PROCEEDINGS OF THE JOINT SCIENTIFIC MEETING OF
ICNAF, ICES and FAO on

FISHING EFFORT, THE EFFECT OF FISHING ON RESOURCES AND THE SELECTIVITY OF FISHING GEAR

Volume 1 - Reports

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Proceedings of the

Joint Scientific Meeting of the

INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES
INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

on

FISHING EFFORT, THE EFFECT OF FISHING ON RESOURCES AND THE SELECTIVITY OF FISHING GEAR

Held in Lisbon at the invitation of the Portuguese Government

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* Texts of contributed papers to be published in Volume 2.

Introduction

In introducing a purposeful meeting such as this it is the inevitable lot of the chairman to say some things which have been repeated many times and which are therefore quite familiar to the participants. Familiar though they may be, they do bear repeating even at the risk of our becoming discursive if not text-bookish; for it may help us in our efforts to perceive clearly and plot the attack on the problems which are set before us, to review how this group of people were drawn together on this occasion for this purpose.

This is the second symposium of its kind in which most of those present have worked together on problems of fishery research and techniques for their solution. ICNAF* sponsored the first which was held at Biarritz, France, in 1956, to examine a number of topics, all in relation to one central problem which emerged from discussions among commissioners and their scientific advisers at the 1955 annual meeting of that organization. No formal statement was prepared on the details of these discussions. However, these were principal conditions which were recognized as generally true.

1) An ideal program of fishery conservation should encompass all of the important or potentially important species in the area under consideration.

2) The primary duty of fishery conservationists is not to regulate the use of resources but to *know* about them. So long as we remain ignorant of the size of the resources and their distribution and habits and of the ways in which exploitation affects them, exploitation must remain as it is, a groping in the dark, and our decisions as to whether or not a fishery should be regulated must rest largely on opinion. There is no argument about this. However, if there is to be comprehensive conservation of the sea fishery resources, as contrasted with conservation of one or two principal species (i.e., partial conservation), then our knowledge, and, therefore, our research programmes, must be expanded accordingly.

3) A regulation must be tailored to the fishery and the population of the species which it is intended to benefit. It must be based on an analysis of many kinds of data concerning that fishery and that population, including techniques of fishing; effects which different fishing gears have upon the composition of the catches; relation of fishing effort to catch; behaviour and survival of the fish under various environmental conditions; and interrelations of birth, growth and death.

4) Data concerning these subjects must be adequate to represent facts with reasonable accuracy; i.e., it must be extensive enough to sample the whole of a fishery, the whole of an area in which it operates, the whole of a population exploited, the whole cycle of a year, and a long enough series of years to cover a wide range of annual variations.

5) Such a comprehensive programme as this indicates, involving as it does work at sea and ashore, requires a staff consisting of principal scientists and assistants (the number depending on the size of the fishery and the distances involved), research vessel time, special laboratory equipment and laboratory space. Thus an adequate programme of research on a fishery for one species is costly in money and in scientific talent, both of which are chronically in short supply.

* International Commission for the Northwest Atlantic Fisheries.

6) Throughout its entire range, a species varies in many of the attributes to be considered in determining policy regarding its conservation. It may vary widely, for example, in rates of birth, mortality and growth; its environmental conditions vary and its habits. Also since different groups of countries operate in different parts of its range, using different fishing techniques, the types of fisheries which exploit it vary. Therefore results of an investigation on a species in one area cannot be depended upon to apply to that same species in other areas. Even less can they be expected to apply to other species.

7) Many maritime countries (all of those belonging to ICNAF, ICES* and FAO,** for example) carry on a number of major fisheries, which together exploit populations of many species. To determine how any one of these fisheries should be regulated to effect predetermined yields per recruit requires a special continuous study of each of the species affected.

8) Unfortunately it has not been feasible to do this for all of the major fisheries which might be benefited by regulation, at least not if the research programs must continue to be organized and carried on as they are, according to our concepts of 1955. No country affords the financial support for this. There are not enough scientists available for it. As it is, each country studies one or two species in a region thoroughly, gives a modicum of attention to two or three others, and neglects the rest.

9) Evidently comprehensive conservation is not possible unless large scale programmes are set up for all commercially important species, such as are now applied to cod and haddock. This would mean tremendous increases in funds and staff for which there seems to be no immediate prospect. Even where new programmes are started, it is unlikely that the desired answers could be reached for several years, judging by experience with long established programmes.

With these considerations before them the Commissioners of the ten countries comprising ICNAF in 1955 in effect posed this question to its scientific advisers: Granted that all you say is true, granted that we would prefer an ideal programme to achieve comprehensive conservation but given the cold fact that circumstances force us to fall far short of it, what abridgments in research methods can you devise to effect a practical compromise with the ideal which will bring forth the essential needed information? That is the central problem.

It is a large problem. To solve it requires taking a hard look at the philosophy and the design and the techniques of research programmes. What, in the orthodox fishery research programme, is being done that should not be done? What is not being done that should be done?

It was to begin the attack on this problem that scientists of the ICNAF countries held the special meeting at Biarritz. Representatives of ICES and FAO as well as other invited participants attended, and contributed to the conclusions.

The procedure at Biarritz differed from that practised in most scientific meetings, in which formal prepared papers are read and discussed. It consisted instead of a group of "workshops"; i.e., the participants gathered into small working parties to concentrate on particular subjects, reviewing papers which had been sent ahead, but principally comparing and studying data and other materials, including specimens of fish, scales, otoliths and measuring instruments, which they had collected or used in the course of their several researches. In this way the scientists pooled their varied experiences and opinions, and reached conclusions in which each person could feel more confident than when working alone.

Those who took part in the Biarritz meeting generally found the working party method to be so eminently productive as to want to use it as a pattern for future meetings. It brings forth data which otherwise remain buried in file drawers; it evokes participation by all those in attendance who would otherwise be members of a passive audience; and it leads

* International Council for the Exploration of the Sea.
** Food and Agriculture Organization of the United Nations.

to definite conclusions and decisions. We did find, however, from our experience at Biarritz that we undertook more work than we could complete. This was owing partly to a crowded programme, but to a much greater extent it resulted from the fact that our discussions opened up further problems and advanced ideas and means to attack them, and it was clearly evident that at future workshops we must limit the number of topics. The conclusions of the Biarritz meeting along with the supporting contributions are printed in the ICNAF Special Publication No. 1.* Regarding the principal question, "What abridgments in research methods can be devised ...," the group suggested a number of ways to save labour and improve the efficiency of operations, but found no quick, easy, cheap method of securing the information needed for determining whether and how to regulate the various fisheries. "There is no substitute for collecting the right kind of data for every species of interest".

One of the most important facts that transpired from the proceedings was this: Among scientists working for different institutions in different areas there is no uniformity in the dimensions which they measure (on fish, nets, e.g.), in the methods of measurement, in technical terms and symbols, in the meaning of words, in the comprehensiveness of reporting data. So long as this lack of uniformity in methods and scientific terminology persists, it will not be feasible to collate data from many sources in order to discover principles of wide application. The establishment of uniformity in these respects would eliminate a considerable amount of duplication and effort otherwise misdirected and for that reason alone would contribute substantially to reducing costs in fishery research. At the same time it would not impair opportunity for individual creative work such as is most essential to the advancement of science; rather the contrary.

The necessity for standardization of techniques and terminology has become increasingly pressing among the ICNAF countries. Most of them are also members of ICES, and in that organization also find the same need, especially in connection with the work of the Permanent Commission. Moreover, similar fishery research is carried on in many other parts of the world, for the same kind of problems are met from northern Europe to South Africa, to Australia, to Japan, to the Americas. Since countries of all of these regions belong to FAO, that organization is in a peculiarly favorable position as a unifying influence.

Thus it was that during the 1956 meeting at Halifax, the ICNAF's Committee on Research and Statistics concluded that the work started at Biarritz must be continued, and recommended (and the Commission approved): (1) that a 7-day workshop on Population Dynamics and on the Selectivity of Fishing Units should adjoin the 1957 annual meeting at Lisbon; (2) that ICES should be invited to hold its 1957 meeting of the Comparative Fishing Committee at the same place and during the same period; and (3) that FAO should be invited to hold jointly the special meeting which it had planned on the same theme. Since the subject of immediate interest to ICES was Fishing Effort, it was arranged to include it in the program of the workshop. That is how the Lisbon meeting came to be held.

It seems to be a characteristic of meetings such as this that the publication of the reports is slow. This is unavoidable, what with the problem of assembling the formally prepared versions of the contributions of authors who have returned to their laboratories and departed thence for work at sea, and the time required to edit contributions from many sources, prepared in diverse styles, and the difficulties of the several editors to find in their otherwise fully occupied days enough "spare time" for these tasks. It is also a frequent characteristic of such volumes as this that the introduction is written just before publication. This delay has its advantageous side, since it permits us to gain perspective of the meeting's accomplishments.

The workshops were planned under the general direction of a steering committee composed of Cyril Lucas, Geoffrey Kesteven, and Lionel Walford, representing ICES, FAO, and ICNAF, respectively. The arrangements for

* *Spec. Publ. I.C.N.A.F.*, (1):339 p., 1958.

the separate topics and the working sessions were conducted by convenors, who solicited and later edited the contributions and prepared the final reports. These were Cyril Lucas, Sidney Holt, and John Clark, convenors for Fishing Effort, Population Dynamics and Gear Selectivity, respectively. Before the meeting, preliminary discussions of the contributed papers and reviews revealed that the first two workshops had so much in common that it was desirable to combine them.

Besides sharing in the direction of the workshop and participating in the scientific contributions and discussions, FAO furnished simultaneous translations of the discussions into Spanish, French and English. This facilitated enormously the problem of communication among those in attendance. Thus representatives of 17 scientific institutions in 15 countries and of three international agencies were enabled to reach understanding on points which had not been clear to some of them before, and agreement on other points on which there had been differences of opinion. And thus they were able to go very far in developing a cyclopaedia of concepts, techniques and terms concerning fishing effort and fishing mortality, annotated with descriptions of techniques of research, suggestions for special studies of problems that remain unsolved, and comments on important factors that often go unrecognized in research programs.

Enough time has passed for us to see other accomplishments. A mathematical notation for population dynamics which was agreed upon at the Lisbon meeting has already been published in English, Japanese and German* and FAO is now in the process of making translations into other languages.

Research programs have been profoundly influenced by decisions made at the Lisbon meeting. For example:

> The Woods Hole Laboratory of the United States has studied with underwater television the effects of chafing gear and has thus demonstrated that the specifications set forth under ICNAF regulations do not impair the savings effect of the prescribed $4\frac{1}{2}$ inch mesh.
>
> The Canadian Fishery Research Board has carried on preliminary studies to measure the selective action of fish traps.
>
> The International Training Centre on the Methodology and Techniques of Research on Mackerel (***Rastrelliger***), held at Bangkok in October-November 1958 under the auspices of FAO and the Indo-Pacific Fisheries Council, was in accordance with a recommendation by one of the working parties at Lisbon. It is expected that in future more such courses will take place in various parts of the world.
>
> A recommendation that a serial publication on fishery dynamics be founded led to formation of a committee composed of representatives of the three sponsors as well as of other agencies to explore further the need of the proposed journal and the desire for it. The committee has submitted a favourable report. FAO is now seeking ways and means of establishing it.
>
> Biologists of Canada and the United States have collaborated in assembling and analyzing all existing data on gear selection experiments to determine the escapement effects for various species to be expected from different sizes of mesh and kinds of twine. The results of this study have been published in the 1958 Annual Report of ICNAF.

These are but highlights of the accomplishments of the workshops. The proceedings and conclusions are discussed in detail in the Convenors' Reports and in the supporting papers which follow.

This meeting opened as scheduled on Monday, 27 May, with Dr. Camara, Chairman of the Portuguese National FAO Committee, attending to welcome participants.

There were 46 participants; their names are listed in Appendix 1.

The meeting had before it a total of 93 papers; their titles and authors are listed in Appendix 2.

Lionel Walford
Chairman

* Holt, S.J., et al., A standard terminology and notation for fishery dynamics. *J. Cons. int. Explor. Mer.* 24:239-42, 1959.

REPORT ON FISHING EFFORT AND THE EFFECT OF FISHING ON RESOURCES

Fishing Effort:	Convenor: C.E. Lucas
	Reporter: M.B. Schaefer
Effects of Fishing:	Convenor: S.J. Holt
	Reporter: R.J.H. Beverton

1. Definition of concepts and terms concerning fishing effort and fishing mortality

In addition to some general observations, three specific aspects of this subject were considered, namely, gear classification, concepts and terminology of selection processes, and mathematical notation.

1.1 GENERAL

Fishery science is relatively new, and is a long way from having a sufficient amount of precise descriptive data to enable a comprehensive set of absolute definitions and concepts to be formulated at this stage.

Bearing this in mind, it is nevertheless highly desirable that there should be a careful process of scrutiny and testing of concepts and terms as they come into use in response to a need for description or to express some idea.

With respect to 'fishing effort' and 'fishing mortality', a provisional schedule of elements of the systems involved, and of the concepts that have emerged concerning these elements and the relations between them, are as follows:

Elements:	Processes:
Fishery	Fishing
Fishing unit	Fishing effort
Fishing craft	Fishing mortality
Fishing gear	
Fisherman	
Fish stock	
Fishing grounds (area)	
Catch	

With respect to each element, there is to be found an array of characteristics or properties that determine the part it plays in the systems concerned.

