+1}\right) = N - NP(0) \qquad (4)$$

where P(0) is the probability of no recaptures. When the probability of recapture is small this bias will be quite appreciable. In fact the correct order of magnitude of N may not even be obtained.

In a multiple sampling scheme a first series of samples is taken for marking and a second series for recapturing. Some of the samples of the second series may coincide with those of the first but this is not necessary. In estimating the size of a fish population it will usually be the case that the marking is done from catches taken by a special ship, while recaptures are obtained from catches by vessels of the commercial fleet. For such situations the number marked at any time will not be a large fraction of the total population, which itself will be very large. Under these conditions,

if M_i = number of individuals marked at i^{th} marking, first series, taking place at time a_i $(i = 1, 2 \ldots\ldots p)$
n_j = number of individuals taken in j^{th} sample of second series, taking place at time b_j $(j = 1, 2 \ldots\ldots k)$
m_{ij} = number of individuals originally marked at i^{th} marking and recaptured in j^{th} sample of second series
$j(i)$ = smallest value of j such that animals marked at i^{th} marking have a non-zero probability of being recovered in j^{th} sample of second series

then provided $n_j M_i/N$ remains finite the maximum likelihood estimate of N is

$$\hat{N} = \left(\sum_{i=1}^{p} \sum_{j=j(i)}^{k} n_j M_i\right) \Big/ \left(\sum_i \sum_j m_{ij}\right). \qquad (5)$$

It may be noted that in this formula recaptures from different markings appear grouped together. It might appear that by treating the recaptures at time j from different markings separately more information would be gained about N, but this is not the case as noted by Chapman (1952). The form of the estimate (5) is the same as given by Schnabel (1938). An adjusted version of (5) given by Chapman is

$$\tilde{N} = \left(\sum_i \sum_j n_j M_i\right) \Big/ \left[\left(\sum_i \sum_j m_{ij}\right) + 1\right]. \qquad (6)$$

This is approximately unbiased and has variance given, with sufficient accuracy for most situations, by

$$\operatorname{var}(\tilde{N}) = \frac{N^2}{\Sigma\Sigma\, n_j M_i}\left(1 + \frac{2N}{\Sigma\Sigma\, n_j M_i}\right). \qquad (7)$$

An example of the use of formula (5) is given by Schaefer (1951). Using the data due to Krumholz (1944) utilised by Schaefer the values of (6) and (7) for the final set of observations are

$$\tilde{N} = \frac{513{,}975}{53 + 1} = 9518$$

$$\begin{aligned}\operatorname{var}(\tilde{N}) &= \frac{(9518)^2}{513{,}975}\left(1 + \frac{2\ (9518)}{513{,}975}\right)\\ &= 176.2582\ (1 + 0.0370)\\ &= 182.78.\end{aligned}$$

The standard error of N is therefore ± 13.5.

For multiple censuses some form of sequential design is desirable in order that sampling may be terminated when a sufficiently accurate estimate of N is obtained. Little work seems to have been done on this aspect of capture-recapture theory. (But see Chapman (1952).)

Instead of using direct sample designs a method of *inverse* sampling may be adopted. In this type of design the number of recaptures is fixed in advance and the total sample size required to achieve this is recorded. From the statistical viewpoint the method of inverse sampling results in a simplification in that, in single censuses, an unbiased estimate of population size is available and also an exact expression for the sampling variance.

With the same notation as above an unbiased estimate of N is, as shown by Bailey (1951),

$$\hat{N} = \frac{n\ (M + 1)}{m} - 1 \qquad (8)$$

where now n is a random variate and m is fixed. The variance of this estimate is

$$\operatorname{var}(\hat{N}) = \frac{(M - m + 1)\ (N + 1)\ (N - M)}{m\ (M + 2)}. \qquad (9)$$

The problem of estimating the size of a population stratified in space or time or both and in which mixing of the strata occurs between marking and the subsequent sampling for marked individuals has been considered by Schaefer (1951) and Chapman & Junge (1956). The latter authors have investigated the consistency of three possible estimates of N. Using the following notation

p = number of strata

N_{ij} = number of individuals in stratum i at time of marking and in stratum j at time of subsequent sampling

M_{ij} = number of marked individuals in stratum i at time of marking and in stratum j at time of subsequent sampling

n_{ij} = number of individuals in subsequent samples from stratum j which were in stratum i at time of marking

m_{ij} = number of marked individuals recaptured in stratum j which were marked in stratum i

$$\Sigma_j M_{ij} = M_{i.} \qquad \Sigma_i M_{i.} = M$$

$$\Sigma_i n_{ij} = n_{.j} \qquad \Sigma_j n_{.j} = n$$

$$\Sigma_j m_{ij} = m_{i.} \qquad \Sigma_i m_{ij} = m_{.j} \qquad \Sigma_i m_{i.} = \Sigma_j m_{.j} = m$$

the estimates considered are

(a) Petersen estimate $\hat{N}_1 = \dfrac{nM}{m}$

(b) Schaefer estimate $\hat{N}_2 = \sum\sum \dfrac{n_{.j} M_{i.} m_{ij}}{m_{i.} m_{.j}}$ (10)

(c) Chapman & Junge estimate $\hat{N}_3 = \Sigma_j \hat{N}_{.j}$. (11)

The Chapman & Junge estimate involves the prior estimation of the sizes of the individual strata from the set of equations

$$\begin{aligned} m_{11}\frac{N_{.1}}{n_{.1}} + m_{12}\frac{N_{.2}}{n_{.2}} + \ldots + m_{1p}\frac{N_{.p}}{n_{.p}} &= M_{1.} \\ m_{21}\frac{N_{.1}}{n_{.1}} + m_{22}\frac{N_{.2}}{n_{.2}} + \ldots + m_{2p}\frac{N_{.p}}{n_{.p}} &= M_{2.} \qquad (12) \\ \cdot \qquad\quad \cdot \qquad\qquad & \\ \cdot \qquad\quad \cdot \qquad\qquad & \\ \cdot \qquad\quad \cdot \qquad\qquad & \\ \cdot \qquad\quad \cdot \qquad\qquad & \\ m_{p1}\frac{N_{.1}}{n_{.1}} + m_{p2}\frac{N_{.2}}{n_{.2}} + \ldots + m_{pp}\frac{N_{.p}}{n_{.p}} &= M_{p.} \end{aligned}$$

These p simultaneous equations give first $N_{.1}/n_{.1}$, $N_{.2}/n_{.2}$, ... from which $N_{.1}$, $N_{.2}$, ... may be estimated by multiplying by the known quantities $n_{.1}$, $n_{.2}$, ...

Chapman & Junge define a consistent estimate $\hat{N}$ as one such that $\hat{N}$ tends in probability to N with increasingly large samples from increasingly large populations under certain assumptions which, briefly, require that a random sampling procedure be used in each stratum and that the individuals in each stratum are thoroughly mixed *after moving* to the different strata. That is, no assumptions are made concerning the marked individuals' movement between the time of marking and the time of entry into the final stratum occupied ("migration pattern") when subsequent sampling takes place, but only on their movement from the time of entering till the time of subsequent sampling.

These authors show that estimates (a) and (b) above are, unlike (c), only consistent when subsequent sampling within strata is proportional to the size of strata, i. e. only when $n_{.j}/N_{.j}$ is constant. The consistency of (c) is ensured provided the set of equations (12) has a unique solution.

The large sample variance of $\hat{N}_3$ derived by Chapman & Junge requires that the marking does not alter the movement of the individuals and that these move independently of one another. The authors note that such assumptions may be difficult to check and suggest that the variance of the estimate of N may be obtained empirically by regarding the individuals marked in each stratum as belonging to several groups and estimating N from the data for each group separately. The resulting estimates may then be used to give an estimate of the variance of the average of the separate values of $\hat{N}_3$ in the usual way.

The number of individuals migrating from any one stratum to any other, $\hat{N}_{ij}$, is given by

$$\hat{N}_{ij} = m_{ij}\, \hat{N}_{i.}\, \hat{N}_{.j}/M_{i.}\, n_{.j} \qquad (13)$$

This is a consistent estimate provided the movement between strata is the same for marked as for unmarked individuals. The authors give a formula, of a somewhat complicated nature, from which the large sample variance of $\hat{N}_{ij}$ may be derived.

Group II Designs

The estimation of population death-rate as well as population size has received considerable attention from many writers. Chapman (1954) has studied the estimation of these population parameters for the case of either no recruits to the population from births or immigration, or, if there are new recruits, they are distinguishable and may be eliminated. Chapman considers the case of a large population, so that the effect of sampling without replacement may be ignored. Using the same type of sampling scheme as described above (p. 343) if P is the proportion of individuals alive at time t which survive till time $(t + 1)$ the maximum-likelihood estimates of N and P are given by the pair of simultaneous equations

$$\hat{N} = \Sigma\Sigma\ M_i\, n_j\, \hat{P}^{-a_j}/\Sigma\Sigma\ m_{ij}$$

$$(\Sigma\Sigma\, m_{ij})(\Sigma\Sigma\, a_i M_i n_j P^{-a_j}) = (\Sigma\Sigma\, a_i m_{ij})\,(\Sigma\Sigma\, M_i n_j \hat{P}^{-a_j})$$

$$\text{where } \Sigma\Sigma = \sum_{i=j}^{p}\ \sum_{j=j(i)}^{k}$$

The quantities necessary for the evaluation of the variance of $\hat{N}$ and $\hat{P}$, and also their co-variance, are given by Chapman.

With schemes such as this there is a non-zero probability that a marked individual may occur more than once. The estimates given by (10) and (11), however, ignore multiple recaptures which, when N is large and the number marked on any occasion is small in comparison with N, will be very small. This model is therefore applicable to the situations ordinarily prevailing in sampling fish populations in the open sea, especially where recaptures are made by commercial vessels.

In the case of commercially exploited fish populations the value of N is usually of much less importance than the mortality rate, which is the sum of two distinct components, namely natural mortality and fishing mortality. When only mortality rates are to be estimated from marking experiments it is not necessary to consider the whole population, but only the sub-population of marked individuals.

If S is the survival rate, then at any time t after release the number of marked individuals available for recapture is MS^t. If sampling for recaptures is done at fixed times only, and if the expected number of recaptures is given by

$$m_t = kMS^t \tag{14}$$

where k is a constant depending on the sampling method which must remain the same at all times, then

$$\log m_t = a + bt$$

where $b = \log S$, and a regression of $\log m_t$ on t leads to an estimate of S from the regression coefficient b. This is too simplified a model for general use with commercially exploited populations, as for these sampling is continuous in time and the explicit estimation of the instantaneous fishing mortality **F** and the instantaneous natural mortality **M** is required. Furthermore the specification (14) is not strictly accurate, as the expected value of m_t will depend on previous values of m unless all recaptures are immediately returned to the population. The same criticism applies to the theory proposed by Jones (1956). However, if the values of m_t are very small in comparison with MS^t the model will be sufficiently accurate for practical purposes.

Gulland (1955) has considered the maximum likelihood estimation of **M** and **F** for situations where recaptures are taken in the course of continuous sampling. The solutions of the maximum likelihood equations for his model are not easily found, but Gulland gives approximations which should be reasonably accurate. If n marked fish are recaptured at times $t_1, t_2, \ldots, t_n$ after liberation the approximate estimates of **M** and **F** are

$$\check{\mathbf{M}} = (M - n)\, n/M\, \Sigma\, t_i \tag{15}$$

$$\check{\mathbf{F}} = n^2/M\, \Sigma\, t_i \tag{16}$$

The theory of the estimation of the death-rate in a population using a design in which repeated markings are employed has been studied in detail by Leslie & Chitty (1951), Bailey (1951), Leslie (1952), Hammersley (1953) and Darroch (1959). The method of multiple marking has been employed in practice by Dowdeswell, Fisher & Ford (1940) in studying populations of butterflies and by Fisher & Ford (1947) in studying a population of moths. Briefly the procedure consists of sampling the population on several occasions. At each sampling the number of recaptures from previous markings is recorded, all individuals are marked with a distinctive mark and returned to the population. An individual may thus bear more than one mark, the total number of marks on an individual being equal to the number of times it has been captured.

In practice, however, the number of recaptures will usually be small and multiple recaptures few. In order to simplify the estimation of P it will be desirable to group the observations in some way. The method of grouping adopted by Jackson (1939) and Fisher & Ford (1947) is by marks, a marked individual being counted as many times as it has marks. Thus, for example, in the sample taken at time t the recaptures will consist of individuals marked once,

$$m_{0t},\ m_{1t},\ m_{2t},\ \ldots$$

individuals marked twice,

$$m_{01t},\ m_{02t},\ \ldots,\ m_{12t}\ \ldots$$

individuals marked three times,

$$m_{012t},\ m_{023t},\ \ldots,\ m_{123t},\ \ldots$$

and so on. These are grouped as follows

$$k_{0t} = m_{0t} + m_{01t} + m_{02t} + \ldots + m_{012t} + \\ + m_{012\ldots(t-1)t}$$

$$k_{1t} = m_{1t} + m_{01t} + m_{12t} + \ldots + m_{012t} + \\ + m_{012\ldots(t-1)t}$$

$$\begin{matrix} \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \end{matrix}$$

k_{1t}, for example, being all the recaptures at time t of individuals marked at time $t = 1$. These data may be very conveniently arranged in the form of a "trellis" diagram as illustrated by Fisher & Ford (1947).