Examples of these are:

Fishery:	**Fish stock:**
Location	Location
Magnitude	Magnitude
Structure	Structure
	Distribution
	Accessibility
	Vulnerability
Fishing unit:	**Fishing:**
Fishing power	Location
Fishing capacity	Intensity
Operating rate	Concentration
	Selectivity
Fishing boat:	**Fishing effort:**
Size	Distribution
Power	Intensity
Efficiency	
Fishing gear:	**Fishing mortality:**
Selectivity	Rate
Efficiency	
Fishermen:	
Efficiency	

Each of these characteristics is determined by some other, deeper, characteristic of the element which reacts with its environment and which in turn is determined by a characteristic still deeper. Thus, the magnitude of a fish stock is determined in part, by the growth characteristics of the species and by interaction with environment; growth is determined by nutritional factors, and these by other elements and factors. Thus each characteristic or attribute is the end result of a long chain of cause and effect.

There are then two points to make. Firstly, that concepts can be stabilized only if the net of contributing elements and factors of which a process is composed is understood so well that only non-significant elements remain unidentified. In the present meeting the discussions on selection processes and on the determinants of fishing effort have exemplified the importance of this point. In this sense, the contribution of the present meeting to stabilization of concepts will be seen only after workers have fully assimilated the material brought to it and have taken stock of its conclusions.

Secondly, referring to the areas of fisheries science where stabilization of concepts could or should be accelerated, it is desirable that those concepts and terms should receive attention which lie at the level of, and are commensurate with, the available methods of measurement and analysis. The precision of definition should be subject to the same principle.

To assist generally the work of stabilizing concepts and standardizing terms, *it is recommended that:*

> FAO be encouraged to continue with its work on a decimal classification for fisheries science, and associated glossary and index;
>
> FAO should make a close examination of the concepts referred to in the documents of this meeting and of the terminology used, and should prepare a terminological paper for circulation to the participants and others concerned. In circulating such a paper, FAO should ask each participant: "Having had time to review the papers and the results of the Lisbon meeting, do you believe that, as set out in the attached document, the concepts involved have been correctly described and labelled ?".

1.2 IDENTIFICATION AND CLASSIFICATION OF GEAR TYPES

The worker in population dynamics is concerned with the essential properties of fishing gear in terms of the effective fishing effort that can be exerted with it, viewed both qualitatively and quantitatively. As a consequence, a classification of the properties of gears that is required in population studies should include not only the size and composition of catch that can be taken with them but also their essential features of orientation and operation in relation to the location and behaviour of the fish. Such a classification may not be the same as that required by other groups of fisheries workers such as technologists and economists.

At the present time, it would be valuable if gear technologists could prepare a simple classification of fishing gears that would serve the following purposes:

> stabilize the nomenclature of gears, with special reference to synonymous terms used in various countries;
> assist the population dynamics workers by indicating the essential properties of gears with which they are working; and facilitate the correct comparison of results obtained with different gears in various circumstances.

This classification should be created according to strict scientific principle, should take account of T. Burdon's and A. von Brandt's classifications and should be based on the following attributes:

(1) the precise manner in which capture is effected;

(2) the method or process by which the fish are brought into relationship with the gear;

(3) the actual method by which the gear is operated;

(4) the power required for operation;

(5) the constructional design;

(6) the materials for construction;

(7) the location of operation;

(8) the species captured.

It is recommended that a statement of the problems and requirements of a gear classification, as set out above, be transmitted to the Fishing Gear Congress, Hamburg*.

1.3 SELECTION PROCESSES

Proposed definitions of concepts and terms involved in selection processes are as follows:**

Selection (n.) The act (or result) of choosing, taking, distinguishing or separating a group of individuals from among the larger group, aggregation or population of which they are part, on the basis of difference in one or more recognized characteristics.

(Selection may be voluntary or involuntary, random or systematic. It may be made by an individual or force operating from *outside* the group or population from which the selection is made, or result from influences exerted by an individual or force operating from *inside* the group or population, or result from a combination of or interaction between these).

Selectivity (n.) The intensity with which the process of selection operates; the degree to which a particular process is selective.

(Selectivity may refer to the range and sharpness of the distinction made between those that are taken and those that are not taken; and thus include a measure of the confidence placed in the selective process *not* to take individuals other than those which the process is intended to take.)

If a population is distributed at random, and if a capture process bearing upon a population is random and unrestricted in its operation, then every individual of the population has equal chance of being caught, and the characteristics of the population will appear in the catch in the true proportion they hold in the population. Selective processes cause a departure from this situation. Selective processes operate (i) within the population, (ii) in the capture process, and (iii) by interaction between these.

Selective processes within the population are those which determine the accessibility and vulnerability of the population, or of parts of it, to the gear; differences in distribution and behaviour of different age, sex or size groups may make one or more of these groups more or less liable to capture than others. Particular distributions of fishing effort may result in the selection of areas occupied by particular parts of the population, giving rise to fleet selection effects. If the gear is selective for a group that is made accessible and vulnerable by the internal processes (enhanced by fleet selection) then the resultant total selectivity of the situation will be high and the gear will be rated as being high in efficiency; but in other situations the internal processes may not be in relation with the selection processes of the gear and, although the selectivity of the gear may not be reduced, there will be no measure of it, and in addition there will be an appearance of low efficiency. The selective processes within the population may offer or withhold a particular group whilst those of the gear may retain or reject a group. Accurate measurement of the bias introduced into the determination of size and structure of a population by gear selection processes can be made only after identification of the actual combination of processes within the population and those of the gear. This means that selectivity and efficien-

* See contribution by A. von Brandt to "Modern Fishing Gear of the World" edited by H. Kristjonsson, p. 274. Fishing News (Books) Ltd., London 1959.

** Many of the terms and definitions given below were reconsidered and to some extent revised at the "World Scientific Meeting on the Biology of Sardines and Related Species", convened by FAO at Rome, 1959 (see "Draft Report" of the meeting, 1959).

cy are related in a complex way and that it is important to identify and, if possible, to measure the processes within the population that determine liability to capture.

For the related terms 'vulnerability', 'availability' and 'accessibility', the following definitions are proposed:

Vulnerable (adj.)	Open to attack or capture; open to the application of a force.
Vulnerability (n.)	The degree to which an organism or group of organisms is open to attack or capture, or is open to the application of some specific force or process. (Vulnerability has a meaning only with reference to some particular and specified force or process that can be brought to bear upon the organism or group of organisms.)
Availability	A general term to signify that an organism or group of organisms lies within the range of operation of a variety of forces or processes (e.g. gears). If an organism, or group of organisms, does not lie within the fields of operation of those forces or processes, it is unavailable.
Accessibility	Signifies that an organism lies within the range of operation of a *particular* force or process; the term 'accessibility' is neutral and is a part of the more general 'availability'.

From these definitions, it follows that a species may be ***available*** to a fishery in general, it may be ***accessible*** to a certain type of gear, and the success of operation of that gear will depend upon the ***vulnerability*** of the fish to that gear. ***Vulnerability*** is determined by those particular features of the behaviour mechanisms of the organisms which, responding to the particular features of its environment at the time operation of the specified force or process, cause it (the organism) to be more or less liable to be affected by the force or process. For example, the appetite of a certain species of fish for certain types of bait at certain times makes it ***vulnerable*** to fishing by means of hooks baited with the particular bait; its ***vulnerability*** to, say, a net gear, might at that time be negligible. Similarly, the tendency of a particular species to move toward a light of a particular colour might make it extremely ***vulnerable*** to fishing that makes use of lights of that colour, whereas baited hooks used at that time might be quite unsuccessful. Again a species of demersal fish may be present on grounds that are partly smooth and suitable for trawling, and partly rough and unsuitable for trawling. The species is then ***available*** in the area to a mixed fishery of trawls, lines and possibly other gears; it is ***accessible*** to the trawl only on the smooth ground while ***accessible*** to line on the rough ground - but it might, because of biological factors, be ***invulnerable*** to lines on the rough ground.

Another set of concepts needing clarification are those described by the terms 'unit stock' and 'unit fishery'. Theoretically a ***unit stock*** would be a population of fish in an area, comprising all the individuals of a species that could have or have participated in the reproductive processes. Where hybridization can take place, this would include two or more species. There would be no migration into or out of a unit stock thus defined; and from such a stock the only losses would be the end products of metabolism and the mortality of individuals. Considering the state of knowledge of fish genetics and the present status of the species concept, it is questionable whether there exists in actuality any identifiable entity corresponding to a 'unit stock' defined in this way.

Adoption of such a definition, therefore, would have to be made on the understanding that it had no special implications as to the work needed in connection with the unit systems upon which, of necessity, fishery biologists must now direct their attention. In practice it does not seem possible to define any stock so precisely, and instead the unit stock may be considered as a relatively homogeneous and self-contained population whose losses by emigration and accessions by immigration, if any, are negligible in relation to the rates of growth and mortality. The degree of homogeneity and self-containment that would be required for a valid application of this loose definition would depend upon the precision both of measurement of the parameters and of the answers required.

The formulation of a concept of *unit fishery* presents even greater difficulties, and it is perhaps necessary that this concept should be only a qualitative one; convenient for referring to a relatively homogeneous group of fishing units engaged in exploitation of one or more unit stocks of fish.

For dynamic theory to be applied properly, however, it is necessary to know that the fish population and the fishery based on it can be treated as if it were a unit system. There is no simple definition of such a system, except that it should constitute a collection of fish and the fishing activity on it, whose effects on each other can be interpreted without requiring information 'external' to that system. Population theory has usually been applied to systems delimited in such a way that only the effects of fishing on the fish can be interpreted. In some fishery situations and for some purposes this gives useful practical results. Some examples make this clearer.

A fishery may be based on a variable mixture of fish from more than one spawning stock, in which case the change in numbers of a year-class in successive age-groups may not give a true picture of mortality, because it is a mixed group whose composition may vary from year to year. Even though the recruits to the fishery may come from one spawning stock and receive no immigration later, there may be emigration of older individuals from the area of the fishery in question. In this case, the observed total mortality rate would include loss by emigration which would have to be estimated separately.

If there is more than one fleet exploiting the same collection of fish, the relation between yield and fishing effort for any one of those fleets will depend to some extent - perhaps considerably - on the activity of the other fleets. Thus, in attempting to find a relation between mortality rate and effort in such a case, the total effort on the stock must be taken into account.

In the present initial phase of population study, a wide range of information may have to be used, e.g.:

(a) Distribution of the species. If the limits of the species can be defined, comparison with the extent of the fishing area will indicate whether migration or mixing has to be reckoned with.

(b) Spawning areas. If there is only one main spawning ground, then the population is at least a biological unit insofar as reproduction is concerned. If spawning is widespread, the possibility of mixing exists.

(c) Catch and effort data. If commercial statistics of catch and effort for a sufficient period are available, their interrelation may indicate the extent to which the system is behaving as a unit.

(d) Age-composition data. These can be used in two ways:
(1) relative strengths of year-classes in samples taken from various parts of the area may indicate more than one source of recruitment; (2) mortality estimates can be related to effort and the relation examined as in (c).

(e) Tagging. This may give direct test of mixing; negative evidence is not so reliable.

(f) Morphological or physiological characteristics. There are many examples of the use of these, notably for distinguishing herring 'races'. Having made such a distinction, however, it does not necessarily follow that the unit system has been directly defined, and account must be taken of the distribution of each 'race' and of the fishing on it.

1.4 STANDARDIZATION OF MATHEMATICAL NOTATION

In view of the rapid increase in mathematical publications dealing with various aspects of fishery dynamics, the need was recognized at the Special Meeting of the ICNAF Research and Statistics Committee in Biarritz, 1956, for standardization of notation for the most commonly-used quantities. Anotation was proposed* and accepted for use in the Commission publications at its 1956 Annual Meeting in Halifax and this notation, which is in common use in many ICES countries, has been considered by a representative committee of Japanese fishery biologists. Examination of proposals by the Japanese group for certain alterations has led to the following conclusions:

(1) The need for easy typing makes the use of Greek symbols undesirable.

(2) It is not necessary to recommend any specific notation for subscripts denoting particular years or ages.

(3) The above decisions and the substantial amount of agreement between the ICNAF and Japanese notations leave only one difference to consider, viz., the symbol for fishing effort; for this, the symbols are:

Japanese:	Amount of fishing effort	X
Biarritz:	Recorded fishing effort	g
	Effective overall fishing intensity	f

While it is useful for the relation between fishing intensity and fishing mortality to be emphasized by similar notation (f and F), it is nevertheless possible to consider changes. In particular the use of f for the 'conditional fishing mortality rate' has been suggested by the Japanese and if this is agreed on further consideration by the Japanese workers, adoption of X for the amount of fishing effort is recommended.

A separate symbol for the rate of exploitation is often convenient and E is tentatively recommended. The full recommended notation is given in Appendix 3.

It is recommended: that this report be brought to the attention of the Japanese Committee, who should be invited to forward their comments to a group consisting of Mr. Taylor (ICNAF), Mr. Gulland (ICES) and Mr. Holt (FAO). Any change from the Biarritz notation agreed by this group should then be placed before the first convenient meetings of ICNAF and ICES with the strong recommendation that the revised notation should be adopted by all workers in the respective Organizations. Meanwhile, the group should bring the proposed notation to the attention of workers in areas other than those mentioned above and should take steps to obtain its adoption by other international fishery organizations**.

2. Assessment of simple fisheries

The simplest type of fishery is one where only a single species is taken by a single kind of fishing gear. For such fisheries, the present methods appear to be adequate when (a) the basic assumptions apply, (b) the necessary data can be readily obtained.

With regard to criterion (a), it has been shown that, for instance, the assumption of constant fishing mortality above the presumed selection range could be in error without that fact being immediately evident. Investigations of the validity of this and other basic assumptions is necessary. Comparison of results using different data, assumptions and methods of analysis, and particularly noting discrepancies, may enable the assumptions to be tested.

In the absence of proof, the results presented at this meeting, and of Beverton and Gulland at Biarritz***, suggest that the use of the same model and basic assumptions throughout the analysis and assessment is likely to give the least error in the final result, even when the assumptions themselves are not precisely true.

Mathematical models developed primarily for the study of trawl fisheries may be applied to many fisheries using other types of gear, but often require some modification to take account of the age-selective characteristics of such gears.

* *Spec. Publ. I.C.N.A.F.*, (1):40-42, 1958.

** The Committee designated above completed its work by publication of an agreed notation in *J. Cons. int. Explor. Mer* 24:239-242, 1959. Initiative now rests with the sponsoring organizations to encourage universal adoption of this notation. FAO has given reprints of this paper a very wide distribution to institutions, organizations, and editors and publishers of periodicals. A supplementary document is now in the press giving the terms and their definitions in languages other than English, Japanese and German, which are already published (see Appendix 4).

*** *Spec. Publ. I.C.N.A.F.*, (1):51-66, 1958.

The simplest population model that has been developed for the study of trawl fisheries is based on the assumptions that fishing and natural mortality and the growth parameters are constant over the exploitable life-span of the fish. Also it has been supposed that the selection phase is confined to a relatively short part of the life-span. However, in many fisheries, and possibly including some trawl fisheries, this may not be realistic, as selection may extend over practically the whole of the exploitable phase; so that fishing mortality varies with age. In other cases it may happen that there is a spacial variation in the age composition of a species so that again the fishing mortality varies with age. In these cases the variation of fishing mortality with age will not necessarily be expressible by a simple function as is often possible in the case of gear selection. Fishing mortality may also be a function of the interchange of fish of different ages between different areas, and further complexities can arise if a variety of gears is used in different places.

In some cases assessments can be made by introducing simplifications; for example, it may be possible that the greater proportion of the fishery conforms to the simple type, in which case the use of the simple model may not introduce important error. The next refinement is to consider a range of population models in which fishing mortality is allowed to vary in a simple manner with age. There are two ways of doing this. It can be done algebraically, in which case the model obtained should be comparatively simple and lend itself to reasonably easy computation. Examples are the cases when fishing mortality is either a linear or a simple exponential function of age, for which tabulations have been made. Unfortunately, mathematical models in which mortality varies with age are inclined to be very complex and may not be worth the labour involved in their solution. Search for simple solutions should nevertheless be encouraged. Alternatively, the theoretical effect of varying mortality with age can be studied numerically. This, too, can be tedious but as a method it has the advantage that any arbitrary variation in either fishing or natural mortality or both can be handled just as easily as the model in which mortality varies in a simple manner with age.

It is possible to prepare tables for solving yield equations, in which mortality varies in a simple manner with age. This would be valuable for particular fisheries, such as a simple gill-net fishery. In other cases, we must face the fact that there are complex fisheries, in which there are many gears operating at once, as well as spacial variations in the abundance and age composition of the species. These fisheries must be considered individually. If data can be assembled to measure the effective fishing mortality at each age, simple numerical estimates are possible. If, in addition, transport coefficients can be obtained relating to the interchange of fish between different areas, differential equations can be set up and solved numerically, preferably by high-speed computers (see Section 8).

In practice, however, there are many complex fisheries in which such data cannot be collected. In these cases, whatever data are available must be used to set probable limits to the possible variations of mortality and of other measurable parameters, and a range of possible assessments made. If the calculations involved are sufficiently extensive, it would be worthwhile programming a high-speed computer for the purpose.

3. Assessment of complex fisheries

This subject was considered from two main standpoints: (1) the estimation of effort and catch per unit effort indices; (2) yield assessments. Particular attention was given to the first of these since it is an important problem at the present time in both the ICNAF and ICES areas.

In what follows, problems of effort and catch per unit effort measurement are considered with respect to two particular situations: (1) several species caught by the same gear; (2) one species caught by several different gears. Although many actual fisheries are a combination of the two, it is not thought that they present any problem that cannot be considered under the above headings.

3.1 ESTIMATION OF EFFORT AND CATCH PER UNIT EFFORT

3.11 SEVERAL SPECIES CAUGHT BY THE SAME GEAR

Fisheries for several species may often be simplified by detailed sub-division by time and place, so that the fishing within any single species is then directly applicable. Data should therefore be made available in the smallest possible area breakdown, though grouping may be necessary for some purposes.

Even within the smallest practicable sub-division, however, several species may be caught by the same gear. Useful information for analyzing this situation is data from individual trips or, better, days' fishing from all or a sample of the fleet. A frequency distribution can be drawn up for the proportion of fish of a given species, say cod, in the catch. Two relatively simple special cases then are:

(a) The proportion is nearly constant for all ships. The species may therefore be considered as thoroughly mixed with the other species, and the effort on it is equal to the total effort.

(b) The proportion is either nearly zero, or nearly 100 per cent. The cod effort is then taken as the sum of the efforts of all boats which land almost only cod. Viewed rather differently, the catch per unit effort of boats fishing solely for cod is a good index of cod density. An additional amount of effort should be included to allow for the cod landed by other boats, using the special cod boats as standard, and raising this by the ratio of the total catch of cod to that by the standard boats.

If the regular statistics do not give data by individual trips or days, but it is known that the species in the area are caught separately, then an approximate estimate of the effort on each species can be made. To do this it is necessary to make what seems a reasonable assumption that the economic return to the fishermen is the same for all vessels. If, for instance, cod and redfish are caught separately, and are of equal value, and in 1,000 days', fishing 9,000 tons of cod and 1,000 tons of redfish were caught, then, unless in either cod fishing or redfish fishing the catch per day is much below the average of ten tons, the efforts on cod and redfish must have been about 900 and 100 vessel days respectively.

(c) Finally, the percentage of cod in the catch may cover the entire range of values between 0 and 100 per cent. This problem may perhaps be most easily considered as one of finding a value for catch per unit effort which gives a reliable index of cod density, and in particular one that is not biased by changes in the true relative abundances of cod and other species. However, limiting values, and often most useful limits, are given by catch per unit effort estimates which are biased in known directions. For instance, the total cod catch of all ships, divided by the total effort, will over-estimate changes in relative cod abundance, since at times of relatively low cod density fewer ships will concentrate on that species, and the catches will fall greatly. Conversely, the catch per effort of vessels catching only cod will under-estimate changes in cod abundance, for, as this decreases, fewer ships will concentrate on cod, and the catches of those that do will, to an increasing extent, represent peak densities.

These two limits may between them define the catch per unit effort - and hence, by dividing into total catch, the total effort - with sufficient accuracy. (Note that the two scales of catch per unit effort will be different, the catch per unit effort for the cod boats being relatively greater; the essential question is the extent to which these two indices vary from year to year.) Otherwise, it is necessary to choose some group of vessels whose concentration on cod is likely to remain constant. This may be done by reference to the frequency diagram of the percentage of cod mentioned above. For instance, to take a rather simplified version of an actual fishery, English trawlers at Iceland fish either for plaice or for roundfish; a frequency distribution of the percentage of plaice separates these groups at once: the 'plaice vessels' have between, say, 30 percent and 70 percent plaice, the others less than 5 percent It seems reasonable to take the catch per unit of the plaice vessels as a reliable index of plaice density. Then the total effort is given by

$$E = C \times Ep/Cp$$

where E, C, Ep, Cp are the effort and catch of plaice by the whole fleet and the plaice vessels respectively. Alternatively, the effort data for roundfish trawlers could be taken into account by treating them as a separate gear (as is in detail true) and using the procedures outlined in (3.12) below.

A general conclusion from this analysis is that a proper interpretation of catch and effort data in such cases requires as much additional information about the conduct of the fishing operations as possible. For example, if the 'intention' of skippers can be ascertained reliably (i.e., which species they were deliberately seeking for), this would be a valuable guide in assessing bias in estimates of catch per unit effort. Means of obtaining the willing collaboration of fishermen in providing this kind of information perhaps deserve special attention.

Both bias and variation in effort and catch per unit effort indices are likely to be greater and more influenced by economic factors in a mixed species fishery than in one for a single species. This is because the effort on any one of several species depends partly on the preference for that species, as manifest by the extent to which the fleet tends to concentrate where that species is most abundant. But preference is essentially a question of market demand and supply, so that a change in either of these factors may bring about a change in the preference for that species and hence a re-allocation of the total effort. Such changes could well be more drastic and rapid than in a single species fishery.

3.12 FISHERIES IN WHICH ONE SPECIES IS CAUGHT BY SEVERAL TYPES OF GEAR

Provided statistics of catch and effort are available for each gear separately, catch per unit effort and effort indices for each group can be calculated in the usual way*. An index of total effort can then be computed by selecting one gear as standard (i.e., that thought to give the most reliable index of density) and raising the effort of that gear by the ratio of the total catch by all gears to the catch by the standard gear. If the size selectivity of the various gears is different, the computation needs to be made for each size group of fish.

This procedure does not, however, use the information which is available from the catch per unit efforts of the other gears which, even though they may be thought to be less reliable than the standard gear, may nevertheless contribute information relevant to the whole problem. Of particular importance is a study of the changes with time of the catch per unit effort by the various gears. If these tend to vary together and remain in roughly the same ratios with each other, this would give some confidence for the belief that none of the catch per unit efforts are seriously biased. Conversely, departures from this situation would indicate differential changes in the effectiveness of the gears concerned, and further analysis may enable the causes of this to be established. One such cause may be the searching practices adopted by vessels using a particular gear, and analysis of the statistical distribution of the catch per unit effort of the individual vessels may clarify this.

It may be that no relation can be found between the catch per unit effort by the different gears; in this case the effort data should be directly combined to give the best available estimate of the total effort on the stock.

3.2 YIELD ASSESSMENTS IN MIXED SPECIES FISHERIES

The importance of economic determinants arises again when considering the special problems of yield assessment in a mixed species fishery. Analysis of the dynamics of each species independently, taking account of biological interaction between species as far as possible, can enable yield assessments to be made for each stock. The difficulties arise when attempting to enumerate the independent effort variables in the system. Thus the weighted effort indices for each species, although they may be close-

* See *Rapp. Cons. Explor. Mer*, 140(1):9, 1956.

ly proportional to the fishing mortality coefficient for that species, are not the independent measure of effort input which is required for prediction or assessment. In fact, this has to be some measure of the total effort, e.g., size of fleet, and the relation between it and yield - either total yield or the yield of any one species - cannot be formulated without taking account of the way in which the total effort is distributed over the various species.

The problems arising can perhaps be best illustrated by an example. Suppose that the mesh size used by all vessels in a mixed species fishery is increased by regulation, and that as a consequence the abundance of one particular species (because of its particular dynamic properties) increases much more than that of the others. The response of the fishermen will be to tend to concentrate their effort more on that species than they had done previously (especially if it is a valuable species) and thus, although the total effort in terms of fleet size may be unchanged, the effective effort, and hence the fishing mortality, on every species may be altered. To the extent that this happens, yield assessments based on the assumption that the fishing mortality coefficient for each species will remain unchanged, will be in error.

This problem needs special attention. The data required are the price-supply-demand functions for each species and the tactics that the fishermen employ in conducting their fishing operation, but useful working answers may be obtained simply from data of the relative prices of the species, and by assuming that the intention of each skipper is to maximize the total value of his catch. It may in such a way be possible to establish, for example, that a particular regulation would not cause much change in fleet operations and that simple additive assessments would be satisfactory.

A special case of these problems arises in the regulation of a mixed species fishery in which one or more species are not subject to the regulation. An example has occurred in the mesh regulation of the North Sea, where certain quantities of protected species (e.g., haddock) are caught incidentally by herring trawlers using a much smaller mesh than that permitted for the protected species. One requirement in this case is to assess the influence on the yield of a protected species caught by the regulation gear, of the capture of undersized specimens by a smaller meshed gear. Methods for doing this have been developed and applied to the haddock and herring fisheries of the North Sea.

No detailed attention was given to the subject of biological interaction between different species caught together by the same gear but it is important that this phenomenon is not overlooked when studying the dynamics of mixed species fisheries.

4. The present data on fishing effort

Until the causes of bias in recorded effort units are clearly understood, the use of a wide variety of effort units, involving different gears and different units of fishing power and fishing time for each gear, is valuable. Comparison of the catch per unit effort for different units is helpful in bringing out sources of error and in choosing the best unit of effort. Such comparison of catches per unit effort may also be made for different areas and times for the same stock and indicate changes in vulnerability and availability.

4.1 TRAWLS

Several studies have shown that fishing power increases with size of ship, as measured by tonnage or horse-power. No single easily measured factor, however, appears to be simply proportional to fishing power - in particular, fishing power increases rather less than proportionally to tonnage. Also, the proportion of available engine power actually used may not be constant. It is, therefore, suggested that a convenient size and power of vessel should be taken as standard, and the effort of other sizes of ship converted to this. Such a conversion could in theory take into account other changes in the fishing power of the unit, as by the introduction of, for example, V.D. gear, echo-sounder, Decca navigators, and it is important that investigation of the quantitative effects of these developments should be made.

In practice, effort data are conveniently collected for a small number of size-groups of fishing units (cf. ICNAF statistics) rather than exactly standardized units. There is a danger that there could be a trend of fishing power with time within a size-group, but this could be assessed by periodic checks of the distribution of size within the group.

4.11 UNITS OF TIME FOR TRAWLS

Of the numerous units used for fishing time for trawls, only three seem directly related to the time actually spent fishing - days fishing, hours fishing and number of tows. The number of hours is interpreted here as the total time the gear is on the bottom fishing, and does not include the time handling the gear. As the abundance of fish increases beyond a certain limit, the duration of tow will be reduced. This will reduce the effective amount of fishing per day, and therefore days fishing is a biased measure of fishing time. However, there is certain evidence that reducing the duration of tow increased the efficiency of the trawl, i.e., two one-hour tows will catch more than one two-hour tow (but of course may be less profitable to the fisherman because of the increased time for handling the gear). This suggests that hours fishing could be a biased measure of effort, though biased in a direction opposite to that of days fishing. Research on this question is therefore urgently needed. The best measure of fishing time would appear to be number of tows, plus a correction factor related to the average duration of tow. Until a definite answer is obtained about the effect of duration of haul, the provisional factor might be the duration of tow itself, giving, in effect, 'hours fishing'. Future research could, however, show this to be wrong, and it would then be necessary to correct past data using the separate information of number of tows and duration of tow.