As already noted, quantities other than $m_{0t}, \ldots, m_{(t-1)t}$ will usually be small. The estimation of P, by equating the actual number of days at liberty of all recaptured individuals to the expected number, is illustrated in the following table.

(1)	(2)	(3)	(4)	(5)
t	M			
0	M_0	M_0P^3	M_0P^3	M_0P^3
1	M_1	M_1P^2	$M_0P^3+M_1P^2$	$2M_0P^3+M_1P^2$
2	M_2	M_2P	$M_0P^3+M_1P^2+M_2P$	$3M_0P^3+2M_1P^2+M_2P$
3	M_3			

In column (2) the number of marked individuals liberated at time t are given and the number of these individuals alive in the population at time $t = 3$ are shown in column (3). These latter numbers are derived on the basis of a deterministically operating death-rate in the population. The total number of marked individuals in the population at $t = 3$ is obtained by summing the entries in column (3), and a second summation gives the entries in column (5). The average number of days at liberty is (5) $\div$ (4), i.e.

$$\frac{3M_0P^3 + 2M_1P^2 + M_2P}{M_0P^3 + M_1P^2 + M_2P} \tag{17}$$

and (14) multiplied by the actual number of recaptures in the sample taken at $t = 3$, s'_3 (say), gives the expected number of days at liberty. The observed number of days at liberty of the recaptures is $3k_{03} + 2k_{13} + k_{23}$. Equating these gives the equation

$$3k_{03}+2k_{13}+k_{23} = \frac{s'_3\,(3M_0P^3+2M_1P^2+M_2P)}{M_0P^3+M_1P^2+M_2P} \tag{18}$$

from which an estimate of P may be obtained. This may be done for each value of t, from $t = 2$ onwards (no estimate can be obtained for a shorter chain) and P estimated from the equation obtained by summing all expressions for the expected total number of days at liberty and the actual number of days at liberty. Leslie & Chitty (1951) have shown that this equation for P is equivalent to that given for this method of grouping by the method of maximum likelihood, and they give a computational technique for solving the equation and deriving the variance of P. These authors point out that the method of grouping recaptures by marks results, at any rate in large samples, in a loss of information as compared with the estimate of P from ungrouped data. They suggest an alternative method of grouping which results in no loss of information. This method consists of grouping the recaptures according to the interval of time since they were last captured, i.e. the recaptures are grouped as follows:

$$\begin{aligned} r_{0t} &= m_{0t} \\ r_{1t} &= m_{1t} + m_{01t} \\ r_{2t} &= m_{2t} + m_{02t} + m_{12t} + m_{012t} \end{aligned}$$

etc.

A method of solving the maximum likehood equation for P and of deriving the variance of P for this method is given by Leslie & Chitty. It should be noted that Leslie & Chitty assume a completely deterministic model in their work.

If the multiple-recapture rate is very low there will clearly be little to choose between the two methods from the point of view of efficiency of estimation, but otherwise the second method of grouping is likely, in practice, to be more efficient. To investigate the relative efficiencies of these two methods and also to study the effect of increasing the number of samples, Leslie & Chitty undertook a sampling experiment on an artificial population. Their findings refer to an artificial population of 300 individuals from which samples of 50 individuals were taken at times $t = 0, 1, 2, 3$ and 4. For a chain of three samplings they found little difference between the two methods. They also noted that, under the conditions of their experiment, the use of chains of three samples is not a very efficient method of estimating P, values of P greater than 1 being obtained in some cases. The amount of information on P was found to increase very rapidly with increasing number of samples for both methods, and the superiority of grouping by the interval of time since last capture over the method of grouping by marks became progressively greater as the chain length was increased.

The models used by Leslie & Chitty have been critically examined by Moran (1952). As already noted these models are deterministic in the sense that P is defined as the exact proportion surviving from one time period to the next, being the same for all classes of individuals in the population, marked and unmarked. The essential discreteness of the population numbers and sample numbers is ignored by Leslie & Chitty and their models are, to this extent, approximations. Moran surmises that the variances of the estimates of P derived by Leslie & Chitty will be underestimates of the variances applicable to a fully probabilistic model.

Group III Designs

A method of estimating the birth-rate in a population has been given by Jackson (1937) and referred to by him as the "positive" method. A "negative" method, for estimating the death-rate, was also described by him. Jackson's method of estimating the birth-rate by fitting a curve to "standardized" recaptures has been criticized by Bailey (1951) who has pointed out that it does not employ correct weighting factors. A formal maximum likelihood estimation of birth-rate and population size is given by Bailey.

The "positive" method sampling scheme consists of a single sample taken for marking followed by a series of samples for recapturing. If M is the number marked and if m_j are recaptured in a subsequent sample of size n_j $(j = 1, 2, \ldots.)$ then, provided all marked individuals recaptured are returned to the population (or that M is very large and all m_j/M very small) the equations for B (the birth-rate) and N are respectively

$$\left.\begin{aligned} &\sum_j \frac{n_j - m_j}{N - MB^{-j}} - \frac{1}{N}\sum_j n_j = 0 \\ &N\sum_j \frac{j\,(n_j - m_j)}{N - MB^{-j}} - B\sum_j jn_j = 0 \end{aligned}\right\} \qquad (19)$$

These equations may be solved by the method of scoring described by Fisher (1946).

Most of the models described in this review have been set up to handle data obtained from carefully controlled sampling schemes. In dealing with populations of sea fish there is usually no control over the sampling for recaptures, which are taken incidentally in the commercial exploitation of the population. In particular, the taking of fish from a population is usually selective by size and this can present problems, especially if the rate of exploitation varies in space and time.

Summary

Capture-recapture experiments consist of taking samples from a population, marking the members of the samples and noting the number of these marked individuals subsequently recaptured in later samples. Such experiments provide data from which estimates of population characteristics may be obtained.

Several methods of estimating total population size are here reviewed and their basic practical requirements noted. These methods include the simple "Petersen Method" in which one sample is taken for marking and one for recapturing, and an extension due to Schnabel in which repeated samples are taken for marking and recapturing. The estimation of the size of a stratified population and the number of individuals migrating from one stratum to another is also outlined.

The estimation of population death-rate is also discussed, particular reference being made to methods suitable for fishery research and to schemes which use multiple marks.

Finally the estimation of population birth-rate is briefly discussed.

References

BAILEY, N. T. J. 1951. On estimating the size of mobile populations from recapture data. *Biometrika*, **38**: 293—306.

CHAPMAN, D. G. 1952. Inverse, multiple and sequential sample censuses. *Biometrika*, **8**: 286—306.

CHAPMAN, D. G. 1954. The estimation of biological populations. *Ann. math. Statist.*, **25**: 1—15.

CHAPMAN, D. G. & JUNGE, C. O. 1956. The estimation of the size of a stratified animal population. *Ann. math. Statist.*, **27**: 375—89.

CLOPPER, C. J. & PEARSON, E. S. 1934. The use of confidence fiducial limits illustrated in the case of the binomial. *Biometrika*, **26**: 404—13.

DARROCH, J. N. 1959. The multiple-recapture census. II. Estimation where there is immigration or death. *Biometrika*, **46**: 336—351.

DOWDESWELL, W. H., FISHER, R. A. & FORD, E. B. 1940. The quantitative study of populations in the Lepidoptera. I. *Polyommatus icarus* Rott. *Ann. Eugen.*, Lond., **10**: 123—36.

FISHER, R. A. 1946. A system of scoring linkage data with special reference to pied factors in mice. *Amer. Nat.*, **80**: 568—78.

FISHER, R. A. & FORD, E. B. 1947. The spread of a gene in natural conditions in a colony of the moth, *Panaxia dominula* L. *Heredity* **1**: 143—74.

GULLAND, J. A. 1955. On the estimation of population parameters from marked members. *Biometrika*, **42**: 269—70.

HAMMERSLEY, J. M. 1953. Capture-recapture analysis. *Biometrika*, **40**: 265—78.

HOLT, S. J. et al. 1959. A standard terminology and notation for fishery dynamics. *J. Cons. int. Explor. Mer*, **24**: 239—42.

JACKSON, C. H. N. 1937. Some new methods in the study of *Glossina mersitans*. *Proc. zool. Soc. Lond.*, 1936, 811—96.

JACKSON, C. H. N. (1939). The analysis of an animal population. *J. Anim. Ecol.*, **8**: 238—46.

JONES, R. 1956. The analysis of trawl haul statistics with particular reference to the estimation of survival rates. *Rapp. Cons. Explor. Mer*, **140**: 30—39.

KRUMHOLZ, L. A. 1944. A check on the fin clipping method for estimating fish populations *Pap. Mich. Acad. Sci.*, **29**: 281—91.

LESLIE, P. H. 1952. The estimation of population parameters from data obtained by means of the capture-recapture method. II. The estimation of total numbers. *Biometrika*, **39**: 363—88.

LESLIE, P. H. & CHITTY, D. 1951. The estimation of population parameters from data obtained by means of the capture-recapture method. I. The maximum likelihood equations for estimating the death-rate. *Biometrika*, **38**: 269—92.

MORAN, P. A. P. 1952. The estimation of death-rates from capture-mark-recapture sampling. *Biometrika*, **39**: 187—88.

PETERSEN, C. G. J. 1896. The yearly immigration of young plaice into the Limfjord from the German Sea, etc. *Rep. Danish biol. Sta.*, 1895 **6**: 1—48.

SCHAEFER, M. B. 1951. Estimation of size of animal populations by marking experiments. *Fish. Bull., U.S.*, **52**: 191—203.

SCHNABEL, Z. E. 1938. The estimation of the total fish population of a lake. *Amer. math. Mon.*, **45**: 348—52.

59.

On the Effect of "Holding" Tagged Fish for various Periods before Release

By

R. J. H. BEVERTON and B. C. BEDFORD*

1. Introduction

Although information on the condition of tagged fish when released can be of value in eliminating the relative bias arising from differential survival of fish of various condition (Beverton and Bedford, this symposium, No. 18), it cannot answer directly the question of what proportion of even the best condition fish survive being caught and tagged. One possible way of attacking this problem is to hold fish on board for varying periods before release (both before and after tagging) and to compare the resulting return rates with those from fish released immediately after tagging.

The procedure of deliberately holding tagged fish in various ways for periods of days or even weeks as a means of detecting or measuring tagging mortality has been employed by several workers in connection with tagging experiments on pelagic fish which were suspected of being vulnerable to tagging (e.g., Janssen and Aplin (1945) on sardine; Fridriksson and Aasen (1950) on herring; and Kurata (1954) on mackerel and anchovy); while the death rate of cod held in the tagging tank for up to four days has been reported on by Hylen (1958). The first part of this paper describes the results of holding both tagged and untagged plaice (*Pleuronectes platessa* L.) in a large flooded space on board the research vessel for periods of up to five days before release.

If fish are caught for tagging in fairly large numbers on each haul, it will take some time, perhaps even a few hours, to tag the catch. In such cases the fish are unavoidably held in the tagging tanks for varying periods before release, and Clark and Jansen (1945) have shown that the return rate of sardine tagged towards the end of a large batch can be as low as one-third that of the first fish to be tagged and released. In the whiting tagging experiments reported on by the present authors in No. 18, the duration of the tagging operation varied from a few minutes with small hauls to several hours with the largest hauls. The second part of this paper is, therefore, concerned with a detailed analysis of these whiting data by order of tagging.

2. Holding Experiments on Plaice

(a) Method

The forward part of the fish hold of R.V. "Sir Lancelot," a space of about 23′ × 7′, was flooded to a depth of about 3′ so that some 500 cu. ft. of water could be carried. This well was divided by vertical partitions into several compartments in which batches of fish could be kept separate but between which water could circulate freely. The water in the whole space was renewed and kept in circulation by a pump.

Fish from each haul were divided into three roughly equal batches. Fish of the first batch were tagged and liberated at once in the usual way, their appearance and condition being recorded as described by Beverton and Bedford (No. 18). Fish of the second batch were also tagged and their condition recorded but were then put into the well; fish of the third batch were put into the well untagged. At intervals from two to five days after capture, the fish in the well were examined and any deaths which had occurred were noted; the condition of the survivors was recorded and some were released (the previously untagged fish were of course first tagged). Results showed that the behaviour of the tagged and untagged fish put in the well was virtually identical, both while in the well and in terms of subsequent returns: the data for both these batches are therefore considered together.

Fish were tagged with the Petersen button and the Lowestoft plastic flag tag in equal numbers (see Williams, No. 25), but the data are combined for the present purposes.

The cruise in question was carried out in June 1958 in the southern North Sea. Three grounds were worked, the Cleaver Bank, Haddock Bank and Black Bank; the same procedure was followed on each, but the greatest numbers of fish were liberated on the Cleaver Bank and it is these which permit of the most detailed analysis. Data for the other two banks are given in the tables, but for the most part the numbers are too small to do more than confirm in a general sense some of the conclusions obtained from the Cleaver Bank data.