4.2 DANISH SEINE

The present evidence suggests no obvious features of seiners which are related to fishing power. The unit of power is, therefore, one seiner. The natural unit of fishing time that appears best is the haul, with a correction factor for the length of warp used.

4.3 LINE FISHERIES

Number of hooks, and number of hauls, is the most easily measured direct index of effort for line fisheries. Correction factors are necessary for:

(a) Gear saturation: i.e., the reduction of the average proportion of unoccupied hooks during fishing on dense stocks.

(b) Interference: Because of overlapping of the effective catching ranges of adjacent hooks, there is sometimes a decrease in catch per hook as the number of hooks per unit length of ground-line is increased.

(c) Duration of sets.

(d) Type of bait: This can have a large effect on catches, and the type of bait used can vary from year to year (e.g., because of shortage of the preferred bait). Information should be collected about:

   (i) experiments on the effect on fishing power of the type of bait used;

   (ii) the type of bait actually used in commercial fisheries.

4.4 SEARCHING FISHERIES (using, for instance, ring-nets)

No unit of effort can be definitely recommended. It is suggested that statistics of as many units of effort as possible should be collected, and that a comparison of the resultant catches per unit effort might result in a better understanding of the different units.

5. Causes of variation in fishing effort and fishing mortality

Fishing intensity measures the input into a fishery in physical terms and is the force generating the *fishing mortality* in the exploited resource. It therefore concerns:

(a) the *entrepreneur* and the *economist*, as the primary physical variable of input;

(b) the *fishery biologist*, as the force generating the fishing mortality;

(c) the *legislator*, as one of the variables which may be regulable.

We therefore require measures of fishing intensity, and of the main factors which govern its variation with time, with the objective of elucidating the whole system of cause and effect within the input complex.

Fishing intensity is defined precisely as the fishing effort per unit area, where unit fishing effort is the sum of the products of the fishing power and operating rate of a fishing unit.

The different components of the total effective effort (that weighted sum of unit fishing efforts which is proportional to fishing mortality) which may vary are:

(1) The number of fishing units (vessels, gear and crew).

(2) The number of effort units expended by a fishing unit (either the fishing power or the time operating).

(3) Distribution of the fishing intensity in relation to that of the stock, with respect to space and time.

One or more of these components may be varied by different causative agencies, and at different phases in time and in development of the fishery. We are concerned also with four main classes of variation:

(1) *Long term:* trends or phases of development during the history of a fishery, which may be over periods of 20-100 years;

(2) *Short term:* variations taking place mostly within a decade or less.

(3) *Seasonal variations:* assignable to known causes.

(4) *Seasonal variations:* not assignable to known causes.

Whichever of these is most important and is having the greatest influence will depend very much on the phase of development of the fishery.

5.1 LONG TERM TRENDS

The general features of development of a fishery have been illustrated by Kesteven and Holt in a recent paper*. Their scheme is roughly as follows:

Phase 1: Period of slow growth in fishing intensity - under influence of changing economic and socio-economic factors

Components of fishing effort varying in this stage are mainly the number of fishing units, which operate with whatever technological facilities are available at the time of commencement of fishing. The fishermen are seeking out the fish stock and gaining experience of the nature of the resources.

Economic and socio-economic factors will motivate expansion processes during this stage. ***Marketing*** and ***distribution*** activities grow and under the general motive of maximizing, or at least increasing, profits capitalization takes place.

Phase 2: Period of rapid growth in fishing intensity - under influence of technological advances made within the framework of the existing socio-economic structure

Technological factors may relate to improvements in: gear, marketing or handling. The components of fishing effort varying in this phase are:

(1) Number of units.

(2) Fishing power of units, due to technological advances in gear design and fish detection methods.

(3) Distribution of units of fishing effort - due to technological advances in fish location methods and fleet communication and organization, resulting in increases in the range of operation and concentration on centres of fish density.

This phase will last so long as the economic outlets for the products of the fishery remain at levels which are compatible with the fishermen's profit demands; and the resource remains large enough to supply these products.

Both of these factors must become limiting at some stage of development and the fishery which will then pass into ***Phase*** 3, which is characterized by a levelling off of input, followed by stabilization at this high mean annual level, or at some rather lower level.

* "Papers presented at the International Technical Conference on the Conservation of the Living Aquatic Resources of the Sea", U.N., p. 354, 1956.

This phase of stabilization will persist so long as the main groups of causative agents - socio-economic, technological and biological - do not change substantially.

This is the phase reached by several major fisheries in the North Atlantic. There are still examples of fisheries in this region in which the levelling off process has not been reached; the redfish fishery - at least in some regions - is one example, the capelin fishery is another.

Throughout the history of a fishery much will often have been learned about the economic, technological and biological controlling factors, and a change in any of these at any time may bring about a change in the level of input. One such factor which may become important during this phase is legislative control of some aspects of the fishing operation, either of the total amount of effort, or of another component, such as gear selectivity, which indirectly promotes a change in the level of fishing intensity.

5.2 SHORT TERM VARIATIONS

Long-term trends can be described by a general smooth curve, representing the average changes with time; superimposed upon this are short term variations, which occur either cyclically or irregularly. The factors bringing about these changes are:

Socio-economic. Important among many factors are:

(a) Changes in marketing procedure;

(b) Production of new commodities (this might be persistent);

(c) Changes in market demand with availability or abundance of fish, including, particularly, international trade conditions;

(d) Cost of operation (fuel and gear);

(e) Changes in consumer tastes, causing changes in relative demand for different species.

Biological and environmental. Again a number of different factors may be important:

(a) Changes in distribution and accessibility of fish due to environmental factors;

(b) Fluctuations in total abundance due to natural factors. These may be of very short term but sufficient to cause effort changes. They may be cyclic in character or irregular;

(c) Climatic factors affecting fleet operations. The most important of these are fluctuations in quantity and distribution of sea ice, or variation in wind and wave conditions.

5.3 SEASONAL VARIATIONS

Seasonal or shorter term variations in effort will be reflected also in variations in effort as between years, and will therefore increase the year to year variability considered above. The causes of seasonal variations are:

Economic and socio-economic factors. These are of a shorter term nature than those considered above, but may be of the same general type. They may be systematic as between years, or irregular. Examples are:

(a) Seasonal variation in demand for fishery products;

(b) Seasonal changes in consumer preferences leading to shift of operations from one species to another and from one type of fishing to another;

(c) Seasonal changes in habits of fishermen, especially of part-time fishermen who have alternative seasonal occupations;

(d) Strikes, etc.

Biological and environmental factors. Again, these may be systematic as between years, or irregular. Examples are:

(a) Changes in fish distribution, or accessibility or edibility within a year;

(b) Short term changes in vulnerability;

(c) Weather.

5.4 CAUSES OF VARIATION IN FISHING MORTALITY

In this brief analysis the complex pattern of change in the operations of a fishery has been broken down into the chief phases of change which may be experienced, and to each of these phases has been assigned some of the chief causative agents generating the changes, thus isolating the chief factors bringing about changes in fishing mortality, generated by the effective fishing intensity. We conclude that at all levels of change considered, social factors constitute important determinants. This is particularly true at the long and short term levels. The influence of these factors may be direct or indirect. We question, therefore, whether, in making assessments, and especially predictions, of the effects of fishing as a basis for legislative control and conservation, it is permissible to continue to avoid formal consideration of these basic determinants. Present methods of approach rest on the assumption that the effects of legislative action will not alter indirectly the character of the fishing effort exerted in the fishery, but it is clear that economic and social factors may in fact operate in response to changes in the quality or composition of the catch and bring about changes in the amount or kind of effort input. It is emphasized, however, that this does not imply that assessments at the biological level are no longer of importance; they will continue to form the basis of management studies. For this purpose, measures of the 'effective fishing intensity', to which the instantaneous fishing mortality coefficient is proportional, are needed, and it is necessary to know its long and short term variations and their determinants.

6. Variation in population dynamics

Populations living in a limited environment are controlled by dynamic compensatory mechanisms. The dependence of vital parameters of the population, such as growth, mortality and recruitment, on density is often rather obscure because they are also frequently affected, and to a much greater extent, by density dependent fluctuations in the environment.

However, though detailed knowledge about the compensatory mechanism may often be meagre, there are cases - many of them, indeed - when the environment has been relatively constant, or when it has been possible in analysis to allow for elimination of the effect of the environment, and thus observe the effects of density dependent factors on the growth of the population.

Recruitment depends both upon the number of eggs laid and on the survival of eggs and young. Fecundity is correlated with the biomass of the spawning stock; it is usually inversely correlated with the degree of protection given to the eggs and with their individual size. The mortality during the early stages of life may be density dependent or independent.

Consideration of the density dependence of growth reveals large differences in the effect on growth rate of changes in stock density in different areas and species. Often the dependence will be masked by effects of other environmental factors. In many cases there is no direct influence of total stock density on the growth rate of individuals, but the abundance of fish of about the same age is important for growth. Consequently the fishing intensity on different parts of the stock will have a complex influence on the growth rate.

Observed length at age is the resultant of the growth rates during successive phases of life. For plaice and for some other fish, the growth rate during the first two or three years determines, in some measure, the length at later ages. In other species there may be no differences during the first two or three years of life but marked differences later.

Any growth formula used in a population model must be flexible enough to apply to the different effects of population density in different species and stocks. The von Bertalanffy formula may not always be the most suitable to account for density effects, especially when they act mainly during the early stages of life, or when they do not act through the food supply.

Much more research on the relations between growth rate, feeding and the production of food is needed, both from the point of view of comparative observations on natural stocks and of the dynamics of food supply. Further experimental work on the food requirements for growth and maintenance in commercial species is also required.

Very little information is available about the effect of density on mortality, except at the early stages of life. The natural mortality may be associated with the growth process, and the scarcity of food may result in increased mortality, though not necessarily directly. Cannibalism and predation, inter- and intra-species competition, in general appear to be related to density, though very little is known about them. It can also be envisaged that, at high levels of density, population pressure may affect geographic distribution and thus bring about changes in fishing mortality; further, because of the schooling behaviour of fish, the same total effort may result in a quite different instantaneous mortality rate at different levels of density.

The vital parameters may be interdependent on each other. Thus fast growth is usually associated with high fecundity and early maturity. In considering the density dependence of growth, recruitment and mortality, and indeed any inter- or intra-species competition, it must be remembered that there may be a considerable time-lag between the cause and the effect. Unusual environmental conditions may result in such a time-lag, or it may be related to a slow turnover in the food population.

The density independent variations of each of the vital parameters arise from a complex of natural factors which bring about variability of biological characters. The main problems which they create concern the evaluation of the magnitude of the variation in the final assessments due to them.

Each of two types of variations (irregular or 'random' fluctuations, and cyclic variations or trends operating over a period of years) were considered for each of the population parameters in turn.

6.1 RECRUITMENT

Annual fluctuations in recruitment are, of course, a well-known feature of fish stocks and are due to the impact of varying environmental factors on the early stages of development of the year-classes or on egg production, or to density dependent processes. They are often large and usually contribute the biggest component of variability in the fishery.

In the absence of any means of accurately forecasting density independent variations in recruitment - which is the situation for most fish stocks at the present time - assessments have to be made on a 'per recruit' basis. This is a satisfactory method of handling density independent variations in recruitment, and provides realistic estimates of the relative yield changes deriving from fishery changes. 'Per recruit' assessments are in danger of being seriously wrong only if density dependent variations are occurring. However, even when important density dependent relations between parameters exist, the changes in yield will still be in the direction (increase or decrease) predicted on a 'per recruit' basis, for a change in fishing which would result in an increase in stock size, if the population in question has an asymptotic recruitment curve. The prediction would not necessarily be correct in cases where the curve of recruitment against spawning stock size or against population fecundity was a peaked one.

Both density dependent and density independent time trends in recruitment may show the same general regression of recruitment on stock, so the two types of relation cannot be distinguished in that way. They can possibly be distinguished by plotting the ratio of recruits/stock against stock size. Even so, these two relations may be very difficult to establish in practice because of the large annual variations (see Section 8).

6.2 GROWTH AND NATURAL MORTALITY

For assessment purposes, some estimate of both these parameters must be made, and variations in them cannot be treated in the same way as recruitment variability. The important task in making assessments is to ensure that the estimates used for these parameters are the best average measures for the species over a reasonably long time period. Again, the greatest dangers of error arise when density independent variations take the form of trends in time. In these situations, the only possibility is to seek information other than the time variation parameters, and to adjust the assessments in the light of this evidence.

Analyses of growth data for a number of fish species have shown that both 'parameters' of the von Bertalanffy equation may vary under the influence of density independent forces, and variations between them may be generated by the same environmental factor. However, experience with some North Atlantic species has shown that the coefficient K exhibits relatively less variability. It is this coefficient which largely determines the direction of change in yield which derives from changes in fishing.

Little is known about variability in natural mortality, either between age-groups within the exploited stock or between year-classes. It is the most difficult of the population parameters to measure, and estimates of it, in fished stocks, must be obtained by indirect means. Its variations can be studied from total mortality estimates if the fishing mortality coefficient or the factor relating fishing intensity and fishing mortality is known for each estimate. They also appear as a component of the error of estimate in the regression of total mortality on fishing intensity.