(b) Results — Cleaver Bank

Two kinds of information can be obtained with the technique described above. One concerns what happens to the fish in the well, especially those tagged initially, since the individual history of each of these can be followed. The other comes from the return rate observed from fish released after being in the well for varying periods, compared with that from fish tagged and released immediately after capture.

---

* Fisheries Laboratory, Lowestoft, England.

Table 1

Plaice — Cleaver Bank; deaths in the holding well

Top entry — initial number of fish put in well
Middle entry (underlined) — deaths while in the well
Bottom entry (brackets) — % mortality in well

	Group (2) — 2 days carried (tagged)				Group (3) — 3 days carried (tagged)				Group (4) — 5 days carried (tagged)			
	G	M	P	Total	G	M	P	Total	G	M	P	Total
	19	13	10	42	20	50	17	87	27	36	22	85
A	0	0	0	0	4	6	6	16	6	12	7	25
	(0)	(0)	(0)	(0)	(20.0)	(12.0)	(35.3)	(18.4)	(22.2)	(33.3)	(31.8)	(29.4)
	16	21	31	68	1	3	7	11	4	5	8	17
B	0	3	11	14	0	0	1	1	1	2	4	7
	(0)	(14.3)	(35.5)	(20.6)	(0)	(0)	(14.3)	(9.1)	(25.0)	(40.0)	(50.0)	(41.2)
	35	34	41	110	21	53	24	98	31	41	30	102
Total	0	3	11	14	4	6	7	17	7	14	11	32
	(0)	(8.8)	(26.8)	(12.7)	(19.0)	(11.3)	(29.2)	(17.3)	(22.6)	(34.1)	(36.7)	(31.4)
				116				96				99
	2 days carried			13	3 days carried			18	5 days carried			27
	(untagged)			(11.2)	(untagged)			(18.8)	(untagged)			(27.3)

Deaths in the holding well. Fish caught on the Cleaver Bank were divided into four groups, (1)—(4). Fish of group (1) were tagged and released immediately after capture; group (2) fish were tagged and held for two days before release, group (3) for three days and group (4) for five days. Table 1 shows the initial distribution of condition (*appearance*, good (G), moderate (M) and poor (P); and *activity*, lively (A) and sluggish (B)) in groups (2), (3) and (4), and the deaths that had occurred when the survivors were released (i.e., after two, three and five days, respectively). There is a progressive increase in the number of deaths up to five days, even in the best condition fish; but the more interesting result is that the death rate is clearly a function of initial condition, increasing both in the direction G→M→P and A→B. The death rates among the untagged fish, which cannot of course be related to initial condition since the fish cannot be recognised individually again, are summarised at the bottom of the table; these are very similar to the total death rates among the tagged fish, which shows that tagging itself did not affect the fish adversely, at least during the period of observation in the well. Fish of groups (3) and (4) were also examined after being held for one day; a total of three deaths (tagged and untagged combined) were found in group (3) and two deaths in group (4), so that the death rate over the first day or so was quite low. Finally, fish of group (4) were also examined after three days; 21 tagged and 19 untagged fish had died, corresponding closely to the deaths recorded in Table 1 for group (3) after three days (17 and 18 respectively), and showing that the data of Table 1 can be interpreted as a fair indication of the progressive changes in any one batch of fish held for up to five days.

Table 2

Plaice — Cleaver Bank; change in condition of tagged fish which died while in the holding well

Top entries — number of fish of each condition when first put in well
Bottom entries — number of fish of each condition when last examined alive

	Group (3) — 3 days carried				Group (4) — 5 days carried			
	G	M	P	Total	G	M	P	Total
A	4/3	6/3	6/2	16/8	6/4	12/5	7/7	25/16
B	—/—	—/3	1/6	1/9	1/2	2/5	4/9	7/16
Total	4/3	6/6	7/8	17/17	7/6	14/10	11/16	32/32

If the condition criteria are meaningful one would expect to find that the condition of fish which eventually died had worsened before death occurred. That this is indeed the case appears from Table 2, which shows the change in condition of fish which subsequently died. The most marked feature is the decrease after five days (group (4)) of category A fish (lively) and the increase of B fish (sluggish); changes in appearance are less marked, as would be expected, but there is a tendency for the proportion of M fish to decline and that of P fish to increase. It is also relevant to see what happened to the condition of fish which survived throughout the period in the well, which is shown in Table 3. By two days the condition, both appearance and activity, had im-

Table 3

Plaice — Cleaver Bank; change in condition of tagged fish surviving in the holding well

Top entries — number of fish of each condition when put in the well

Bottom entries — number of fish of each condition when released

	Group (2) — 2 days carried				Group (3) — 3 days carried				Group (4) — 5 days carried			
	G	M	P	Total	G	M	P	Total	G	M	P	Total
A	19/28	13/25	10/8	42/61	16/15	44/15	11/7	71/37	21/24	24/11	15/6	60/41
B	16/19	18/7	20/9	54/35	1/11	3/14	6/19	10/44	3/2	3/11	4/16	10/29
Total	35/47	31/32	30/17	96/96	17/26	47/29	17/26	81/81	24/26	27/22	19/22	70/70

proved; but among the fish held for three days the general condition had worsened, especially in the direction A (lively) to B (sluggish), although the numbers of fish in the best condition (GA) remained nearly constant. The picture after five days (group (4)) is rather similar to that after three days (group (3)), but if anything the deterioration of the survivors is not as pronounced as after three days and the numbers of GA fish have in fact increased slightly.

Returns of tagged fish. The general impression from these observations is that nearly all the fish survived the immediate effects of being caught for a day or so, and some even made a temporary improvement; thereafter, however, those in poorer condition began to succumb, although the fish initially in the best condition maintained their state throughout and survived well. It is of interest to see now how the return rate of fish released after being carried for two, three and five days compares with that of those released immediately. The data are summarised in Table 4, in which columns (**x**) show the number returned up to 1st February, 1961 (first entry) and the number released (second entry), while columns (y) show the percentage returned (underlined and the confidence limits of that percentage at the 0.95 probability level (brackets). The immediate releases are noteworthy in showing no marked effect of either kind of condition (see Beverton and Bedford, No. 18). Among the two-day releases, however, a more definite decrease of the return rate in the direction G-M-P, and in the direction A-B, appears; nearly the same trends are also seen in the three-day releases. In both batches the return rate of the best condition fish is nearly maintained but in the remaining categories it falls to between two-thirds and one-half. Finally, among the five-day releases, the return rate in every condition category increases again, and in the best condition fish it exceeds the return rate of the immediate releases (although not significantly so on the numbers available).

The decline in the return rate of the survivors after being carried for two and three days is perhaps rather unexpected. Apparently, some fish died after being carried for these times and then released which would not have died had they been released immediately, and it would seem that keeping them in the well caused the harm which they had suffered in capture to become permanent and something from which many could not recover even after being returned to the sea.

More important, however, is the extent to which the return rate of the best condition fish increased after being held for five days. From Table 1 it can be estimated that about 25% of fish of conditions GA and MA died during the five days in the well. If it is assumed that the survivors when released suffered no further mortality and that the initial mortality of the immediate releases was also 25%, the return rate of the five-day fish should have been $\frac{1}{1 - 0.25} = 1.3$ times as high as that of the immediate releases, i.e. $57\% \times 1.3 = 74\%$. The observed return rate for GA and MA fish released after five days was, in fact, 70% (Table 4), which is in reasonable agreement. Bearing in mind the fact that the death rate of fish of categories other than these two which were held on board was evidently greater than if they had been returned at once to the sea, it seems reasonable to conclude from this evidence that the true initial tagging mortality of the best condition fish released immediately into the sea was not greater than 25%, and probably less.

(c) Results — Haddock and Black Banks

The data for plaice caught and released on the Haddock Bank and Black Bank are summarised in Tables 5—8 and 9—12 respectively, following the same presentation as for the Cleaver Bank fish. The features which emerge are broadly similar to those already described. Thus, the *Haddock Bank* fish after being carried for five days showed a markedly condition-specific death rate, although hardly any of the best condition fish died (Table 5). Again, there was a marked deterioration from A (lively) to B (sluggish) of fish which subsequently died (Table 6)

Table 4

Plaice — Cleaver Bank; returns of tagged fish held for various periods before release

Columns (x): number returned/number released

Columns (y): percentage returned (underlined) and its 95 % confidence limits (brackets)

	Group (1) — Immediate release								Group (2) — 2 days carried							
	G		M		P		Total		G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	40/67	(72) 59.7 (47)	46/85	(65) 54.1 (43)	31/55	(69) 56.4 (42)	117/207	(63) 56.5 (49)	24/43	(72) 55.8 (38)	15/45	(49) 33.3 (20)	6/17	(62) 35.3 (13)	45/105	(53) 42.9 (33)
B	8/16	(76) 50.0 (24)	16/36	(63) 44.4 (27)	27/49	(69) 55.1 (40)	51/101	(60) 50.5 (40)	8/19	(67) 42.1 (21)	8/31	(45) 25.8 (11)	10/45	(38) 22.2 (11)	26/95	(38) 27.4 (19)
Total	48/83	(69) 57.8 (46)	62/121	(59) 51.2 (41)	58/104	(65) 55.8 (45)	168/308	(61) 54.5 (48)	32/62	(64) 51.6 (37)	23/76	(42) 30.3 (19)	16/62	(39) 25.8 (14)	71/200	(42) 35.5 (28)

	Group (3) — 3 days carried								Group (4) — 5 days carried							
	G		M		P		Total		G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	16/31	(69) 51.6 (32)	19/37	(68) 51.4 (33)	4/21	(43) 19.0 (5)	39/89	(54) 43.8 (33)	24/34	(85) 70.6 (52)	20/29	(85) 69.0 (49)	4/9	(80) 44.4 (11)	48/72	(78) 66.7 (54)
B	4/13	(62) 30.8 (8)	7/20	(59) 35.0 (15)	9/37	(42) 24.3 (11)	20/70	(42) 28.6 (18)	4/7	(92) 57.1 (15)	11/22	(72) 50.0 (28)	13/31	(62) 41.9 (24)	28/60	(61) 46.7 (33)
Total	20/44	(62) 45.5 (30)	26/57	(60) 45.6 (32)	13/58	(36) 22.4 (12)	59/159	(45) 37.1 (29)	28/41	(83) 68.3 (52)	31/51	(74) 60.8 (46)	17/40	(59) 42.5 (27)	76/132	(67) 57.6 (48)

but, in contrast to Cleaver Bank results, the condition of fish which survived throughout seemed to change from M to both G and P rather than from A to B (Table 7). The returns of Haddock Bank fish, summarised in Table 8, are mostly too few to enable any detailed conclusions to be drawn; but the return rate of fish in the best condition (GA) is maintained fairly well throughout, and as very few of these fish died even on board it seems unlikely that the immediate releases of GA fish suffered any appreciable tagging mortality.

The death rate of the *Black Bank* fish after four days was also condition-specific (Table 9) but no deaths occurred among the GA or GB fish. The condition of the survivors appeared to *improve* during carriage, at least in the direction B (sluggish) to A (lively), although some of the M fish evidently worsened to P (Table 11). The returns (Table 12) showed little signs of condition effect (except perhaps

Table 5

Plaice — Haddock Bank; deaths in the holding well

Top entry — initial number of fish put in well

Middle entry (underlined) — deaths while in the well

Bottom entry — % mortality in the well

	3 days carried (tagged)				5 days carried (tagged)			
	G	M	P	Total	G	M	P	Total
A	67 0 (0)	32 0 (0)	16 3 (18.8)	115 3 (2.6)	33 2 (6.1)	36 11 (30.6)	20 13 (65.0)	89 26 (29.2)
B	3 0 (0)	0 0 (0)	2 0 (0)	5 0 (0)	5 0 (0)	8 2 (25.0)	28 26 (93.0)	41 28 (68.2)
Total	70 0 (0)	32 0 (0)	18 3 (16.7)	120 3 (2.5)	38 2 (5.3)	44 13 (29.5)	48 39 (81.2)	130 54 (41.5)
	3 days carried (untagged)			120 6 (5.0)	5 days carried (untagged)			130 54 (41.5)

Table 6
Plaice — Haddock Bank; change in condition of tagged fish which died while in the holding well

Top entry — number of fish of each condition when first put in well

Bottom entry — number of fish of each condition when last examined alive

	3 days carried				5 days carried			
	G	M	P	Total	G	M	P	Total
A	0 / 0	0 / 0	3 / 1	3 / 1	2 / 0	11 / 3	13 / 5	26 / 8
B	0 / 0	0 / 0	0 / 2	0 / 2	0 / 3	2 / 6	26 / 37	28 / 46
Total	0 / 0	0 / 0	3 / 3	3 / 3	2 / 3	13 / 9	39 / 42	54 / 54

Table 7
Plaice — Haddock Bank; change in condition of tagged fish surviving in the holding well

Top entry — number of fish of each condition when put in the well

Bottom entry — number of fish of each condition when released

	3 days carried				5 days carried			
	G	M	P	Total	G	M	P	Total
A	67 / 49	31 / 24	13 / 7	111 / 80	31 / 43	25 / 14	7 / 4	63 / 61
B	3 / 6	0 / 13	2 / 17	5 / 36	5 / 3	6 / 3	2 / 9	13 / 15
Total	70 / 55	31 / 37	15 / 24	116 / 116	36 / 46	31 / 17	9 / 13	76 / 76

Table 8
Plaice — Haddock Bank; returns of tagged fish held for various periods before release

Columns (x): number returned/number released

Columns (y): percentage returned (underlined) and its 95 % confidence limits (brackets)

	Immediate releases								3 days carried							
	G		M		P		Total		G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	29/113	(35) 25.7 (18)	9/56	(28) 16.1 (7)	5/32	(33) 15.6 (5)	43/201	(27) 21.4 (16)	33/107	(41) 30.9 (22)	9/50	(32) 18.0 (9)	5/20	(50) 25.0 (18)	47/177	(34) 26.6 (19)
B	3/14	(52) 21.4 (4)	2/12	(51) 16.7 (2)	5/23	(44) 21.7 (7)	10/49	(34) 20.4 (10)	3/8	(77) 37.5 (7)	5/17	(57) 29.4 (10)	3/29	(28) 10.4 (2)	11/54	(34) 20.4 (10)
Total	32/127	(33) 25.2 (18)	11/68	(27) 16.2 (8)	10/55	(32) 18.3 (9)	53/250	(27) 21.2 (16)	36/115	(41) 31.4 (23)	14/67	(33) 20.9 (11)	8/49	(30) 16.3 (7)	58/231	(32) 25.1 (19)

	5 days carried							
	G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A	19/84	(34) 22.6 (13)	3/28	(29) 10.7 (3)	2/9	(60) 22.2 (2)	24/121	(33) 19.8 (13)
B	0/4	0	3/8	(77) 37.5 (7)	1/15	(33) 6.7 (10)	4/27	(35) 14.8 (4)
Total	19/88	(32) 21.6 (13)	6/36	(33) 16.7 (6)	3/24	(33) 12.5 (2)	28/148	(27) 18.9 (13)

Table 9
Plaice — Black Bank; deaths in the holding well

Top entry — initial number of fish put in well
Middle entry (underlined) — deaths while in the well
Bottom entry — % mortality in the well

	4 days carried (tagged) G	M	P	Total
A	14 0 (0)	16 1 (6.3)	13 3 (23.1)	43 4 (9.3)
B	5 0 (0)	12 2 (16.7)	18 5 (27.8)	35 7 (20.0)
Total	19 0 (0)	28 3 (10.7)	31 8 (25.8)	78 11 (14.1)
	4 days carried (untagged)			71 10 (14.1)

Table 10
Plaice — Black Bank; change in condition of tagged fish which died while in the holding well

Top entry — number of fish of each condition when first put in well
Bottom entry — number of fish of each condition when last examined alive

	4 days carried G	M	P	Total
A	0/0	1/3	3/2	4/5
B	0/0	2/0	5/6	7/6
Total	0/0	3/3	8/8	11/11

Table 11
Plaice — Black Bank; change in condition of tagged fish surviving in the holding well

Top entry — number of fish of each condition when put in the well
Bottom entry — number of fish of each condition when released

	4 days carried G	M	P	Total
A	14/16	14/14	8/13	36/43
B	5/4	9/2	13/14	27/20
Total	19/20	23/16	21/27	63/63

the PB fish after four days) and, in particular, the return rate of fish released after four days was nearly the same as that of the immediate releases, in all categories (except PB). Taken in conjunction with the low death rate among the better condition fish held on board it again seems unlikely that the immediate releases suffered much initial tagging mortality.

3. Whiting — Analysis of Order of Tagging

(a) Method

In another paper presented to this symposium (No. 18), the authors have reported on the effect of condition on the return rate of whiting and have showed that both appearance condition (good (G), moderate (M) and poor (P)) and activity condition (lively (A), sluggish (B) and "sinkers" (S)) influenced the return rate. The number of fish tagged from each haul varied from a dozen or so to nearly five

Table 12
Plaice — Black Bank; returns of tagged fish held for various periods before release

Columns (x): number returned / number released
Columns (y): percentage returned (underlined) and its 95% confidence limits (brackets)

	Immediate releases								4 days carried							
	G		M		P		Total		G		M		P		Total	
	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)	(x)	(y)
A ...	6/13	(75) 46.2 (18)	12/21	(78) 57.2 (33)	5/16	(59) 31.3 (10)	23/50	(61) 46.0 (32)	18/37	(66) 48.6 (31)	13/24	(75) 54.2 (33)	9/19	(72) 47.4 (25)	40/80	(62) 50.0 (38)
B ...	2/3	67	8/14	(83) 57.1 (28)	5/12	(73) 41.7 (13)	15/29	(67) 51.8 (32)	6/8	(100) 75.0 (30)	5/10	(82) 50.0 (18)	3/25	(32) 12.0 (2)	14/43	(49) 32.6 (28)
Total	8/16	(76) 50.0 (24)	20/35	(75) 57.1 (38)	10/28	(56) 35.7 (18)	38/79	(60) 48.1 (36)	24/45	(68) 53.3 (37)	18/34	(71) 53.0 (34)	12/44	(43) 27.3 (15)	54/123	(54) 43.9 (34)

Table 13

Whiting; effect of order of tagging on return rate

Top entry — number returned / number released
Bottom entry (underlined) — percentage returned

Categories A and B

Order of Tagging	1—120 releases			121—300 releases			> 300 releases		
	G (A+B)	M (A+B)	P (A+B)	G (A+B)	M (A+B)	P (A+B)	G (A+B)	M (A+B)	P (A+B)
1st 60	132/565 23.4	205/1,057 19.4	64/566 11.3	70/334 21.0	103/599 17.2	28/375 7.5	13/44 29.5	25/64 39.1	1/12 8.3
2nd 60	11/57 19.3	16/136 11.8	12/129 9.3	41/220 18.6	78/495 15.8	26/469 5.5	8/30 26.7	19/70 27.1	7/20 35.0
3rd 60				26/128 20.3	42/266 15.8	12/188 6.4	14/46 30.4	16/67 23.9	2/7 28.6
4th 60				6/22 27.3	10/45 22.2	0/23 0	10/41 24.4	8/63 12.7	1/13 7.7
5th 60				0/0 0	0/0 0	0/0 0	7/21 33.3	9/73 12.3	1/26 3.8
6th 60							0/18 0	4/62 6.4	1/34 2.9
7th 60							0/14 0	0/35 0	0/11 0
8th 60							0/1 0	0/16 0	0/6 0

Category S ("Sinkers")

Order of Tagging	1—120 releases			121—300 releases			> 300 releases		
	GS	MS	PS	GS	MS	PS	GS	MS	PS
1st 60	11/46 23.9	24/107 22.4	11/83 13.2	1/1 (100)	0/0 —	0/0 —	0/0 —	0/0 —	0/0 —
2nd 60	23/60 38.3	28/123 22.8	12/109 11.0	2/13 15.4	7/38 18.4	0/14 0	0/0 —	0/0 —	0/0 —
3rd 60				14/57 24.6	15/172 8.7	3/179 1.7	0/0 —	0/0 —	0/0 —
4th 60				28/81 34.6	15/161 9.3	9/144 6.2	0/2 0	0/1 0	0/0 0
5th 60				0/5 0	3/43 7.0	0/46 0	0/0 —	0/0 —	0/0 —
6th 60							0/4 0	0/1 0	0/1 0
7th 60							1/9 11.1	0/4 0	0/3 0
8th 60							2/14 14.3	0/20 0	0/2 0

hundred and the duration of the tagging operation varied correspondingly from a few minutes to several hours. No direct record of time was kept during the tagging operations, but it is sufficient for the present purposes to group fish into batches of sixty releases (it took, in fact, about forty minutes to tag and release sixty fish), and to examine the return rate from successive batches.

(b) Results

Table 13 shows the combined results from the three cruises by order of tagging. In this table, activity conditions A and B have been combined, since on only one of the three cruises was a significant difference between them observed. Fish of category S ("sinkers") have been treated separately, since they were swimming at the bottom of the tagging tank without distended bodies and so were not usually tagged until near the end of the tagging operation. Finally, as it is often noticed that fish taken in large hauls seem to be in better condition than those in small, the data have been grouped into hauls in which 120 or fewer fish were released, those in which between 121 and 300 fish were released, and those in which more than 300 fish were released. It should be noted that this last group comprises two hauls only, from Cruise XVIII/1958.

Considering first the combined categories A + B, the percentage returns of Table 13 are shown plotted against order of tagging in Fig. 1. No particularly striking trends emerge from the 1—120 and 121—300 groups of releases; there is a small but consistent decline in the return rate between the 1st and 2nd batches of 60 releases in every case which, however, is not maintained in the 3rd and 4th batch. In the two largest hauls (> 300 releases) on the other hand, there is a marked and continuous decline in the return rate of "moderate" (M, A + B) fish from something in the region of 40% from the first batch of 60 to zero from the 7th and 8th batches, (although 51 fish were released in these last two batches). Fish of category "Good" (G, A + B), in contrast, maintain a return rate in the region of 30% up to the 5th batch, after which it falls abruptly to zero. While it is possible, with the numbers of fish involved, that the true return rate of G (A + B) fish could have declined to some extent with order of tagging from the beginning, a chi-squared test shows it to be most unlikely that it declined as fast as in the M (A + B) fish. The return rate of fish of category "Poor" (P, A + B) also decreases with order of tagging after the second batch of 60, but the numbers of fish in this category are too few to enable any more detailed conclusions to be drawn.

The number of "sinkers" (S) released in successive batches is rather uneven, but two features emerge from Table 13 which are worth noting. One is that the return rate of the best condition "sinkers" (GS) tends to increase towards the end of the tagging operation in both small (1—120) and medium (121—300) hauls, and that the rates attained (38% and 35%) are the highest recorded of any category except the M (A + B) fish from the 1st batch in the two largest hauls. The other is that the "sinkers" tagged towards the end of the two largest hauls, after 300 fish had been released, gave only three returns from 58 releases, which is significantly lower ($P \simeq 0.01$) than the average return rate of this category from the combined data. This result is rather unexpected in that the observers at the time reported that these "sinkers" were swimming actively at the bottom of the tagging tank and appeared to be in no worse condition than sinkers tagged from smaller hauls.

4. Discussion

(a) Plaice

The main objective of the plaice experiments was to establish whether with the normal tagging procedure (fish released immediately after being caught and tagged without reference to condition provided they are reasonably fit) there is any appreciable initial tagging mortality and, if so, to measure it. On the evidence presented here, the essential results which bear on this question would seem to be the following:—

(i) The return rate of fish released immediately after being caught and tagged is not greatly dependent on their condition.

(ii) If fish are held on board for periods of up to five days a highly condition-specific death rate is observed, being smallest among the best condition fish, and not becoming apparent until after the second or third day.

(iii) There is a general deterioration in condition of the survivors held on board except among fish initially classified as of the best condition (GA).

(iv) In the experiment in which some deaths of even the best (GA) fish occurred after five days (Cleaver Bank), the return rate of the survivors of this category was a little higher than that of the initial GA releases. In the other experiments, where hardly any deaths of GA fish occurred on board, there was no detectable difference between the return rate of the survivors and that of the initial GA releases.