The natural mortality rate probably varies between rather narrow limits under the influence of density independent processes but the importance is recognized of the predator-prey system as a source of variability and of the occasional incidence of sporadic large fluctuations due to climatic factors or epidemics. In practice it is necessary to use limiting values of the natural mortality rate in assessment calculations, because of the difficulties of obtaining accurate estimates of it, and it is likely that in this way the normal range of density independent variation will in fact be encompassed.

6.3 ELABORATION OF MATHEMATICAL MODELS

When recruitment is primarily determined by environmental factors and not by fecundity, when the mortality in the post-recruit phase of life is density independent, and when growth is not restricted by the lack of food, the model in which all parameters are independent of density is applicable in the neigh bourhood of the observed conditions. Even when the vital parameters are density dependent, the density independent model may often be appropriate and the inclusion of the density relations primarily a refinement. However, there are cases when the density independent model cannot properly describe the situation or be used for prediction; one example is the Pacific salmon. Density independent variations in one or more of the parameters may be treated as stochastic processes, and stochastic terms introduced in the theoretical models for yield prediction. This is a desirable step if information on the type and range of variability of the parameters is known. Recruitment has already been treated in this way in theoretical studies; the difficulty at the moment is in measuring the variability of parameters, and this is now an important task. Attention should be focussed on the environmental determinants of variations; their identification governs to a large degree the extent to which fluctuations in parameters can be taken into account in predictions of yield, and hence in the preparation of fishery forecasts. The value of studying the time trends in deviations from regressions of pairs of variables is stressed. For example, whereas in plotting total mortality rate against fishing effort, the variations may appear randomly scattered about the regression line, these variations may, when plotted against time, reveal periodic trends for which an environmental determinant may be determined.

The applicability of population models based on a simple growth law, such as the Pearl-Verlhurst logistic equation, was discussed. There is a definite need for such models because in many cases detailed information on the vital parameters is available only for a short period of time, but long term information may be available for catch and effort. Furthermore, methods of estimating the vital parameters have not yet been developed for some types of fish. However, such models have to be applied with caution. There may be a time lag between change in fishing effort and the response of the population, and not all species populations would be expected to follow the same type of growth pattern. The desirability of studying conditions which result in different types of population growth laws is indicated by the development of more complex models and by the experimental studies of fish populations maintained under controlled conditions that are being conducted at present by several workers.

For a population model to be realistic, it should take account of biological characteristics of the fish and not only of the statistics on the stock. The stock should, ideally, be analysed by small sub-populations which are homogeneous with regard to their biology and ecology. For each sub-population, the factors which are critical in the sense that they control growth, mortality and recruitment should be determined, and these observations incorporated in the model.

Thus, although density-independent models, or models making allowance for the probable forms of density effects may be adequate for present purposes, further progress depends on increases in knowledge of the actual form that the density relations take in the principal fish stocks. Such knowledge can only be gained by further intensive ecological research.

Considerable importance is also attached to continued compilation and analysis of existing data pertinent to the further understanding of growth.

It is recommended that yield assessments based on incomplete information, should be examined with regard to the probable errors of predictions with the aim of estimating the risks involved in acting on incorrect predictions. In assessing overall error of estimation by population models, it is useful to compute the deviations of observed catches from predicted average catches, over a series of years and thus obtain empirical confidence limits.

7. Comparative studies of the effects of fishing

In recent years progress in fish population dynamics has tended towards the development of mathematical models which are being applied to a variety of different stocks: for the most part, primarily because of lack of relevant data, these models assume constancy of population parameters and treat the stock of one species as an independent unit. Comparative population studies, especially with reference to the reaction of stocks to fishing, may well be of value in several ways.

7.1 Such studies offer a means of testing the validity of the mathematical model as something more than a short-term predicting device. Long-term comparisons of the effect of fishing on the abundance and structure of various populations may enable their reactions to fishing to be classified and compared with what would have been predicted from theory. Age and size compositions of populations have been estimated from fossil records covering a period of up to 5,000 years. In some cases, characteristics such as the mean length of fish remained nearly unchanged to the present day. In others, changes had occurred which could be interpreted in terms of the kind of effects of fishing which would be predicted from a simple theoretical model. Since 1890, as fishing intensified, changes in the abundance of certain North Sea species (as computed from German trawler statistics) have followed different patterns, there being a contrast between species in the northern and southern parts of the area.

7.2 Long-term studies may permit genetic effects of fishing to be detected. Nearly all kinds of fishing must be selective to a greater or lesser degree, since they tend to take, preferentially, the faster or slower growing individuals (depending *inter alia* on the selective characteristics of the gear), those that have the best ability to avoid predators or other causes of natural death, and also those which are least able to avoid the fishing gear. Fishing also tends to reduce the average age of the spawning stock, which might conceivably change, in the long run, the 'vigour' of the population. In these and possibly other ways, it may be that a population gradually adapts itself so as to reduce the impact of fishing on it. In a study of a long time-series of data, there are technical problems of analysis, i.e. the distinctions between, and the measurement of, cycles, trends and random variation, to which application of the appropriate statistical techniques is necessary.

7.3 It is reasonable to suppose that not only individual animals but also whole populations are adapted in some degree to their environment; in the latter case, this would mean that the magnitude of one or more of the vital rates was such that best enabled the population

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* *Convenor's note:* Since this meeting a useful review of the literature relating to this problem, especially as regards freshwater and diadromous stocks has been published by R.B. Miller (1957), *J. Fish. Res. Bd Can.*, 14:797-806.

to occupy a particular ecological niche and perpetuate itself. There may well be some pattern of association between parameters such as growth, maturity and natural mortality which would bring this about. Examples are known of short-lived fishes such as the sand-eel, in which the growth pattern is completed in a correspondingly short time and maturity occurs at a much younger age than in other species with a longer life-span and less rapidly developed growth pattern. There are ***Tilapia*** species in certain African lakes between which there were marked differences in growth rate. Nevertheless, the size at first maturity tends to vary directly with the growth rate, so that the fish matured at approximately the same age. Such an association would tend to compensate the effect of a slower growth rate in reducing the reproductive capacity of the population: comparative studies of the vital parameters, singly and as sets, of populations of the same or related species in different environments might lead to generalizations which would materially advance understanding of their dynamic properties. In particular, if some definite pattern should emerge, it may well provide at least working estimates of parameters in the absence of direct information. A complementary approach would be to see whether certain parameters of populations of different species inhabiting the same environmental niche in different areas might by adaptation be of similar magnitude. These procedures are essentially similar to the approach of the comparative anatomist and physiologist*.

7.4 It should be stressed that the critical adaptive mechanism of a population may not operate in the adult phase, but, rather, may occur very early during the life of the larvae. Certainly, the enormously high mortality during early life, which is known in so many cases to be greatly influenced by environmental factors, renders this highly probable. Thus it is necessary, when attempting to identify the adaptive mechanism of a population, not to restrict the search to characteristics of the adult phase alone, but to consider all parts of the life history, and also the self-regenerating properties of the population (e.g., comparative studies of fecundity and the stock-recruitment relation).

7.5 The comparative approach takes on a special significance when we are trying to understand the dynamic properties of fish communities or of communities involving fish and other organisms. Here an analysis species by species may be impractical and, in any case, fails to reveal the true interactive mechanisms except perhaps in the most obvious instances of direct predation or competition for food. Comparative studies of the effect of fishing on community balance may be a fruitful way into this problem, especially where it is possible to contrast highly selective fishing for one or a very few species with fishing which takes all - or nearly all - species in roughly equal proportion. The general intensity of interaction within a community would itself be expected to depend in some way on the environment, and it may eventually be possible to deduce this intensity from certain environmental characteristics. Experimental data from inland fish cultural research may be of value here.

It would be premature to recommend that formal comparative population studies on a world-wide scale should be initiated at this stage. More information on the dynamics of individual stocks is needed, but it is recommended that workers in this field should take every opportunity of examining their results comparatively within the area with which they are acquainted. Comparative studies on a limited scale have already been made, for example on the stocks of plaice in the North Sea and the Baltic, and enough information may already exist to make worthwhile a comparative study of the dynamics of certain other stocks. Examples include the haddock of the North Sea and Georges Bank, and the cod of Newfoundland, Greenland, Barents Sea, the North Sea and the Baltic, and the redfish on the two sides of the North Atlantic.

* For follow-up of this recommendation, see contribution by Beverton and Holt to Ciba Colloquium on "Life Span of Animals", London, April 1959. Analysis of compiled data showed that there are indeed clear relations between the parameters of natural mortality and of growth and maturity, and indications of consistent relations between these and environmental temperature, metabolic rates, and sex of fish.

Modern techniques of population analysis and assessment, while still far from giving a true description of all features of the dynamics of populations and environmental influences, nevertheless provide a means of expressing population properties by a relatively few parameters and of codifying the effects of fishing on stocks. This makes possible a comparative study of population dynamics in a way which was not previously possible, and it may well be that the broad search for consistencies and anomalies between stocks, expressed in these admittedly imperfect ways, is nevertheless now the most fruitful approach to understanding of many aspects of the dynamics of fisheries resources.

8. Treatment of data

The preceding sections of this report are concerned mainly with the theoretical analysis of various fishery problems and with summarizing the results obtained by applying analytical methods to particular situations. The precise methods of dealing with available data have been dealt with in many recent publications and at this meeting only those problems were considered which were raised specifically by contributed papers. The conclusions are reported under two headings.

8.1 METHODS OF ANALYSIS

Methods of estimating in a fish stock mortality due both to fishing and to natural causes are extremely important at the present stage of fish population studies. It has been recommended previously*, in view of the difficulties and many sources of error in the various methods available, that for any particular fishery as many methods as possible should be used and the results compared. Some progress has since been made in clarifying the sources and kinds of bias involved in different methods.

Special consideration has been given to the use of measures of the 'virtual population' (that is, the total catch of a year-class throughout its life-span) in estimating mortality; the technique was used in several contributions to this meeting. Although it has not been possible to give the method the rigorous mathematical investigation which is required, preliminary examination and the working of a hypothetical example led to the following tentative conclusions:

(a) If the fishing mortality and natural mortality coefficients remain relatively constant throughout the period investigated, then the 'virtual population' method will give estimates of total mortality no different from those obtained from catch per unit effort data. The use of the 'virtual population' may, however, tend to reduce the sampling error. In any case, if there is no variation in effort and fishing mortality over the period of investigation neither method permits resolution of total mortality into its fishing and natural components.

(b) If natural mortality is constant but fishing mortality varies from year to year because of changes in effective fishing effort, then use of the 'virtual population' will tend to exaggerate changes in total mortality and give too low an intercept value of natural mortality in a plot of total mortality against effort. This bias will be greater, the greater are the variations in fishing mortality and the lower is its value relative to natural mortality.

(c) If natural mortality varies from year to year, then the changes in natural mortality, and thus in total mortality, will tend to be averaged out by the use of the virtual population.

(d) The virtual population method does not appear to assist in revealing variations in availability and/or vulnerability, unless fishing mortality is very much greater than natural mortality. If estimates of fishing effort are unreliable, meaningful plots of total mortality against effort will in any case be impossible.

* *Spec. Publ. I.C.N.A.F.*, (1):43, 1958.

(e) The 'virtual population' method differs from the method using average annual catch per unit effort of all age groups in that the former estimates the population at the beginning of the fishing season, while the latter measures the mean population present during the season. In comparing results from the two methods, this should be borne in mind.

(f) The tendency for the 'virtual population' method to smooth out year to year variations may lead to dangerously 'good' results in which important biases are concealed*.

Attention is drawn to the general danger of spurious regressions in population dynamic analysis. When plots are made of one term against another, the terms usually contain 'constants' which are in fact subject to variation. This variation may generate spurious regression, perhaps similar to the one expected, and thus give misleading results. The possibility of variation occurring in such 'constants' should therefore always be borne in mind. A special case of interpretation of variations of recruitment time series is mentioned in Section 6.

8.2 COMPUTATION

Development of mathematic methods and the magnitude and number of the solutions required in making assessments for a wide variety of fisheries has reached the stage where attention should be paid to the improvement of computational procedures, with special reference to their speed and costs. Two approaches to this problem were considered: the preparation of tabulations of standard functions, and the use of analogue and high-speed digital computers both for processing crude data and for computing assessments. Progress has been made in formulating a steady state constant parameter yield equation in terms of the incomplete Beta-function, which has been tabulated. With regard to other tabulations, it should be noted that as they may be used by research workers less familiar with the theory on which they are based than the persons who prepared them, great care should be taken to see that the number of significant digits to which the tables are prepared is adequate to avoid introduction of computional errors. Further, as the time required for interpolation in these tables may reduce the advantage gained by using them, they should be prepared in such detail that a minimum of interpolation is required.

High speed computers are now being used or constructed for performing calculations in fish population studies. Further examination of the potentialities of their use in this field is necessary, but it will certainly not be possible at present for each laboratory nor even each country to carry out the necessary research work, nor would it be desirable at this stage. Contact with general data processing centres such as the International Computation Centre in Rome, would be desirable for fisheries scientists working with electronic computers, but it is important that fisheries scientists should themselves continue to study the use of these machines and that this should be done at centres of fisheries research.

There are two general fields for the application of computers in fisheries research:

(a) DATA PROCESSING. This refers particularly to the processing of commercial statistics and research vessel data, by extracting the information and assembling it in a form which can be used for population assessment (e.g., weighting catch and effort statistics; back calculating fish lengths and weights from scale data; converting length frequencies based on measurements of the total length to the cm. below to length frequencies based on fork length to the nearest cm.).

(b) YIELD ASSESSMENTS, under the more complex conditions of varying parameters, especially for further treatment of density dependence and the evaluation of non-steady-state models.