It is suggested that the simplest conclusion from this evidence is that conditions for survival on board were evidently much more adverse than in the sea, and hence that the observed death rate among the best condition fish held on board can reasonably be

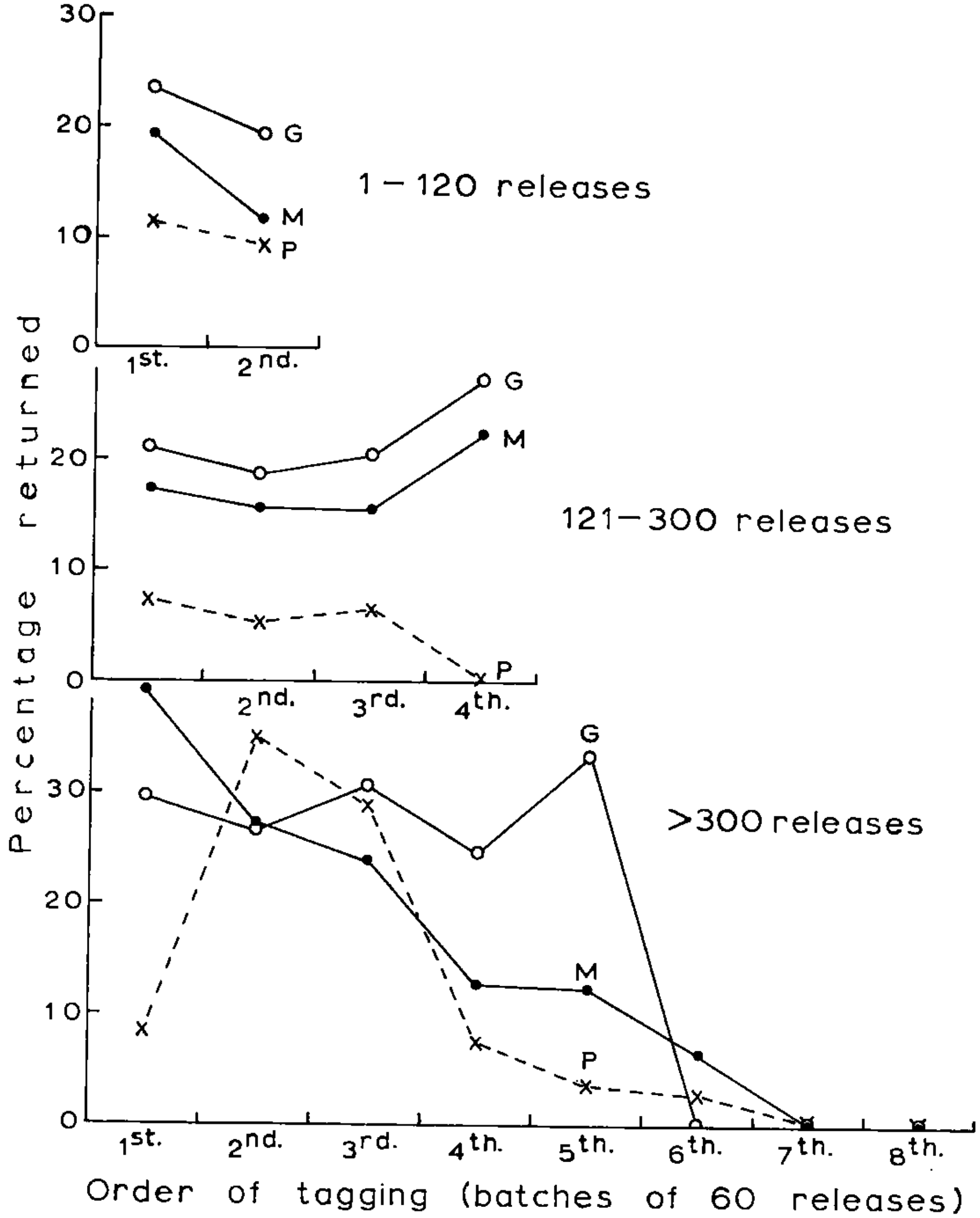


Figure 1. The effect of order of tagging on the return rate of whiting. The data are grouped in three sizes of total release batches, of which the largest (> 300 releases) shows a marked effect of order of tagging and the highest initial return rate.

taken as a maximum estimate of the initial mortality suffered by these fish if released immediately. In the experiments reported here it seems, on this basis, that the initial mortality of the immediate GA releases on all three grounds is unlikely to have exceeded 20% and may well have been substantially less, despite the large differences in total return rate observed between grounds.

A further question is prompted by these results, namely whether the technique of holding plaice on board for a period before release is worth-while as a routine procedure. The answer seems to be that it is not, at least on the present evidence. If it had been that the return rate of immediate releases was highly condition-specific (as in whiting, cod and sole), keeping a batch of fish on board would at least serve to eliminate the poorer fish and so increase the effective return rate. In fact, the return rate of immediate releases of plaice does not seem to be much affected by condition; moreover, there is evidence that holding fish on board for two to three .days may even reduce their chances of subsequent survival. The best routine procedure therefore still seems to be the conventional one of returning plaice to the sea as soon as possible after being caught and tagged, but with their condition recorded as a check against any unusual circumstances which might influence survival.

(b) Whiting

It would appear from the whiting data summarised in Table 13 and Fig. 1 that in hauls from which up to 300 fish were tagged, neither the time during which fish were held before being released (up to about $2^1/_2$ hours) nor the size of haul (and hence also density of fish in the tagging tank) had much influence on the tagging mortality. In the two largest hauls, however, not only was there a marked decline in return rate with order of tagging (delayed in the best condition fish but progressive in the rest) but extrapolation of the graphs of Fig. 1 to zero time indicates that the maximum return rate, i.e., that from the first released, was higher than in any of the batches from smaller hauls. Hylen (1958) has reported what seems to be a similar higher return rate of cod tagged from large hauls than from small ones. It is interesting that the return rate from "moderate" (M, A + B) fish at zero time is as high as that from "good" (G, A + B) fish) or higher; and even fish of category "poor" (P, A + B) gave exceptionally high returns from the 2nd and 3rd batch of 60, although the numbers involved are small. Evidently, there was a gradual deterioration in viability of fish while in the tagging tank which was not apparent visually, and it seems that this deterioration became more condition-specific the longer the fish were in the tank up to about three hours, after which even the best fish were seriously affected. There is something of a parallel here to the results reported above for Cleaver Bank plaice (Table 4), in which the return rate from fish held for two and three days was not only lower than from immediate releases but was also more clearly condition-specific.

The practical implication of a decline in return rate with order of tagging needs no emphasis, since failure to take account of it could clearly lead to major errors of interpretation if data from hauls of widely differing size are being compared It is also possible that where a consistent effect of order of tagging and size of haul can be established, the information can enable a better idea to be obtained of the initial tagging mortality of even the best condition fish. The fact that, in the whiting data, only the two largest hauls (both in the same cruise) showed a significant trend of return rate with order of tagging, makes it rather uncertain whether the maximum return rates estimated from them (in the region of 35% to 40%) are truly applicable to all the results, but it would clearly be worth-while trying to confirm these findings whenever particularly large hauls are obtained. The lack of a marked effect of "appearance condition" (G, M, P) among the early releases from the two largest hauls lends additional support to the conclusion that the extrapolated return rates approach more nearly to the "true" return rates in the absence of initial tagging mortality (cf. plaice). In whiting, however, there is the complication that probably most of the fish had ruptured swim-bladders which may have caused an additional mortality unrelated to their appearance condition at the time of release. Until this point is resolved it seems necessary to reserve judgement on how nearly the highest of the observed return rates approaches the "true" rate in the absence of any tagging-induced mortality.

5. Summary

(a) The results are described of holding tagged plaice in a large well on board the research vessel for periods of up to five days before release, and of the effect of order of tagging in the case of experiments with whiting.

(b) Although the effect of condition on the return rate of plaice tagged and released immediately after capture was not marked, the death rate in the holding well was increasingly condition-specific up to five days. The death rate among the best condition fish, however, remained small or nil. The return rate of tagged plaice released after being held for periods of two, three and five days was also more condition-specific than the immediate releases.

(c) It appears that holding plaice which have suffered some damage on capture decreases their changes of survival when subsequently released; but since the best condition fish were able to survive it is concluded that their initial tagging mortality, if released immediately after being caught and tagged, is likely to be small.

(d) Order of tagging was not found to have any appreciable effect on the return rate of whiting caught in small or medium sized hauls, but had a marked effect in the case of large hauls when it took between four and five hours to tag the catch. The return rate of the first fish to be tagged from these large hauls was, however, higher than from any fish caught in small or medium hauls.

(e) It is concluded that analysis by order of tagging may be critical in "fragile" species such as whiting, especially if the size of haul varies considerably, and that the information from such an analysis may also provide further evidence on the magnitude of the initial tagging mortality.

References

CLARK, F. N. & JANSSEN, J. F. (Jr.). 1945. Movements and abundance of the sardine as measured by tag returns. *Fish. Bull., Sacramento*, No. 61: 7—42.

FRIDRIKSSON, A. & AASEN, O. 1950. The Norwegian-Icelandic herring tagging experiments. Report No. 1. *Fiskeridir. Skr. Havundersøk.*, 9 (11).

HYLEN, A. (1958). Marking experiments on Arctic cod. C. M. 1958, No. 74, ICES.

JANSSEN, J. F. (Jr.) & APLIN, J. A. 1945. The effect of internal tags on sardines. *Fish. Bull., Sacramento*, No. 61: 43—62.

KURATA, H. 1954. Holding experiments on tagged fishes. *Bull. Hokkaido Reg. Fish. Res. Lab.*, No. 10: 16—28.

60.

A Radioactive Internal Tag for Herring

By

NORMAN J. WILIMOVSKY*

Bulk handling of herring in western North America precludes the use of an external tagging technique based on visual detection. Regardless of high individual visibility, external tags would pass virtually undetected through the present herring processing plants. Previous studies in Alaska and Canada have shown the ease with which internal tags might be inserted into herring and the relatively low mortality rate brought about by internal tagging.

The metallic or magnetic tag has been proven partially effective in both herring and pilchard investigations along the West Coast of North America. However, investigators using either type of tag recognize that the magnetic and metal detectors miss a percentage (often large) of tagged fish. Even a safety magnet, located in a powdered-meal line, occasionally is blocked by a sufficient thickness of meal so that the magnetic flux is insufficient to retain a whole tag, and tags are lost. More important, all tags that are collected on the magnet at the end of a production line have lost much of their potential usefulness, since there is no way of determining from what fish or group of fish they originated. Also the present widespread use of electrical machinery in reduction plants greatly increases the electronic filtering problems and difficulty of maintaining electronic balance circuits in magnetic or metallic detection equipment.

The cost of developing improved circuitry to assure a greater percentage tag recovery is prohibitively high. In all probability, these more sophisticated circuits would require more skilful technicians and more consistent maintenance in the field than is usually feasible. Consequently, development of a new means of detecting an internal tag was sought.

Our objectives were to develop a system with (1) an internal tag that would be easy to apply and to detect, (2) a tag detection device which would operate at extremely high levels of sensitivity, (3) a detection-ejection technique that would isolate only the specimens containing tags. (Equipment previously employed for use with internal metal tags would eject up to two dozen fish at a time, and it was often necessary to dissect specimens to locate one containing a tag.) (4) Finally, the ejection gear was not to interfere with or delay normal processing techniques at reduction plants.

Of the many detecting methods for internal tags considered, several were rejected because their use was impractical under Alaskan field conditions, e.g. because of high cost of operation and maintenance in isolated areas. The only promising technique of detecting a tag in herring when it was screened by a mass of fish, slime, and water appeared to be the employment of a radioactive tag. Radioisotopes have been tried for fish tagging under laboratory conditions, and at least one worker suggested the use of a radioactive fish tag for field use. However, the survey of the problem by Seymour (1957) indicated that for most applications the use of radioisotopes for tagging was not feasible. The single exception was for the type of operation used in taking herring and similar fishes for reduction.

The construction of the equipment described below was carried out by the Fisheries Instrumentation Laboratory, Bureau of Commercial Fisheries, Seattle, Washington. To a great degree the technical competence of Richard Van Haagen and Richard Othberg made the engineering system which we advanced a working practicality. A paper describing the electronics and engineering details has been prepared for publication and the apparatus may be reproduced.

Description of Equipment

Essentially, the units of the system may be described as follows.

The tags themselves are made of Alnico V magnetic rods $^1/_2$ inch long and $^1/_8$ inch in diameter. Alnico V was chosen because it is the strongest permanent magnet known and because of its cobalt content. The tags are gold-flashed and labelled radioactive. Each bears a serial number and directions for return, should it fall into the hands of a member of the general public. Finally, the tag is coated with transparent polyethylene and sealed to insure inertness in the herring and in sea water. At one of the National Laboratories tags are irradiated to the very low level required for detection by the newly designed sensitive equipment. Gamma emission from Cobalt 60 at a level of 10 microcuries would fall well within safety requirements and would remain within a level to assure detection even if the tag was shielded by a mass of other fish and debris. Preliminary studies have

---

* Institute of Fisheries, University of British Columbia, Vancouver 8, Canada.

This work was performed while the author was with the Marine Fisheries Investigations, U. S. Bureau of Commercial Fisheries, Alaska.

shown that this level of radiation can be borne by herring without harm.

Tags are packaged in plastic cartridges to facilitate identification and handling efficiency.

Tag injection equipment has been designed and made to insert the tag into the abdominal cavity of the fish. Narcoticized herring (to reduce mortality from handling) are impaled on the injector, and pressure from a foot pedal gently inserts a tag into the peritoneal cavity. At the same time, an antibiotic is sprayed over the tag and over the wound to reduce the possibility of infection*.

Tagged herring are recovered from the commercial catch at reduction plants. The tag detector consists of a radiation detector and associated electronic circuits. The detector unit is relatively unsophisticated, except for the "fail-safe" features of the circuit. The detection unit provides a signal to operate the tagged fish ejector at the proper instant.

The detection and ejection of tagged fish may be accomplished as the fish enter the processing plant. Because the detection equipment is an integral part of the unloading conveyor system, it was designed to eject fish with a minimum of delay to the processing machinery. This in itself is a significant advance, in that plant operators appear to offer less objection to installation of units into the production lines than to the old metal detectors. It is to be recalled that reduction plant operators participate in any tagging program wholly on a voluntary basis. As herring are unloaded, they pass through the plant's weighing machine and thence onto the tagged fish detector and ejector. In essence, the detector and ejector units appear to be part of the conveyor belt. Radiation from any and all tagged fish is picked up by a scintillation detector at the head of the ejector; in a fraction of a second the machine comes to a stop; in a second fraction of a second, the tagged fish and all fish in the immediate neighborhood are ejected from the main conveyor belt, and in a third fraction of a second, the machinery is again in operation at full speed — the total elapsed time being less than three seconds. With this schedule, ejection will not in any way impede plant operations.

The ejected fish are picked up individually by a small conveyor belt, and each is examined for radioactivity. The tagged fish are diverted into a separate receptacle, and all remaining fish are droped back on the main conveyor line at the head of the ejector. Thus, the fish are checked for radioactivity a second time as they pass the radiation counter. One hundred percent efficiency of tag detection is thereby assured. High safety factors and "fail-safe" techniques are built into the machinery. A third detector is located at the terminal end of the ejector and would halt the equipment should any breakdown allow tags to pass the first detection stage.

Safety Provisions

Additional safety measures have been taken to prevent any radioactive tag from reaching the finished meal product.

The magnetic nature of the tag ensures retention even if through some unlikely and nearly impossible chance a tag should pass through the ejector equipment undetected. The tag itself would magnetically attach to the first piece of metallic machinery it contacted. Even if it were ground to a powder, each particle would become a new magnet, and the metallic dust would be retained on plant machinery rather than enter the meal. The metal detector, which is a part of the plant's debris straining equipment, would pick out any minute particles of the tag that might reach the end of the meal line. As a further safeguard and to alleviate possible criticisms from the consumer the meal product is checked with radiation survey meters. To recover tags that may be lost from rotting fish, the holds of herring fishing vessels are examined with survey meters at frequent intervals.

There is relatively little possibility that any person in the general public will come in contact with one of these tagged herring. The meal produced by the reduction operation is used in high protein poultry feeds, and the oil is used in paints, cosmetics, and ore flotation processes. The chances of obtaining a tagged herring in a catch of bait are extremely small. Should this occur, however, the danger from exposure to radiation would be negligible. The prospect of anyone swallowing a tag in a pickled herring is even smaller. If the tag were not discarded in gibbing the fish, the sealed nature of the tag itself insures that, if it were not discovered in chewing, it would pass intact through the digestive system, giving a negligible dose of radiation to the digestive tract. Several tags would have to be *dissolved* in the body fluid before the radiation level in the liver (the organ which accumulates cobalt faster than others) would reach a dangerous point — a most unlikely circumstance.

Further evidence of the inherent safety of the tag and of the low levels of radiation employed are the simplified shipping and storage procedures prescribed by Government regulations. Shipment of tags through U.S. mail in egg crate cartons is permissible.

To monitor any radiation effects on personnel participating in the tagging program, film badges are worn. Personnel using the injection equipment also wear adhesive thumb-type badges.

---

* Present incomplete experiments suggest that this cautionary feature may not be necessary.

Field Operation

Any widespread use of radioactive materials apparently is of concern to the general public. Our proposed use of radioactive tags was made known to the public, processors, wholesalers and health agencies. As the use of radioactive materials was to conform to Atomic Energy Commission specifications, no objections to our application were registered. In February of 1960, the U. S. Atomic Energy Commission granted a license for the employment of our technique.

Installation of detection and ejection equipment at the three operating plants in Southeastern Alaska was completed by early summer 1960. Field use of the equipment pointed out some shortcomings which were relatively easy to rectify. The major problems involved modifying existing plant features to accommodate our equipment. A limited number of herring was tagged and released during the summer of 1960, and by the end of the fishing season, some recoveries were made. Final evaluation of the technique is currently being conducted in Alaska.

Summary

Use of internal metal tags has been successfully applied to pelagic fish such as herring, but efficient recovery of individual tagged fish has been a major problem in the past. A research and development program designed to perfect a better tag detecting system resulted in the design of a radioactive magnetic tag, tag injection equipment, and associated detection and ejection machinery. The equipment has been designed to detect radioactive tags at high speeds and under heavy radiation-masking conditions, with virtual 100 percent efficiency. The system costs a fraction of that required to make the less efficient magnetic and metallic detectors. Appropriate safety features are an integral part of the system, which has been granted an Atomic Energy Commission license. The technique is currently being used in Southeastern Alaska to study herring (*Clupea harengus pallasii*) populations.

References

SEYMOUR, A. H. 1957. The use of radioisotopes as a tag for fish. *Proc. Gulf Caribb. Fish. Inst.*, 10th Sess., 118—25.

61.

An Initial Inquiry into a Photoelectric Device to Detect Menhaden Marked with Fluorescent Pigments

By

JOHN W. REINTJES*

Introduction

Each year over 5,000,000,000 menhaden (*Brevoortia* spp.) are the raw material for the fish meal and oil industry of the Atlantic and Gulf coasts of the United States. Catching, handling, and processing are done by mechanical means, and there is no opportunity to detect marked fish visually. Therefore, mechanical or electronic methods are required to detect marked fish released into the fishable population.

Detection or recovery of tags by magnetic or electronic devices has been used for several herring-like fishes. Recovery of nickel belly and opercle tags from Pacific herring, *Clupea pallasii*, was reported by Rounsefell and Dahlgren (1933a, 1933b) and Dahlgren (1936). Magnetic recovery of tags was also employed in studies of the California sardine, *Sardinops caerulea*, (Clark and Janssen, 1945), the Norwegian herring, *Clupea harengus*, (Fridriksson and Aasen, 1950) and the Panama anchoveta, *Cetengraulis mysticetus*, (Klima and Bayliff, 1961). Recently, electronic devices for detection of ferromagnetic and radioactive tags were tested experimentally in the Pacific herring fishery (van Haagen and Dale, 1959; Anonymous, 1959).

Trials showed ferromagnetic tags to be unsuited to the menhaden fishery. An internal tag large enough to be recovered magnetically caused severe visceral damage to the fish, particularly among juveniles. In some menhaden reduction plants, magnetic recovery would be difficult as much of the solids is not pulverized into meal.

Marking young fish with biological stains, including luminescent** pigments, suggested the use of a photoelectric device for detection. Jackson (1959) used luminescent pigments for the mass marking of fish by spraying. Two recent publications have reported successful mass marking of salmon (Bouchard and Mattson, 1961) and a number of freshwater fishes (Deacon, 1961) by immersion. Marking juvenile menhaden with biological stains has shown that mass staining by immersion or feeding might be possible (Carlson, unpubl. MS***). With these results in mind, a device was designed and constructed by the Fisheries Instrumentation Laboratory, Bureau of Commercial Fisheries, Seattle, Washington. Results of an initial inquiry into the use of this device as a means of detecting menhaden marked with fluorescent pigments are reported.

I wish to acknowledge the suggestions and technical assistance of Richard H. van Haagen, Gordon F. Esteberg, and other staff members of the Fisheries Instrumentation Laboratory. Frank T. Carlson of the Menhaden Program performed many of the preliminary trials with the device.

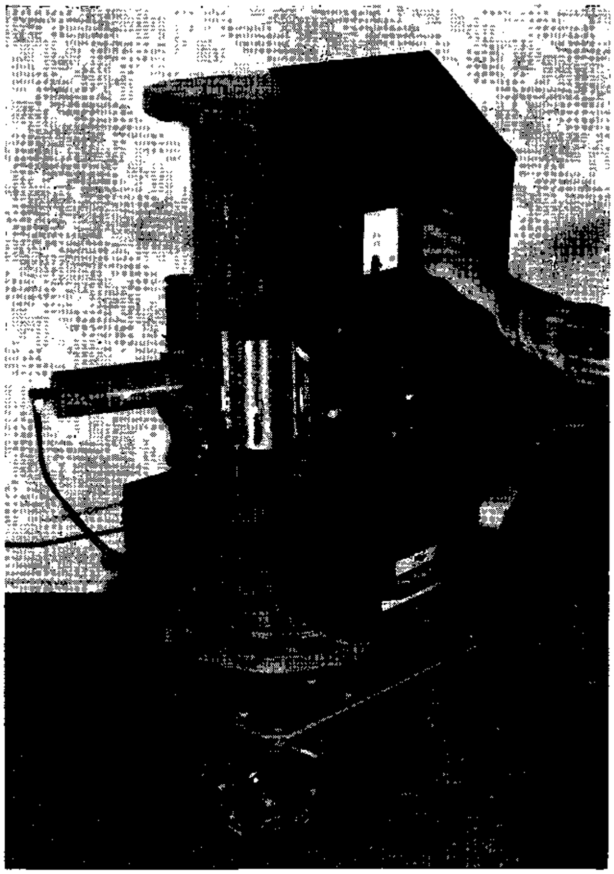


Figure 1. Fluorescent detector in the laboratory during trial operations.

---

* Fishery Research Biologist; Bur. of Com. Fish., Beaufort, N.C., U.S.A.

** Luminescence is classified as (a) fluorescence, if it lasts only during the period of excitation and (b) phosphorescence, if it persists when the exciting source is removed.

*** "Preliminary results of experiments to mark juvenile menhaden with biological stains by immersion or feeding" by Frank T. Carlson, U. S. Bureau of Commercial Fisheries, Millville, Delaware.

General Description of the Device

The laboratory model of an electronic detector to measure fluorescence was constructed with a three-foot section of steel pipe (inside diameter 10 in.) of the type used to unload menhaden from the boats at the reduction plants. The pipe was mounted upright on a steel platform 24 in. × 24 in. × $^1/_4$ in. (Fig. 1). Six ports, $2^1/_2$ in. × $2^1/_2$ in., were equally spaced around the middle of the pipe. A $3^1/_8$ in. × $3^1/_8$ in. filter housing was mounted at each port. To each of three alternate ports was mounted an ultraviolet transmitting filter (Corning No. 5860), and an ultraviolet lamp (General Electric S-4) with an adjustable aperture and a cooling fan. To each of the remaining ports was mounted a plate with a $2^7/_8$ in. × $^3/_4$ in. ring adapter for attachment of the multiplier phototube, viewing eyepiece, or fiber cap. One or more filters were mounted at each detection port to cut off ultraviolet light. A ten-stage multiplier phototube (DuMont Type 6292) with a flat end-window photocathode was mounted in a brass shield. Gelatin or glass filters (Eastman Kodak, Wratten Nos. 8, 9, 15, and 16 and Corning Nos. 3486 and 4308) were used to block ultraviolet light from reaching the photocathode.

The electronic equipment was mounted around the outside of the pipe and on the platform. The upper box (Fig. 2) contains a modified audio vacuum tube voltmeter (Heathkit Model AV-3), an amplifier with a hundredfold gain, high and low voltage power supplies, threshold control, coarse sensitivity control, master switch, and storage space for the multiplier phototube and cables. The lower box contains ballast transformers and individual switches for the ultraviolet lamps. A transformer to provide constant line voltage to the upper box only was mounted on the platform. A schematic diagram of the electronic circuits is shown in Appendix 1a—b. A list of

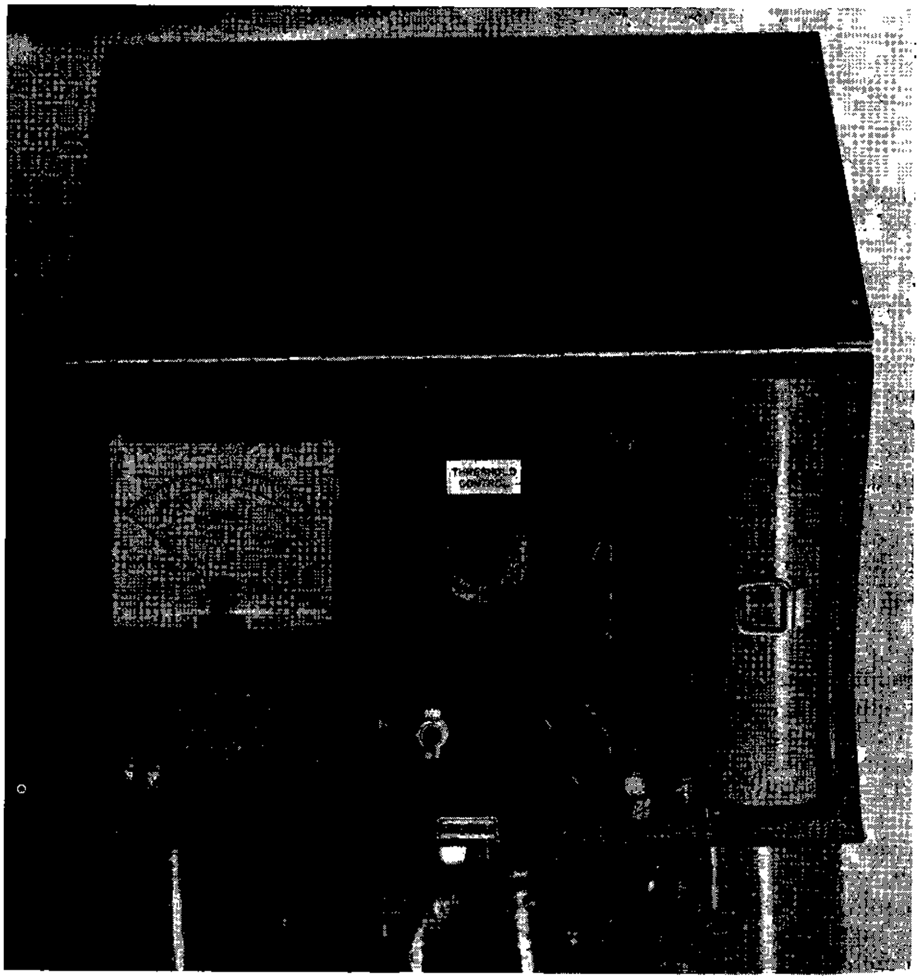
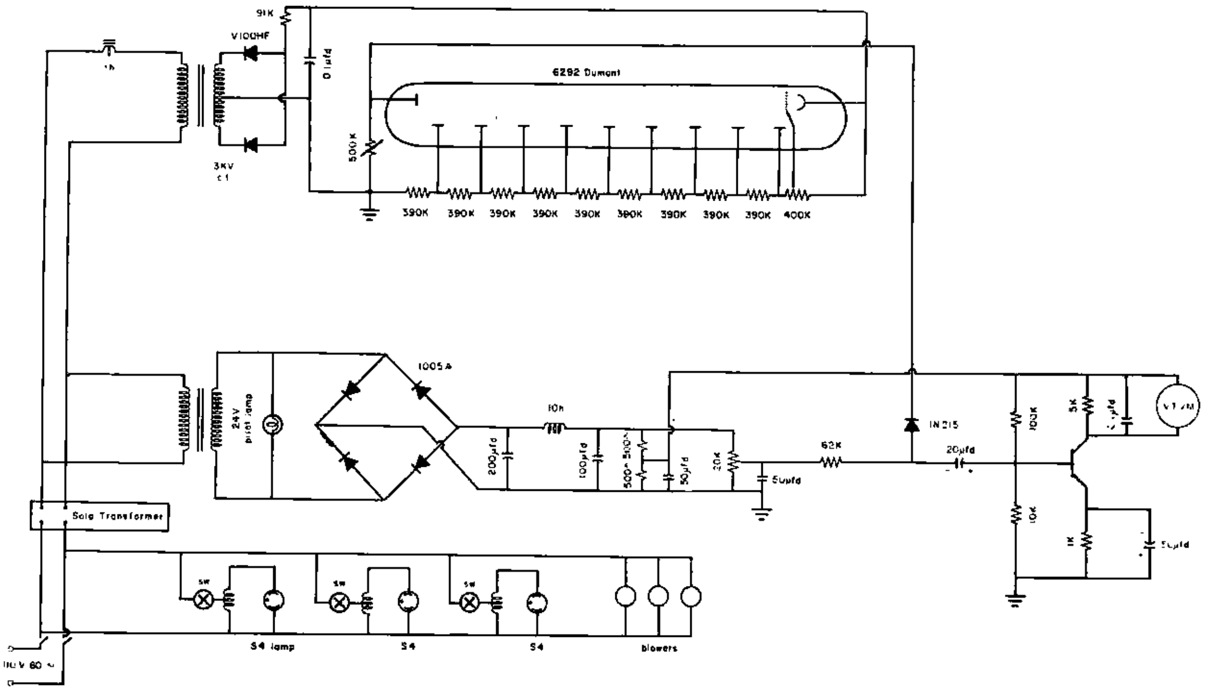