Fishery workers are at present concerned with the development of computers in fisheries work and these are widely scattered throughout

* The 'virtual population' method has since been examined in detail and the results published (see Y.M.M. Bishop, *J. Fish. Res. Bd Can.*, 16:73-90, 1959, and J. E. Paloheimo, *J. Fish. Res. Bd Can.*, 15:1371-1381, 1958). Abstracts of these papers are given in Appendix 4 of this report, p. 45.

the world. It would be valuable, therefore, if FAO could assist in maintaining contact between these workers and prepare and distribute abstracts of papers in this higly specialized field, that are relevant to fishery work. At a later stage, when more experience has been gained in the construction and use of computers, a seminar of the interested workers should be considered*.

A joint meeting of the Canadian and U.S. fishery biologists working in the ICNAF area should take the opportunity to discuss the development of the use of computers in fisheries research and invitations should be sent to appropriate persons outside that group to attend the meeting.

Liaison

Recent rapid advances in fishery science, especially in the analysis of effects of fishing on stock abundance and yield, and in their applications to management of the commercial marine fisheries, have given rise to urgent problems with respect to the training of scientists in techniques of fishery analysis, the relating of this field to other pertinent fields of knowledge, and the promulgation of the results of investigations, both among research workers and among other interested persons.

Consideration of some aspects of these problems led to the following recommendations:

9.1 TRAINING

Realizing the great importance of the developing techniques of stock analysis and yield assessment to the rational utilization of fishery resources, and the limited number of people qualified in this field, laboratories with specialists in population dynamics are urged to make them available for conducting suitable training courses. Such training courses could be either international at some appropriate centre, or conducted by visits of specialists to laboratories requesting such training. Publication of a text book based on the 1957 Lowestoft training course would encourage more widespread training at fisheries laboratories and universities**.

9.2 COLLABORATION

Progress in investigations of rational exploitation of fishery resources, which have advanced rapidly in recent years, has been due in large measure to close co-operation between fisheries biologists and mathematicians in evaluating fish stocks and assessing yields.

It is recognized that further advances in the analysis of the effects of human activities upon fish stocks, and vice versa, will be speeded up through similar collaboration with scientists having specialized knowledge of disciplines such as technology and economics. It is therefore urged that fisheries biologists should make opportunities to discuss relevant problems with such scientists.

9.3 DISSEMINATION OF INFORMATION

The rapidly growing output of contributions to the study of the dynamics of aquatic resources is leading to their publication in a very wide range of journals and reports. In addition, contributions from specialists outside the immediate field of fishery research often appear in publications not normally included in the libraries of fisheries laboratories. Consequently, it is becoming increasingly difficult for workers in this field to keep in touch with progress of the subject and to derive the understanding which can come only from comparative studies.

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* References are being included in FAO's "Current Bibliography for Aquatic Sciences and Fisheries". The proposed International Journal of Fishery Dynamics would be the appropriate vehicle for more detailed reports. Meanwhile, current information about computers and their use in biological research is usefully being given in the journal "Behavioural Science" (see note on editorial policy with regard to abstracts, news and review papers in 4(2):162-72, 1959).

** Such a course was conducted in connection with the International Training Centre on the Methodology and Techniques of Research on Mackerel (*Rastrelliger*) conducted in Bangkok, Thailand, October-November 1958; see Report of the Centre by the Associate Director, S.J. Holt (*Rep. F.A.O. / E.T.A.P.*, (1095), Rome 1959). The lecture and practical material used at this and other such courses will be incorporated in a Manual of Methods for Fish Stock Assessment, to be published by FAO.

There is therefore a need for a serial publication having, essentially, a world-wide coverage to meet these requirements. The scope of such a publication would include:

(a) Contributions on any aspect of fishery dynamics (marine and freshwater) which are of some general interest, with special reference to methods and techniques of analysis and assessment and examples of their application.

(b) Contributions from specialists outside the immediate field of fishery research, including mathematicians, statisticians, technologists and economists, which have a relevance to fishery dynamics.

(c) Critical reviews and correspondence, which can play a valuable role in encouraging the growth of a relatively new discipline.

It is recommended that FAO, with the assistance of a panel of experts to be nominated at this meeting, should find what support this project would receive throughout the world and what form the publication could best take. In the event of support being forthcoming, ways and means of establishing such a publication should then be found*.

FAO is urged to continue its efforts in preparing a comprehensive annotated bibliography for fisheries science**.

Considering the progress which has been made with respect to the recommendations contained in ICNAF Special Publication No. 1, 1958, it is recommended that FAO be asked to prepare and distribute a report of this progress and of the conclusions reached at the present meeting. This report should be a non-technical account for publication in trade journals***.

Further, wherever the opportunity arises FAO is asked to assist countries in preparing special versions of this account, having regard to local requirements.

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* The experts nominated were: Dr. M.B. Schaefer (North and South America), Dr. G.L. Kesteven (Indo-Pacific and Mediterranean regions, in collaboration with Mr. J.A. Tubb and Mr. M. Girard), Mr. R.J.H. Beverton (Africa) and Dr. C.E. Lucas (Europe). A summary of the results of their enquiries showed a favourable response; after consideration by the Steering Committee, it was decided that FAO would undertake to find ways and means of establishing such a journal. As this goes to press, arrangements are nearly completed.

** Issued monthly during 1958 as "Current Bibliography for Fisheries Science"; title changed as from January 1959 to "Current Bibliography for Aquatic Sciences and Fisheries"; distributed in printed version as from January 1960.

*** Action on this recommendation has included distribution of a News Letter on the subject in the Indo-Pacific region, preparation of a Summary Report of this meeting and of various notes, and is continuing.

REPORT ON SELECTIVITY OF FISHING GEAR

Convenor: J. R. Clark

1. Introduction

For many years biologists have studied the relations between the physical properties of fishing gear and the composition of catches. Their purpose has been first to verify, with scientific evidence, an existing common observation that gear is selective; next to measure the degree of selection that its various components exert; then to determine which of its structural properties could be modified to select from the stock advantageously, and finally to devise appropriate modifications. Most of these studies have been concerned with the factors that affect sizes of fish caught, since optimum yields for fisheries are most often defined in terms of the appropriate sizes at which a stock should be harvested. Such a slight modification as adjustment of mesh size, for example, may be sufficient to produce a substantial increase in the long-term yield of a fish stock.

The philosophy of research in gear selection has evolved from a qualitative to a quantitative basis. The emphasis has changed from such questions as "How can the destruction of small fish be prevented?" to "Precisely what proportions of fish of various sizes available to the gear are captured under various conditions?" This evolution has been stimulated by the advances and the consequent demands of theoretical population dynamics analysis. It has become apparent from this growing need for precision and detail that much of the earlier work was inadequate in these respects and had to be repeated. Furthermore, much data collected by different people under various circumstances by different methods led to conflicting conclusions and were not comparable.

The purpose of this meeting was to bring together experts in gear selectivity research, to review and evaluate the results of previous work, and identify problems that remain to be solved. The discussions were organized into several working groups, each concentrating on a particular aspect of gear selectivity. Although valuable contributions came from all over the world, most of the participants represented countries belonging to ICNAF or ICES or both, and consequently the discussions centered around North Atlantic problems, primarily those involving the otter trawl which is by far the most important gear used in that area.

The selection with which the meeting was mainly concerned is that which results from direct interaction of the gear and the fish entering or contacting it. In most fisheries, however, the composition of the catch is also affected by many factors extrinsic to the gear itself. The extrinsic factors are not so well understood as the intrinsic ones, because they are much more difficult to measure.

2. Selection extrinsic to the gear

The main extrinsic cause of selection is variation in distribution of fish of different sizes, coupled with the fact that fishermen rarely distribute their activities such as to permit capture of all sizes of fish, in proportion to their abundance. This is especially true in pelagic fisheries for migratory species whose behaviour patterns change with age and which tend strongly to school by size.

Some of these selective influences may remain rather constant while others may be expected to fluctuate markedly in space and time.

Patterns of distribution and behaviour of fish, as well as of the fleets, change seasonally; and these changes vary from year to year. In mixed gear fisheries the nature and magnitude of selective influences vary with changes in composition of the fleet. They may also differ markedly as between species, whose habits, reactions, size distributions and vulnerabilities differ.

A major objective of gear selectivity research should be the analysis of factors causing variation in the degree of vulnerability of different size groups to various types of gear. For this, detailed information on spatial distribution of sizes is required for the stocks subject to major fisheries.

The following methods of investigation are indicated:

(1) Observations of the behaviour of different sizes of fish in the vicinity of the gear during fishing operations. These can be made by using underwater television, photography and free divers.

(2) Comparative fishing experiments to measure size selectivity by features of the gear other than mesh size. These experiments should be conducted with different rigs of one kind of gear and with different kinds of gear.

3. Selectivity of different kinds of fishing gear*

Some amount of selection is inherent to the gear used in any fishing operation. Its nature will, of course, vary for different species as well as for groups or individuals of the same species possessing different attributes. At the present level of our knowledge we are able to consider the selective action of hooks, gill nets, and otter trawls. Our knowledge about otter trawls far exceeds that for the other types of gear.

3.1 HOOK SELECTION

A very limited amount of experimental evidence available on selection of fish by hooks shows that differences in the sizes of hooks and baits can affect, in a systematic manner, the size of fish caught. Larger hooks and larger baits catch fewer small fish than smaller hooks and smaller baits. While present data do not permit a clear-cut separation of the independent effects of hook size and bait size, they do suggest that hook size may be the more important factor. The size of fish taken may also be influenced by the type of bait used.

Considerable further research must be conducted to answer even the most basic questions concerning hook selection. At present there is little experience to draw upon in devising methods of research, although rigging the gear with alternate hooks of various size along the line seems a promising approach. It is suggested that the following factors be taken into consideration in carrying out hook selection research:

(1) Differences in the attraction of baits.

(2) Length of time that baits stay on hook.

(3) Length distribution of fish in relation to the anticipated selection range of the gear (i.e., sizes below, within, and above the selection range should be represented).

(4) Seasonal and diurnal variations in patterns of behaviour (e.g. many species do not eat, or eat less during spawning).

(5) Availability of natural food.

(6) Relation between density of fish, spacing of hooks and competition for the hooks.

(7) Incidental catch of secondary species.

(8) Distances between hooks on line.

(9) Changes in hook shape with use.

(10) Probable loss of larger fish by breaking of lines or hooks.

(11) Differences in characteristics of stocks if gear must, during comparative fishing experiments, be tested on different grounds.

It is recommended that a pilot study be conducted to compare various experimental techniques on a given ground under closely controlled conditions. From the results would evolve a methodology for the programmes to

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* A list of definitions and terminology appears on pages 7 and 8 of the Effort Report.

follow. Observations of capture and escapement processes with underwater television and in aquaria might also contribute information which would be useful in designing field programmes.

Many problems encountered in comparing and evaluating the results of various experiments arise from the lack of accurate descriptions of hooks and from the inadequacy of classification systems. All published results should include detailed descriptions of the hooks used. The development of a workable system for classification of hooks should be undertaken as soon as possible. We cannot with present knowledge determine the relative importance of the various measurable characteristics of hooks in selecting sizes of fish. The outside dimension across the back and shank of the hook as well as the length of the line normal to the shank from back to shank are important, as also is the twist of the shank.

3.2 GILL NET SELECTION

The various factors which could influence the selectivity of gill nets must be considered mainly theoretically because of the inadequacy of experimental data. The methods which have been used in studying gill net selection can be grouped as follows:

(1) Comparison of catches of gill nets with those of other gears.

(2) Comparison of catches between gill nets of different mesh sizes.

(3) Theoretical considerations based on observations of fish girth and mesh size.

Discussion of these methods and results from them indicate that future research should be carried out in relation to the following factors which seem of primary importance in the selection of fish by the meshes of gill nets:

(1) Mesh size.

(2) Elastic stretching of the net.

(3) Inelastic stretching of the net, including stretching of the knots.

(4) Hanging coefficients of the net (which govern the degree to which the meshes open).

(5) Strength and flexibility of the twine.

(6) Visibility of the twine.

(7) Shape of the fish, including compressibility of its body.

(8) Degree to which fish are meshed at parts of body other than pectoral area.

(9) Patterns of behaviour of the fish.

In addition to these considerations, the development of a standardized technique for measuring the meshes of gill nets is to be encouraged. The general principle employed for the otter trawls appears promising, i.e., the use of inner length of the elongated mesh after use and while wet. However, account must be taken of the considerable differences in extensibility among various materials presently used in gill nets.

3.3 OTTER TRAWL SELECTION

3.31 THE EFFECTIVENESS OF SPECIALLY DESIGNED GEARS

It has been well demonstrated that fish escape through otter trawls according to a relation between their size and the size of meshes of the net. However, many workers have believed that selective action could be improved and escapement increased through development of special gears. Attempts to design nets with improved escapement characteristics have resulted in such innovations as the Ridderstadt Trawl and the use of kite-shaped and square meshes. Recently, a cod-end made partially of rigid wire meshes was tried in fishing for haddock and silver hake. Another was made of strips of netting having different mesh sizes rigged in such a way as to prevent the meshes from closing as the load in the cod-end increased.

None of these innovations has given selection characteristics of sufficient superiority to justify their adoption in commercial practice. Observations with underwater television of trawls in action have demonstrated that under normal circumstances little is to be gained in selective performance by adopting special designs; they would only add to the cost and complicate the maintenance and operation of the gear.

A special gear may be necessary in some instances, as for example where a required large size mesh would greatly weaken the net. A design which gives the proper selectivity while having adequate strength would then be desirable.

3.32 EFFECTIVE ESCAPE AREA OF THE TRAWL

Although the cod-end is the smallest component of an otter trawl, it is generally considered to be the most important part for the escapement of fish. Unfortunately, there has been little experimental evidence by which to compare quantitatively the cod-end with other parts of the trawl in this respect. Data from recent studies have shown that fish do indeed escape through the forward netting, sometimes more than through the cod-end. This is owing partly to the fact that meshes in the forward netting are nearly always larger than in the cod-end. In general, fewer fish escape from the forward netting than from a cod-end which has the same mesh size.