Figure 2. Close-up view of the upper control box with the multiplier phototube and cables in the storage position.



Appendix 1a. Schematic diagram of electronic_circuit

equipment, manufacturers, and additional specifications is provided in Appendix 2.

Operating Trials and Results

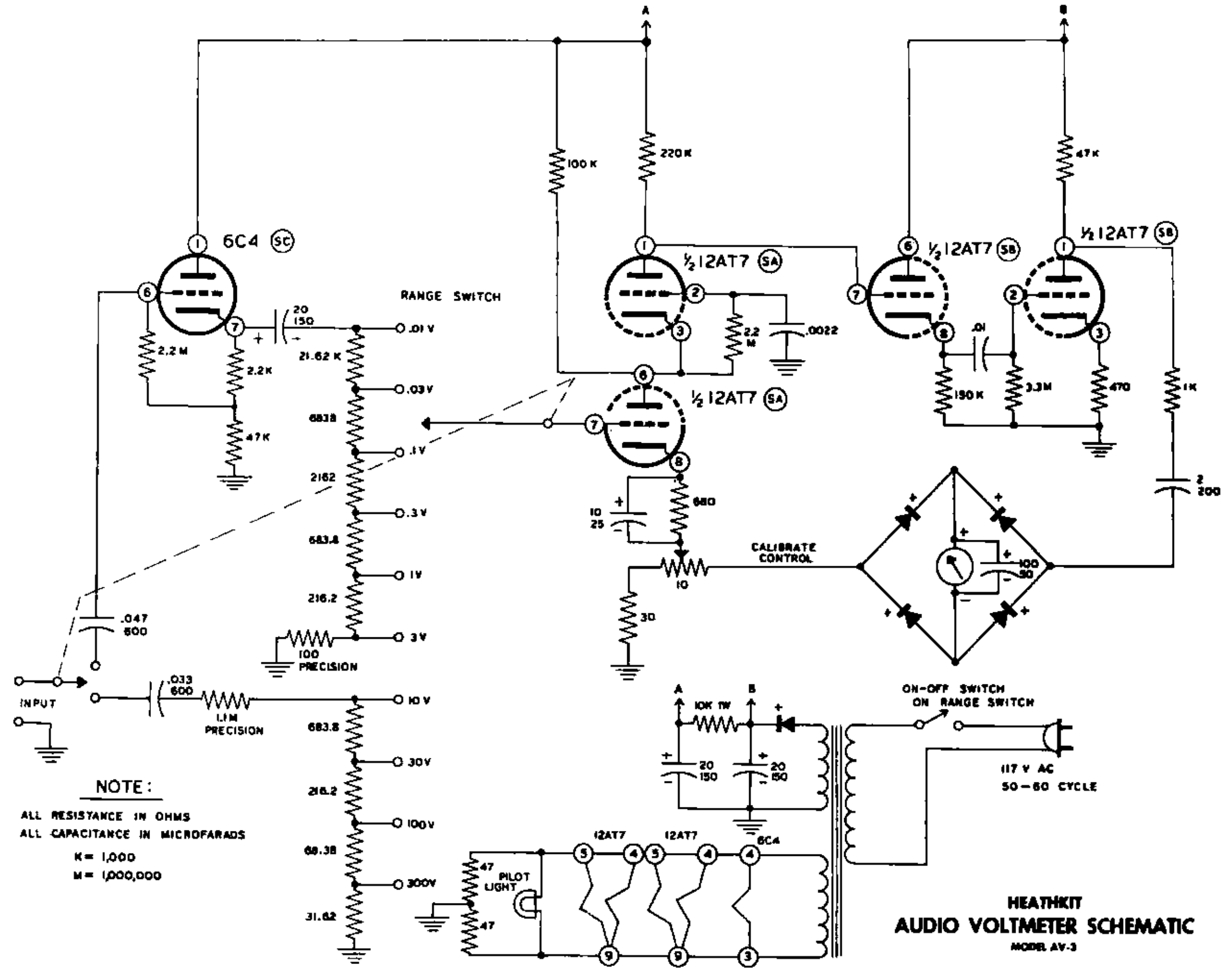
Operating characteristics of the device were determined for different combinations of ultraviolet light and cut-off filters. Background light excited the multiplier phototube to give a voltmeter reading when the pipe was empty and sealed from all external illumination. The threshold control was turned to suppress the reading. It was learned that background came, principally, from three fluorescent sources: (1) the inner surface of the pipe, (2) dust, bacteria, and similar particles suspended in the air, and (3) the ultraviolet cut-off filters. Of these, the last was of major concern because of the magnitude of the photoresponse.

A filter was mounted at each detector or viewing port to cut off ultraviolet light from reaching the photocathode. Initially, a K-2 (Wratten No. 8) gelatin filter, mounted between two pieces of plate glass, was used. The filter fluoresced from the diffused ultraviolet light to give a relatively high background reading. This was eliminated by the threshold control. However, when ultraviolet light was reflected from a non-fluorescent object, the incident rays caused the filter to fluoresce above the background level. The response to reflected ultraviolet light on the filter often exceeded the signal from fluorescent objects, which made it impossible to distinguish between the two. Other gelatin filters were tried but all gave similar results.

A glass filter (Corning No. 3486) was substituted for the K-2 gelatin filter. The glass filter also fluoresced, but at a much lower intensity; the ultraviolet light, therefore, could be increased to where the difference between the diffused and reflected ultraviolet was less pronounced and the effect of either could be suppressed by the threshold control. To further dampen the effect of the fluorescing filter, another glass filter (Corning No. 4308) was placed between the cut-off filter and the photocathode. The second (Corning No. 4308) filter was selected to cut off most of the yellow-orange light emitted by the first (Corning No. 3486). The Corning No. 4308 also fluoresced, but with such low intensity as to be easily suppressed with the threshold control.

Trials were run to determine the photoresponse of the multiplier phototube to inorganic and organic substances exposed to ultraviolet light. Objects were suspended level with, or dropped past, the photocathode. Nearly all materials tested fluoresced to emit some visible light.

A preliminary screening of materials was conducted to determine the operational performance and limitations of the device and the fluorescent properties of commonly occurring substances, dyes or pigments, and marine organisms. The objects were



Appendix 1b. Schematic diagram of electronic circuit (continued)

suspended in the center of the pipe, level with the apertures of the ultraviolet lamps and the photocathode window. The objects were rotated until a maximum response registered on the voltmeter. A tabulation of the findings is presented in Appendices 3, 4, and 5.

The device detected and measured fluorescent light over a wide range of intensity and color. Fluorescent substances of low intensity, as well as especially prepared pigments of high intensity, were apparently within the performance range of the instrument. No limitations appeared within the response range of 2 to 3000 mv for a background setting of 200 mv. No readings in excess of 3000 mv were obtained with the pigments and light source tested.

Fluorescence occurred in most substances examined in the laboratory (Appendix 3). Inorganic objects, such as glass, metal, and tap water, fluoresced a small, but detectable amount. Pigmented glass filters, glass mirrors, and sand each fluoresced to some extent. Organic substances including paper, cellulose, polyethelene films, and other plastics varied widely in fluorescence. Pigments and dyes also varied widely; especially prepared fluorescent pigments effected near the maximum response obtainable with the ultraviolet source and instrument settings employed (Appendix 4). Less than maximum response (ca. 3000 mv) was obtained from several fluorescent pigments. This might be due to the emission spectra and the blocking effect of the cut-off filters.

The natural fluorescensce of marine animals, especially the fishes, was of primary importance to the inquiry. Laboratory trials were limited to a few fishes and marine invertebrates (see Appendix 5) commonly occurring in the vicinity of Beaufort, North Carolina. The results showed that fish and other marine organisms fluoresce with varying intensity by species.

Additional trials were run to determine the maximum velocity at which fluorescent objects could pass the photocathode and still be detected. The results showed that objects marked with fluorescent dyes could be detected up to a velocity of 30 feet per second. Higher velocities were not tried because those tested exceeded the maximum expected in menhaden reduction plants.

Conclusions from Preliminary Inquiry

The laboratory model of an electronic detector for fluorescent objects measured the emitted light over a wide range of intensity. Fluorescence was common to all organic substances tested and probably occurs naturally in all animals and plants. The detection of marked animals may depend upon the relative intensity and spectral emission. Furthermore, the model detected fluorescent objects moving at velocities expected within the fish exhaust pipes at menhaden reduction plants.

Phosphorescent rather than fluorescent pigments might be used to mark menhaden. Phosphorescence can be detected by the device if modified so that the ultraviolet light and the multiplier phototube alternately are turned on and off, 60 or more times a second.

Further studies are needed to determine whether sufficient separation of intensity or spectrum exists between artificial and natural luminescence.

Future Work and Prospects

The results and conclusions from the initial inquiry have shown the need for further studies. The extent of these inquiries and the progress made toward the ultimate solution of the problem to mark and detect menhaden with luminescent pigments will depend upon the satisfactory completion of each successive phase. Briefly, the studies needed are:

1. Spectrophotometric survey of marine organisms encountered in the menhaden landings, to determine the intensity and spectra of naturally occurring fluorescence and phosphorescence. The purpose is to discover a spectral gap and a difference of intensity that could be occupied with an introduced pigment.
2. Selection of luminescent pigments and narrow-band-pass filters determined from the spectrophotometric survey.
3. Application of selected pigments to menhaden to determine methods, toxicity, and retention.
4. Screening trials with the electronic detection device.

The development of a method of marking menhaden and a device for detecting these marked fish during mass production of fish meal and oil depends on the satisfactory solution of several successive and dependent problems. Any conclusions concerning the functional application and detection of luminescent marks must be withheld until the completion of additional studies. However, the results of the initial studies indicated that the device may be used as a laboratory or field instrument for short-term marking experiments with menhaden, even though the ultimate use as an automatic detector in menhaden reduction plants may not be realized.

Summary

A photoelectric device to detect menhaden marked with fluorescent pigments was constructed and tried in the laboratory. The occurrence of natural fluorescence in menhaden and other marine organisms made the discrimination of marked menhaden impractical without further modifications of the device. The conclusions reached from the preliminary trials were (1) that phosphorescent rather than fluorescent pigments should be used and (2) that narrow-band-pass filters might be employed to distinguish marked fish. Future studies were proposed to make the device functional for experimental or field use.

References

ANONYMOUS 1959. Progress report on Alaska fishery management and research, 1958. *Spec. Sci. Rep. U. S. Fish Wildl. Serv.*, **294**: 28.

BOUCHARD, L. G., and C. R. MATTSON 1961. Immersion staining as a method of marking small salmon. *Progr. Fish. Cult.*, **23** (1): 34—40.

CLARK, F. N., and J. F. JANSSEN, Jr. 1945. Measurement of the losses in the recovery of sardine tags. *In* Results of tagging experiments in California waters on the sardine (*Sardinops caerulea*). *Fish Bull. Sacramento*, **61**: 63—90.

DAHLGREN, E. H. 1936. Further developments in the tagging of Pacific herring, *Clupea pallasii*. *J. Cons. int. Explor. Mer.*, **11** (2): 229—247.

DEACON, J. E. 1961. A staining method for marking large numbers of small fish. *Progr. Fish. Cult.*, **23** (1): 41—42.

FRIDRIKSSON, A., and O. AASEN 1950. The Norwegian-Icelandic herring tagging experiments. *Rep. Norw. Fish. Invest.*, **9** (11): 1—43.

JACKSON, C. F. 1959. A technique for mass-marking fish by means of compressed air. *Tech. Circ. N. H. Fish. game Dep.*, **17**: 1—8.

KLIMA, E. F., and W. H. BAYLIFF 1961. Tagging of anchovetas (*Cetengraulis mysticetus*) in Gulf of Panama. *Proc. Gulf Caribb. Fish. Inst.*, **13**: 151—156.

ROUNSEFELL, G. A., and E. H. DAHLGREN 1933a. Races of herring, *Clupea pallasii*, in south-eastern Alaska. *Bull. U. S. Bur. Fish.*, **48** (17): 119—141.

ROUNSEFELL, G. A., and E. H. DAHLGREN 1933b. Tagging experiments on the Pacific herring, *Clupea pallasii*. *J. Cons. int. Explor. Mer*, **8** (3): 371—384.

VAN HAAGEN, R. H., and H. P. DALE 1959. Fisheries Instrumentation Laboratory offers biologists new research "tools". *Comm. Fish. Rev.*, **21** (4): 27—31.

Appendix 2
List of equipment and manufacturers

1. Electric cooling fan
   Type 69 C F. A. Smith Manufacturing Company
   Rochester, N. Y.

2. Audio vacuum tube voltmeter
   Heathkit AV-3 Heath Company
   Benton Harbor, Mich.

3. Multiplier phototube
   DuMont type 6292 10-stage with $1^1/_2$ inch flat end window photocathode having a S-11 spectral response.
   Allen B. DuMont Laboratories Inc.
   Clifton, N. J.

4. Glass filters
   Ultraviolet transmitting Corning Glass No. 5860 (C.S. 7—37)
   Blue-green filter Corning Glass No. 4308 (C.S. 4—70)
   Cut-off filter Corning Glass No. 3486 (C.S. 3—69)
   Corning Glass Works
   Corning, N. Y.

5. Gelatin filters
   Wratten No. 8 K-2 Eastman Kodak Co.
   Wratten No. 9 K-3 Rochester, N. Y.
   Wratten No. 15 G
   Wratten No. 16

6. Ultraviolet lamp
   S-4 100 watt General Electric Co.
   Schenectady, N. Y.

7. Constant voltage transformer
   Sola No. 3003 95 v.—125 v. 115 v.
   Sola Electric Co.
   Chicago, Ill.

8. Autotransformer (ballast) for 100 watt H or S-4 mercury vapor lamp.
   General Electric Model No. 9T64Y3518
   General Electric Co.
   Fort Wayne, Ind.

Appendix 3
Fluorescent photoresponse (mv) to inorganic and organic objects. (ultraviolet background light — 200 mv)

Object	Size	Photo-response
Glass miror	25 mm × 25 mm	5
Plate glass	80 × 80 × 5 mm	50
Pyrex test tube	50 ml	0
Aluminium foil	25 mm × 25 mm	50
Distilled water in Pyrex test tube	50 ml	0
Tap water in Pyrex test tube	50 ml	10
Filtered sea water in Pyrex test tube	50 ml	150
Unfiltered sea water in Pyrex test tube	50 ml	200
Beach sand in Pyrex test tube	50 ml	50
Millipore filter	22 mm diameter	5
Millipore filter	47 mm diameter	150
Filter paper		
Eaton and Dikeman No. 615	25 mm × 25 mm	700
Whatman No. 40	25 mm × 25 mm	400
Whatman No. 42	25 mm × 25 mm	300
Ping-pong ball	37 mm diameter	900
Saran plastic film	25 mm × 25 mm	20
Polyethylene film	25 mm × 25 mm	50

Appendix 4
Fluorescent photoresponse (mv) to synthetic pigment colors. (ultraviolet background light — 200 mv)

Object	Size	Photo-response
Derbylite[1] fluorescent pigment colors		
N 580, N 590, N 600	25 mm × 25 mm	3200
N 100, N 108, N 410, N 490, N 500, N 520, DO 531, N 560, D 589, D 610, DO 615, DO 616, N 630, DO 660	25 mm × 25 mm	3000
DO 491, DO 530, N 570, N 650	25 mm × 25 mm	2800
DO 585, N 620	25 mm × 25 mm	2500
DO 480	25 mm × 25 mm	2300
N 651	25 mm × 25 mm	1500
DO 670, DO 673, DO 674	25 mm × 25 mm	1000
Paulite[1] phosphorescent materials		
1207	25 mm × 25 mm	2800
1218	25 mm × 25 mm	1500

[1] Trade names for products of Luminous Resins, Inc. 166W. Washington St., Chicago, Ill.

Appendix 5
Fluorescent photoresponse (mv) to marine organisms. (ultraviolet background light — 200 mv)

Common name	Scientifiic name	Number of specimens	Size range (mm)	Mean photoresponse (mv)
Atlantic menhaden	*Brevoortia tyrannus*	5	93—103 F.L.[1]	230
Yellowfin menhaden	*B. smithi*	3	270—275 F.L.	3000
Planehead filefish	*Monacanthus hispidus*	2	130—169 F.L.	2500
Northern searobin	*Prionotus carolinus*	4	105—225 F.L.	2100
Scorpion fish	*Scorpaena* sp.	2	132—140 F.L.	1300
Bluefish	*Pomatomus saltatrix*	2	168—181 F.L.	1000
Spot	*Leiostomus xanthurus*	1	182 F.L.	1900
Northern puffer	*Sphaeroides maculatus*	1	130 F.L.	1400
Summer flounder	*Paralichthys dentatus*	2	196—250 F.L.	3000
Butterfish	*Poronotus triacanthus*	3	113—143 F.L.	1000
Weakfish	*Cynoscion regalis*	1	224 F.L.	1400
Atlantic croaker	*Micropogon undulatus*	2	200—215 F.L.	1800
Clearnose skate	*Raja eglanteria*	1	350 T.L.[2]	2300
Atlantic squid	*Loligo peali*	1	154 M.L.[3]	2600
White shrimp	*Penaeus setiferus*	1	52 C L.[4]	1300
Mantis shrimp	*Squilla empusa*	1	60 C.L.	1600
Swimming crab	*Portunus* sp.	2	45—70 C.L.	3000
Rock shrimp	*Sicyonia* sp.	2	47—50 C.L.	2200
Keyhole urchin	*Mellita testudinata*	2	101—109 diameter	0
Starfish	*Astropecten* sp.	2	90—93 diameter	800

[1] F.L. — fork length
[2] T.L. — total length
[3] M.L. — mantle length
[4] C.L. — carapace length

62.

Estimates of Mortalities and Population Size for the Nogies Creek Maskinonge (*Esox masquinongy* Mitchill)

By

B. S. MUIR[*]

The population studied was a small one isolated in a 400-acre impounded section of a stream in southern Ontario (Crossman, 1956; Muir, 1960). The population was exploited by a nine-year fishery, using fixed nets, under the control of the investigator. Fish were netted in the spring, tagged, and returned to the water. In the fall fishery the fish were examined for tags or scars and planted out into neighbouring public lakes. All fish handled were measured, scale samples taken, and records of catch per unit effort kept. Fishing intensity was varied in the fall fishery from year to year, with the estimated exploitation rate varying from 0.18 to 0.64. In two years no fish were removed, all individuals caught in the fall fishery being tagged and returned. During the study period, 1952 to 1960, approximately 4,000 maskinonge were handled, 2,000 of them being tagged and returned.

The tagging experiment was complicated by mortality due to tagging and by tag loss. However, assessments were made of these losses and corrections applied. Population estimates were made during the fall fishery. A Petersen estimate was made each year on the recapture of tags attached the previous spring, correcting for tagging mortality and tag loss. In the two years when the fish were all returned Schumacher estimates (as outlined by DeLury, 1958) were also made. These estimates are listed in Table 1, where it may be seen that good agreement was obtained by the two methods. Estimates of the DeLury (1947) type were also made but these grossly under-estimated the population. It is most likely that a seasonal decline in the coefficient of catchability biased the DeLury estimates. In the closed population, the ratio methods of Petersen and Schumacher would be less sensitive to the decline in catchability.

The recapture of spring tags in the fall fishery was also used to make estimates of the level of exploitation each fall. Consideration of the exploitation in relation to fishing effort, on the assumption that natural mortality was negligible over the brief period of the fishery, yielded a value for the coefficient of catchability (q). Tagging data further provided information on a trend in catchability with age. The estimated coefficient was 0.0026 for age IV and older and 0.0030 for age V and older.

After applying the factors for the change in catchability with age, the catch-effort data were analyzed for mortality by the Beverton and Holt (1956) method, using a modification outlined by Paloheimo (1961). The method considers a regression of the estimated instantaneous mortality (Z) on effort over a period of years. Paloheimo's modification eliminates the iterative procedure and provides an approximate solution by considering the mean effort for the pair of years involved in each estimate of Z. The estimates by this method for the coefficient of catchability of age IV and older and age V and older (0.0024 and 0.0029) were slightly lower than those

Table 1

Summary of the estimates of mortality coefficients and population sizes by the various methods

Method of estimation	Average coefficient of catchability		Population size N_0		Average instantaneous natural mortality		Average instantaneous total mortality	
	q_{IV} +	q_V +	1956	1959	M_{IV} +	M_V +	Z_{IV} +	Z_V +
Tagging experiment	0.0026	0.0030						
Petersen (modified)			858	198	0.14 A.D.* ± 0.23	0.33 A.D.* ± 0.28		
Schumacher			854 (632—1555)	223 (168—331)				
DeLury			337	115				
Paloheimo (Beverton and Holt)	0.0024	0.0029			0.18	0.29	0.73	0.99
Catch curve							0.71	0.87

* Average Deviation

---

[*] Abstract of Ph. D. Thesis, University of Toronto, 1961. Present address: Department of Zoology, University of Hawaii, Honolulu 14, Hawaii.

from the tagging experiment. As seen in the table, the Beverton and Holt method yielded estimates of instantaneous natural mortality (M) quite comparable to those obtained by successive Petersen estimates from the tagging data.

Finally, from the catch curve an estimate of the average instantaneous total mortality (Z) was obtained which was slightly lower than the average of individual estimates from the Beverton and Holt method. The two methods utilized the same basic catch data and the estimates are not completely independent.

The rate of natural mortality for the Nogies Creek maskinonge appears to be relatively low at age IV but increases with age. The coefficient of growth decreases with age and the curves for the coefficients of growth and mortality against age would cross at about age V. The relative strengths of nine consecutive year-classes were estimated and no more than a two-fold variation was found between the extremes. Much of the variation found can be at least tentatively accounted for as being due to the effect of planting hatchery fingerlings. The removal of large fish apparently resulted in a marked increase in the catchability of those age III and younger. It is believed that this was a result of increased mobility of the smaller fish.

References

BEVERTON, R. J. H. and S. J. HOLT, 1956. A review of methods for estimating mortality rates in fish populations, with special reference to sources of bias in catch sampling. *Rapp. Cons. Explor. Mer*, **140** (1): 67—83.

CROSSMAN, E. J., 1956. Growth, mortality and movements of a sanctuary population of maskinonge (*Esox masquinongy*, Mitchill). *J. Fish. Res. Bd Can.* **13**: 599—612.

DELURY, D. B., 1947. On the estimation of biological populations. *Biometrics*, **3**: 145—167.

DELURY, D. B., 1958. The estimation of population size by a marking and recapture procedure. *J. Fish. Res. Bd Can.* **15**: 19—25.

MUIR, B. S., 1960. Comparison of growth rates for native and hatchery-stocked populations of *Esox masquinongy* in Nogies Creek, Ontario. *J. Fish. Res. Bd Can.* **17**: 919—927.

MUIR, B. S., 1962. Vital statistics of *Esox masquinongy* in Nogies Creek, Ontario I. Tag loss, mortality due to tagging, and the estimate of exploitation. J. Fish. Res. Bd Canada (received for publication).

MUIR, B. S. and H. White, 1963. The application of the Paloheimo linar equation for estimating mortalities to a seasonal fishery. J. Fish. Res. Bd Canada. (received for publication).

PALOHEIMO, J. E., 1961. Studies on estimation of mortalities. 1. Comparison of a method described by Beverton and Holt and a new linear formula. *J. Fish. Res. Bd Can.* **18**: 645—62.