The relative magnitude of escapement through various parts of trawls varies greatly according to their design and operation. It varies also according to differences in morphological characteristics and behaviour patterns of fish species. Variations in shoaling behaviour of fish (i.e., whether the fish swim more as a shoal in any direction relative to the netting or whether they respond as individuals) may affect experimental results.

For research to provide more information on forward escapement the following methods are suggested as the most promising:

(1) Cover experiments. These may employ either a small mesh cover or a gill net of mesh size slightly smaller than the trawl mesh.

(2) Parallel hauls.

(3) Direct underwater observation with television.

(4) Enumeration of fish meshed in various parts of the trawl.

The use of small mesh covers has been effective for measuring cod-end selection, but it is much more difficult to make covers function properly on forward parts because of the expanse and configuration of the netting. Controlled parallel tow experiments are probably better. Underwater television observation is an additional promising technique, the use of which should be strongly encouraged. Mesh size data and numbers, sizes, and positions of meshed fishes should be recorded during fishing operations wherever possible.

In view of the apparently significant effect of water flow on selectivity and fishing power and the paucity of data on this and related physical properties of nets, it is recommended that more direct investigation be made of the hydrodynamics of trawls to explain in particular how net construction (including mesh size in various parts) influences water flow and consequently the reactions of the fish, and, in turn, the catches.

Forward escapement may affect cod-end escapement for the following reasons. If some of the fish entering the cod-end had not escaped earlier because of some physiological condition (e.g., they were too weak while stronger fish of the same size did escape) then those fish would also be less likely to escape from the cod-end. If a substantial number of fish of sizes within the selection range of the cod-end had spent most of the tow in the forward parts, where they were selected, and passed into the cod-end only towards the completion of the tow, then the measured value for cod-end mesh selection would have been diminished below the value it would otherwise have had. If total catch affects cod-end selection, so they will forward selection since it affects the quantities caught. The results of cod-end mesh selection experiments as determined by parallel towing could therefore be greatly altered by variations in escapement through the forward netting.

Nor does escapement take place in equal proportions through all parts of the cod-end. Recent results indicate rather conclusively that for moderate catches, the bulk of the escapement from the cod-end occurs in its after portions. Probably more fish escape from the upper side of the cod-end than from the under side. Underwater television and SCUBA observations have provided evidence regarding the portion of the cod-end which the fish occupy during towing. It appears that the exact area of escapement varies with size of catch. When catches are large more fish escape through the forward parts of the cod-end than through the rear.

3.33 THE EFFECT OF DIFFERENCES IN FISH SHAPE AND MESH SHAPE

There is some reason to believe that the shape of the fish has much to do with its ability to escape. The most important dimensions for "roundfish" are probably the maximum girth of the fish and cross-sectional shape at that point. There are several possible measurements which can be used, such as maximum natural girth, maximum constricted girth, or the girth of some incompressible part of the body such as the head. It is not particularly important which is used provided that these different measurements bear a constant relation to one another. However, certain factors must be taken into account, such as the increased body girth which may result from full gonads, full gut, and expansion of the air bladder such as occurs when the fish are brought up from deep water.

Similar considerations apply to some flatfishes such as plaice, in which girth and breadth bear a constant relationship to one another, and consequently for some species measurements can for convenience be of breadth and conversion made to girth if desired. This is not feasible for all flatfishes, however, for some species are so flexible that probably neither girth nor breadth could be satisfactorily related to the probability of escape. This problem requires special study.

In addition to girth and breadth, the cross-sectional shape of the fish affects its ability to escape. For example, a herring and a haddock of equivalent girth will have entirely different cross-sectional shapes. This of course affects their respective abilities to pass through meshes of a given shape and size. Although this problem has been given some attention recently in connection with the use of the ratio of body depth to breadth, it needs further examination.

In all mesh experiments, certain measurements should be obtained relating to length, girth, body depth and body breadth. Special attention should be given to observing spawning condition of fish, since the body may be enlarged by developing gonads. It is recommended that a standard method of measuring girth be adopted.

The shape of the mesh is also a factor to consider in determining escapement. There are two important aspects of this:

(a) The relation of mesh shape to the girth and cross-sectional shape of the fish. The essential data relating to mesh are its size as ordinarily measured and the degree to which it is open while fishing. The latter can be defined in terms of one of the internal angles or, alternatively, the ratio of length to width of the mesh.

(b) Variation in the size or shape of meshes throughout the cod-end. It seems probable that if the meshes of a net are not adequately sampled, the error of measurement might seriously distort the selection curve.

It is recommended that during selection experiments, measurements of meshes should be distributed in such a way as to provide a representation of their sizes throughout the cod-end. It is also important to record the position of each mesh measured. Statistical measures of variation should be reported in addition to the means. Consideration should be given to determining the working shapes of meshes throughout the cod-end; this will be more difficult since the determinations must be made while the gear is in operation.

3.34 THE EFFECT OF VARIATIONS IN PATTERNS OF FISH BEHAVIOUR

Little is known about the behaviour of fish in relation to selection processes. Among the questions to be answered are the following:

(a) Do fish try to escape or are they carried passively through the meshes?

(b) If they do try to escape, how do they go about it?

(c) Do they persist in their efforts to escape?

(d) Is effort to escape related to size of fish?

(e) Do fish block the meshes gradually as they become fatigued, or are they carried directly to the end of the cod-end to block the meshes immediately?

(f) Is there a relationship between size of fish and their endurance, and hence their chance of escape?

(g) Do different species have different behaviour patterns which affect the probability of their escape?

(h) How is escapement affected by turbidity of the water and by light intensity?

(i) What part do the various sense organs of the fish play in their perception of the net and their reactions to it?

(j) If many fish enter the net simultaneously, how do they affect each other's efforts to escape?

(k) In what directions do fish swim in relation to the net, and is there some critical angle of approach beyond which escape is impossible?

At present is is possible only to speculate on these matters which are among the most important factors affecting escapement. It is therefore recommended that investigations of their influence be commenced as soon as possible. Underwater observations by free divers using cameras and by underwater television should yield valuable results. Several films have already been made; a recent one records the televising of the inside of a cod-end. Underwater observations now provide means of observing the behaviour of the trawl in action and the behaviour of the fish in the net during the process of escapement.

3.35 SUBSTANTIVE CAUSES OF VARIATION IN COD-END ESCAPEMENT

The problems associated with cod-end selection do not arise from a general inadequacy of data as is true of so many other aspects of selection, but rather from conflicting results and the sources of variation that cause them. This variation can be considered in two categories; substantive, or that associated with the conditions of ordinary fishing, and experimental, or that associated with the conditions of the experiment. The important known substantive factors are discussed below.

3.351 *Duration of tow*

Results from research bearing on this subject show that escapement increases with the duration of tow. This could be simply because the longer fish are in the net the greater is their opportunity to escape. The duration of tow in mesh selection trials should then be governed by the manner in which the results are to be used. Workers are encouraged to extend their trials over a range of tow durations but particularly to include the range corresponding with commercial practice. Complete information on tow duration should always be included in presentations of results.

3.352 *Catch size*

Size of catch is a significant variable in cod-end selection, i.e., for a given length of tow, lower escapement is associated with larger catches. This suggests that the opportunity to escape diminishes as the number of fish which are crowded into the net increases. The crowding rate is determined largely by the density of the fish on the grounds. Another possible cause of this decrease in escapement is the general decrease in mesh size from the rear of the cod-end forward, the consequence of which is that the fish are left with smaller meshes for escape as the cod-end fills. In order to obtain data pertinent to this point, the size of individual catches should always be reported in the records of mesh experiments.

3.353 *Speed of tow*

Insufficient direct observations have been made to evaluate the effect of towing speed on escapement. Valuable leads might be found by analysing the data of past experiments in which different speeds were used. In studying this problem, it will probably be necessary to define towing speed in terms other than that of the ship relative to the surface waters. Workers should extend their trials over a range of towing speeds but include particularly those corresponding with commercial practice, and should always record these rates in published results.

3.354 *Vessel size*

The effect of size of vessel on escapement has not been given special study. However, results of mesh selection experiments in general indicate that this is probably not in itself significant.

3.355 *Net material*

A considerable amount of data concerning nets of different materials is available from which certain obvious conclusions may be drawn. For example, nets made of cotton and artificial fibres have in a number of experiments given consistently higher selection factors than nets made of manila and sisal. Although the causes of such effects cannot be definitely stated, it appears likely that the following qualities of materials and nets may be involved:

(a) Runnage.

(b) Strength of twine (preferably measured wet and knotted).

(c) Elongation properties or extensibility.

(d) Smoothness.

(e) Flexibility.

(f) Chemical treatment of material for preservation.

(g) Method of fabricating netting (i.e., whether single or double twine).

It is recommended that all those engaged in selectivity studies should record each of these particulars in future experiments, and should re-examine existing data to determine whether any conclusions on the effects of the qualities of twine can be deduced therefrom. Meanwhile, the co-operation of the fishing gear industry and interested agencies should be sought in order to obtain reliable and comparable specifications of materials.

Certain twines shrink during continued use, while others stretch. The effect of these changes upon the selectivity of trawls and seines may be exceedingly important. The recommendation proposed in *I.C.N.A.F. Spec. Publ.* (1), that existing data on shrinkage of net twines be reported, is re-emphasized.

3.356 *Light intensity*

No data bearing on the effect of light were available. Since this could be an important factor, the records of past experiments in which fishing was carried on with the same gear during day and night should be analyzed and new experiments conducted, to determine the influence of light intensity on selection.

3.357 *Relative fishing power of different mesh sizes*

The fact that fishing power is a function of mesh size must be taken into account in specifying an appropriate mesh size for a particular regulated fishery and in all research to test the effects of the regulation.

The weight of available evidence indicates that large meshed cod-ends take more fish at the upper end of the selection range, and beyond, than do smaller meshed nets. This may not however be a universal rule; the converse has been shown for one species of sole.

Further work is recommended to elucidate these problems. A careful study of existing information should precede and guide the development of new field experiments. Underwater observations of trawls in action should again be most useful in these experiments.

3.36 EXPERIMENTAL VARIATION IN COD-END SELECTIVITY RESULTS

3.36. *Use of covers*

The simplest and most direct method of measuring the selectivity of cod-ends is by use of a covering mesh of fine netting to retain the escaping fish. However, this method has often been criticized because the cover may interfere with escapement and result in under-estimation of it. This can be obviated by proper design and attachment of the cover. There should be sufficient slack in the cover to allow it to rise up free of the cod-end.

It is necessary to ensure that the entire upper side of the cod-end is covered. The underside is not so important for roundfishes, which escape for the most part through the upper side. Insufficient data are available to evaluate this effect in the flatfishes.

The meshes near the latchets are often excluded from the cover to facilitate handling of the gear. It is advisable to cover these meshes with additional netting to prevent fish from escaping through them. To minimize possible masking effects, covers should be made of meshes no smaller than is necessary for their purpose.

It is recommended that underwater television observations of covers and topside chafing gear be undertaken as soon as possible to provide more definitive answers to problems involving the effect of covers.

3.362 *Replicate tows*

The results of experiments with replicate tows have often differed from those with covered cod-ends in yielding considerably higher estimates of escapement than the latter. These differences may indicate errors, which could be due to adjustment of replicate tow data, or to the masking effect of covers, or, in covered cod-end experiments, to the return into the cod-end of fish that had previously gone through into the cover. Since none of these factors appear to be important enough to account for the differences which often occur, we must search for other, as yet undetermined, factors arising from use of the replicate tow method.

Some leads may be obtained from examination of the selection curves resulting from two replicate experiments. The replicate tow method does not measure escapement directly but rather compares catches of nets having different mesh sizes. The nature of the method is such that many additional sources of variation are admitted. One problem is that selection curves rise above the theoretical 100 per cent point for length categories where catches of the larger mesh exceed those of the smaller mesh. Types of selection curves have been found in which:

(a) The curve levels off and remains at 100 per cent. retention, as would be obtained by using covers.

(b) The curve levels off, and remains, above the 100 per cent. retention level.

(c) The curve rises smoothly through the selection range and continues to rise above the 100 per cent. retention level, reaching a peak a few centimeters therefrom and then descending to level off and remain at or somewhat below the 100 per cent. retention level.

At present there is no explanation of these peculiarities. The effect described under (b) might occur if larger meshes were more efficient than smaller ones in taking fish either above the selection range only or throughout the entire range of size. The effect described under (c) might result if larger meshes caused the trawl to be more efficient for small fish (which mainly pass through the meshes) than for large ones. This seems reasonable because the ability of fish to avoid the net either by dodging around it or by staying ahead of it probably increases with their size.

It is reasonable to assume that if a difference in efficiency holds for sizes above the selection range it also holds for sizes within the selection range. Following this assumption, the accuracy of selection figures might be improved by adjusting the catches within the selection range of the larger mesh nets by the ratio of catches of small to large meshed nets beyond the selection range. However, care should be taken in applying such adjustments, especially if the selection curve is of the type described under (c) above.

The various shapes of selection curves about the 100 per cent. point which have been observed suggest that trawls may not representatively sample all lengths within the population. Attention should be given to this in the development of improved sampling gear. Since the efficiency of sampling will probably vary with differences in essential characteristics of the gear, comparisons of data collected with different gear may give misleading results. The use of a standard trawl for research purposes would be helpful in facilitating comparison of various collections of data. The advantage of this must of course be balanced against the fact that such a standard trawl will probably not be the most efficient for every purpose.

4. Mesh measurement and gear specification

Properly to apply the results of selectivity studies a standard classification and specification of gear must be established. A particularly pressing need is for an adequate method of defining mesh size. This was brought out at the Biarritz meeting (see *I.C.N.A.F. Spec. Publ.* (1)) and again emphasized here.

4.1 MEASURING METHODS

Most workers have found the "internal longitudinal stretched mesh dimension" most satisfactory. It should therefore be used both in experimental work and in enforcement of mesh regulations. At the same time the possibility that a better dimension than this could be developed should not be overlooked. Such a mesh dimension might be one which would inherently correct differences in selectivity, e.g., as between materials.

The amount of pressure applied to meshes while measuring them varies from worker to worker. Pressures of 3 to 4 kg. are adequate for most purposes with the longitudinal method. A decision as to the exact amount which is most appropriate cannot be reached without special studies of change in mesh size with increasing pressure. Such studies should be carried out with materials commonly used.

4.2 THE GAUGE PROBLEM

The same method of measurement is desirable for both experimental work and enforcement. The practical problems involved are, however, quite formidable. Generally, the gauges used for research purposes are designed and built to give maximum precision in measurement, and therefore are expensive. Such gauges may not be practicable for enforcement purposes. If a different gauge is used for enforcement, it should be as accurate as is necessary to fulfil the requirements of the law.

The adoption of a standard technique for measuring meshes throughout the North Atlantic is desirable; to this end a standard gauge should be developed. Since this may not be feasible at present, computation of factors for converting to a common basis the measurements obtained by those presently in use could be the first step towards standardization. This should be done for the "longitudinal pressure" gauge, which is now most commonly used, and of which there are several types, and also for the "vertical pressure" wedge gauge, which is also rather widely used. The work of developing these conversion factors should be divided among workers in ICNAF and ICES countries. The following points should be borne in mind in conducting research on gauge standardization:

(a) Factors developed should convert to a common standard rather than from one gauge to another.

(b) Tests should be made on all the netting materials in common use.

(c) Sufficiently large samples of measurements should be taken with each gauge to provide statistical tests of variation.

(d) A survey of opinion on the relative convenience of operating the various gauges is desirable.

Gauges and materials to be tested should be exchanged among laboratories conducting the research. This would facilitate the development and acceptance of a standard research gauge.

The evidence that fish escape from many different areas of the trawl indicates the necessity of routinely measuring meshes in parts other than the cod-end during selectivity experiments. Standard procedures for prescribing mesh sizes throughout the trawl should be developed.

5. Problems of presentation and accessibility of data

Evaluation of the results of gear selectivity studies have too frequently been impeded by lack of information on experimental conditions. Failure to collect or record such information greatly limits the usefulness of the data. Many inconsistencies among results of selection studies could have been resolved if adequate descriptions had originally been given of such matters as design of the gear, size of the individual catches, length of time the gear was operated, the type of material used in netting methods of measuring meshes, etc. The importance of recording and reporting detailed information on all such factors cannot be stressed too strongly.

Selection factors for different species and different types of net materials are often derived and used under the more or less tacit assumption that the relation between the 50 per cent point and mesh size is linear. Recently completed experiments with a species of *Merluccius* and a sole, however, have shown a curvilinear relation of these two factors. The selection factor is then not constant but increased flexibility of larger meshes or possibly through increased vigour or differences in behaviour of larger fish. It is recommended that existing data be studied and tested for validity of the assumption of linearity.

Finally it is recommended that all data bearing on selectivity compiled at one centre should be disseminated, on request, to scientists requiring them for special studies. The advantages of such a centre are obvious. Much data would be recovered for further study and integration that now remain in the files of various laboratories or of individual workers. At present, such data are rarely fully evaluated and they are then needlessly duplicated by new field programmes. If a centre were designated as a repository, it would be necessary to have data submitted in a standard form. This in itself would remind workers of the kind of information required and encourage them to improve the comprehensiveness of their observations. The design and operation of a data centre, including the details of standard forms and estimates of cost, should be planned by a panel of experts from ICNAF and ICES countries with the assistance of FAO.

List of participants

Akyuz, Mr. Erdogan	Et va Balik Kurumu, Turkey
Ancellin, Monsieur P.	Institut Scientifique et Technique des Pêches Maritimes, Boulogne-sur-Mer, France
Beverton, Mr. R.J.H.	Fisheries Laboratory, Lowestoft, England
Boerema, Dr. Luit K.	Rijksinstituut voor Visserij Onderzoek, Ijmuiden, Netherlands
Cieglewicz, Dr. W.	Morski Instytut Rybacki, Gdynia, Poland
Clark, Mr. John R.	U.S. Fish and Wildlife Service, Woods Hole, Massachusetts, U.S.A.
Dementieva, Dr. T.	Institute of Fisheries and Oceanography of the U.S.S.R., Moscow
Fleming, Dr. A.M.	Fisheries Research Station, St. Johns, Canada
Gilis, Professor C.	Institut d'Etudes Maritimes, Ostend, Belgium
Graham, Dr. Herbert W.	U.S. Fish and Wildlife Service, Woods Hole, Massachusetts, U.S.A.
Gulland, Mr. John	Fisheries Laboratory, Lowestoft, England
Hansen, Dr. Paul M.	Gronlands Fiskeriundersogelser, Charlottenlund, Denmark
Hempel, Dr. G.	Biologische Anstalt Helgoland, Hamburg, Germany
Herrington, Dr. W.C.	State Department, Washington 25, D.C., U.S.A.
Holt, Mr. S. J.	Food and Agriculture Organization of the U.N., Rome, Italy
Jones, Mr. Rodney	Scottish Home Department Marine Laboratory, Aberdeen, Scotland
Jónsson, Mr. Jón	University Research Institute, Reykjavik, Iceland
Keir, Mr. Ronald.	International Commission for the Northwest Atlantic Fisheries, Halifax, Canada
Kesteven, Dr. G. L.	Food and Agriculture Organization of the U.N., Rome, Italy
Kristjonsson, Mr. H.	Food and Agriculture Organization of the U.N., Rome, Italy
Le Cren, Mr. E. D.	Freshwater Biological Association, Ambleside, Westmorland, England
Lucas, Dr. C. E.	Scottish Home Department Marine Laboratory, Aberdeen, Scotland

Lundbeck, Professor J.	Institut für Seefischerei, Hamburg, Germany
McCracken, Mr. F. D.	Atlantic Biological Station, St. Andrews, Canada
Margetts, Mr. A. R.	Fisheries Laboratory, Lowestoft, England
Martin, Dr. W.R.	Atlantic Biological Station, St. Andrews, Canada
Medico, Dr. E.	U.S. Fish and Wildlife Service, Woods Hole, Massachusetts, U.S.A.
Paloheimo, Dr. Jyri	Atlantic Biological Station, St. Andrews, Canada
Parrish, Mr. B. B.	Scottish Home Department Marine Laboratory, Aberdeen, Scotland
Pope, Mr. J. A.	Scottish Home Department Marine Laboratory, Aberdeen, Scotland
Poulsen, Dr. Erik M.	International Commission for the Northwest Atlantic Fisheries, Halifax, Canada
Rodriguez, Dr. O. Martin	Direccion General Pesca Maritima, Madrid, Spain
Rollefsen, Mr. Gunnar	Institute of Marine Research, Bergen, Norway
Ruiv, Mr. Mario	Instituto de Biologia Maritima, Lisbon, Portugal
Saetersdal, Dr. G.	Institute of Marine Research, Bergen, Norway
Sahrhage, Dr. D.	Institut für Seefischerei, Hamburg, Germany
Schaefer, Dr. M. B.	Inter-American Tropical Tuna Commission, La Jolla, California, U.S.A.
Sörensen, Mr. S.	Havsfiskelaboratoriet, Lysekil, Sweden
Taning, Dr. A. Vedel	Danmarks Fiskeri-og Havundersogelser, Copenhagen
Taylor, Mr. Clyde C.	U.S. Fish and Wildlife Service, Woods Hole, Massachusetts, U.S.A.
Templeman, Dr. W.	Newfoundland Fisheries Research Station, St. John's, Newfoundland, Canada
Travin, Dr. V.	Polar Institute of Marine Fisheries and Oceanography, Murmansk, U.S.S.R.
Treschev, Dr. A.	Institute of Fisheries and Oceanography of the U.S.S.R., Moscow, U.S.S.R.
Von Brandt, Prof. A.	Institut für Netz und Materialforschung der Bundesforschungsanstalt für Fischerei, Hamburg, Germany
Walford, Dr. Lionel A.	U.S. Fish and Wildlife Service, Washington 25, D.C.
Zebroski, Mr. Z	Morski Instytut Rybacki, Gdynia, Poland

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S.30	Clark, John R.	Stimulus-response in mesh selection

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Terminology and Notation for Fishery Dynamics

A. *Notation agreed by ICNAF and Japanese workers*

Total numbers of fish in the exploitable phase of the stock	N
Total weight of fish in the exploitable phase of the stock	P
Number of fish in the catch	C
Weight of fish in the catch	Y
Number of recruits entering the exploitable phase of the stock	R
Annual fraction surviving (survival rate)	S
Length	l
Weight	w
Time	t

B. *Notation recommended at Biarritz, and again recommended at this meeting, but for which alternative Greek letters have been suggested by the Japanese Committee*

Instantaneous total mortality coefficient	Z
Instantaneous fishing mortality coefficient	F
Instantaneous natural mortality coefficient	M
The ratio of fishing mortality to fishing intensity	$q\ (=F/X)$

C. *Other*

Fishing intensity:	
Biarritz recommendation	f
Japanese recommendation	X
Suggested at this meeting (if f is to continue to be used by Japanese workers for a mortality rate)	X

D. *Notation as eventually agreed and published in J. Cons. int. Expl. Mer* 24:239-242, 1959

English definition	*English term*	
Total number of fish in stock	Stock number	N
Total weight of fish in stock	Stock biomass	P
Total number of fish in catch	Catch in number	C
Total weight of fish in catch	Catch in weight	Y
Instantaneous total mortality coefficient $= -dN/Ndt = F + M$	Total mortality coefficient	Z

Instantaneous coefficient of mortality caused by fishing	Fishing mortality coefficient	F
Instantaneous coefficient of mortality by (natural) causes other than fishing	Natural mortality coefficient	M
Number of fish entering the exploitable phase of a stock in a given period	Number of recruits (Annual) recruitment	R
Length of a fish	Fish length	l
Weight of a fish w (stock) $= P/N$ w (catch) $= Y/C$	Fish weight	w
Time, either absolute or in terms of life-span of fish, thus:		
Age at which fish are recruited to fishable stock and	Age at recruitment	t_r
Age at which fish are first liable to capture by the fishing gear in use	Age at first capture	t_c
Length of fish at age t_c	Length (size) at first capture	l_c
Weight of fish at age t_c	Weight at first capture	w_c
Length of fish at age t_r	Length at recruitment	l_r
Weight of fish at age t_r	Weight at recruitment	w_r
Fishing effort. This symbol should be used only if no ambiguity will arise with statistical notation in this context; otherwise the following notation is to be preferred, and used in any case when distinction is to be made between uncorrected fishing effort statistics, as recorded, and the ***effective overall fishing intensity*** computed from them.	Fishing effort	X
Fishing effort as recorded	Uncorrected fishing effort	g
Weighted mean fishing effort per unit area, expressed in standard units and calculated with weighting factors equal to the density of fish in each area	Effective overall fishing intensity	f
$exp(-Z)$	Fraction surviving (Mean) survival rate	S
$1-S$	Mortality rate	—
$(1-S)F/Z$	Exploitation rate or Unconditional Fishing mortality rate or	E
$(1-S)F/Z$	Expectation of death by capture	
$(1-S)M/Z$	Unconditional natural mortality rate or Expectation of death by natural causes	D
F/f	Catchability coefficient	q
Y/f, C/f, Y/g., C/g	Catch per unit effort	—
		Suggested suffixes:
Year-class		i or x
Age-group		j or n

"A METHOD OF ESTIMATING NATURAL AND FISHING MORTALITIES"*

BY

J.E. PALOHEIMO

Abstract **

A method of estimating instantaneous fishing and natural mortality rates has been developed by using estimated year-class sizes, based on statistics on catches at age and effort, in place of F.E.J. Fry's "virtual population" sizes

It involves calculating for each year-class the weighted sum of catches from all age-groups from a given age on. The weighting factor, usually a different one each year, is the inverse of the fraction of the total mortality caused by fishing. If the statistics cover the life-span of a year class, this sum is an estimate of the year-class size at the start of the given age, otherwise a correction factor must be applied.

The weighting and correction factors depend on the unknown fishing and natural mortality rates. Since, however, the data on the year-class sizes at successive ages determine, providing large enough variations in effort, the fishing and natural mortality rates, this set of circumstances can be used to arrive by iteration at their best values.

"ERRORS IN ESTIMATES OF MORTALITY OBTAINED FROM VIRTUAL POPULATIONS" ***

BY

YVONNE M.M. BISHOP

Abstract

The bias in each estimate of the mortality coefficient, M, derived from the ratio of successive virtual populations is defined algebraically and shown to be unchanged whether one or more year classes are considered, the mortality coefficients being assumed constant for all exploitable fish. Limiting and probable values of this bias are shown graphically for fishing mortality, F_r, ranging from 0 to - 2.0 in the year, r, for which the estimate is obtained; these values are drawn for constant M of - 0.2 and - 0.4, and for both increasing and decreasing fishing effort. Bias in individual estimates is greatest when there are large fluctuations in fishing effort, particularly when fishing mortality is low relative to natural mortality; the bias increases with increased natural mortality. It is concluded that linear regression of a series of virtual population ratios would, in general, give an intercept value that was an underestimate of M, and a slope that was an overestimate of c, the coefficient of fishing mortality, but during a gradual decline in fishing effort the errors in both mortality rates would be in the opposite direction

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* *J. Fish. Res. Bd Can.*, 15:749-58, 1958.
** This abstract is different from that of the original paper.
*** *J. Fish. Res. Bd Can.*, 16(1):73-90, 1959.