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Some of the Unknowns in Research Information Necessary for Calculations of Maximum Sustained Yields of Commercial Fishes in the ICNAF Area

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Introduction

It was originally intended that this paper should form part of the review by Templeman and Gulland of possible conservation actions for the ICNAF area. It was, however, considered wiser to submit the research section as a separate document.

Over the past decade fishing effort in the ICNAF area has increased greatly. The effects of this increased effort have been evident in declining standing stocks, especially of larger fish, and in decreases in catch per unit effort. The maximum effects of these increases in effort on the established fisheries for the major groundfish species have been reduced by the application of much of the increased effort to underfished stocks of redfish, cod, herring and silver hake.

Considerable additional increases in fishing effort in the ICNAF area are envisaged by many ICNAF and other countries and no unfished or very much underfished stocks of the major groundfish species are available. It thus appears likely, unless some additional regulatory action is taken and fishing effort controlled, that fishing may in due course, from the application of much too great an effort to limited and declining stocks of fish of commercial size, become unprofitable for many if not all the ICNAF countries.

Up to the present time, ICNAF has used only a few simple mesh specifications for fisheries regulation. At such a time as this, when the imposition of new regulations is likely to be considered and studied, it is as well for biologists to consider seriously how far the knowledge, theory, research vessels, equipment and staff at their command will enable them to give the necessary advice to their national fisheries administrators and to ICNAF and with what reservations this advice must be given. It is also as well for the Commission and fisheries administrators generally to realize the limitations under which the biologists operate and the amount of what President Franklin D. Roosevelt used to call "weasel words" (if, but, may possibly, etc.) which must be used in hedging when they give advice.

It seems certain that few fisheries biologists writing about these matters would speak with the same voice. They would have different opinions and different degrees of frankness and emphasis, and would give different advice depending on whether they were optimists or pessimists and on their backgrounds and interests in fisheries research.

A paper could be written with many literature references on each of the many subjects mentioned in the course of this presentation, but, in the interests of clarity and brevity of expression and to provoke discussion and controversy which often produce new ideas and new patterns of research, positive statements have been made, reflecting some of the experiences, thoughts, beliefs and prejudices of the author and without literature references.

In recent years an excellent body of mathematical theory has been developed for dealing with fish population. In meetings devoted to consideration of other animal populations the statement is often made by the biologists concerned with these populations that fisheries biologists are leaders in the field of population dynamics.

Fisheries biologists, associated with these studies in population dynamics of fish stocks, have developed a group of symbols constituting a special language, and it is only necessary to mention F,M,Z,E,S and Q, etc. of a fish population to begin a discussion or an argument. This special language, which, like all the many special languages in the fields of science, is absolutely necessary for the mental progress of its devotees and for the many and often complex mathematical equations, has tended to isolate many of the less mathematically-inclined fisheries biologists from the active thinking of the group working in population dynamics.

The pure fish biologists (i.e. those not knowing enough population dynamics language or theory or not having enough interest to follow the discussions and read the papers of their more mathematical colleagues) have usually followed at a distance in the disturbed wake of the fish-population theorists, assuming that such obviously intelligent and apparently confident people were likely to be right.

For most of the many fish stocks of the ICNAF area there are, however, far too few fisheries biologists and fisheries research vessels, and in some cases far too poor statistics of catch and effort. Also, the period of study has been far too short to provide adequate information on the effects of the environment on the fish stocks or on the resilience of the fish stocks when the rapidly increasing predations of man are added to those of the natural predators and the vagaries of nature. Under these circumstances the best available fish-population theory must be used and presumably has been used by filling in the available data and by making the best assumptions possible regarding missing data. There is some latitude here in the choice of models and the choice will often be a personal one. However, it should be explicitly understood that any action by fisheries administrators taken under these theories is an experiment, and that the experiment requires an adequate background of data, time and study. It should also be understood that not all the results of the experiment (and very often only a few of them) can be predicted with confidence. For example, an increase in mesh sizes will certainly reduce the relative numbers of small fish caught by trawls. In some cases where much of the smaller fish is discarded it can be predicted with some degree of confidence that the larger fish retained after the regulation will eventually be worth more than the fish retained before the regulation. It may also be predicted by the best available theory that the maximum sustainable poundage of fish caught will also increase, but as a rule there can only be very limited confidence in this third presumption. The result in any particular case remains to be proven.

Fish population workers, therefore, must at the present time usually work to a great degree in the dark. It is the purpose of this paper to point out briefly, but not necessarily to illuminate, some of these dark and dimly-lighted areas, in the hope that in the course of time more research effort can be devoted to them.

Present Research

Fisheries research in laboratories of ICNAF member countries chiefly produces the kind of useful information on catch, effort, size, age and growth, recruitment, mortality, selectivity by gear, fish distribution and relation of fish concentration to depth, temperature and food, migration and stock divisions, most of which can be used for the current ICNAF assessments of yield per recruit. These researches are reaching respectable proportions but in many cases the catch is sampled from only a very small part of the vessel units and in some cases the commercial catch is not sampled at all. In all cases the separation of mortality into natural and fishing mortality components could stand much closer definition. Reliable estimates even of total mortality are not available for many stocks. The natural mortality of the earlier years of the pre-recruit phases needs much more study even to arrive at approximations.

Stock and Recruitment

Equally important is the need for other research information necessary for estimating the real sustained yield of a population but of which little is known or in progress for ICNAF fish stocks. What egg production is necessary to keep the production of young recruits to the fishery at the maximum sustained level and to what degree are populations dependent on egg and larval recruits from other populations? At present biologists usually assume that for major populations of marine fishes the egg production is so great under the usual ranges of stock numbers that differences in the numbers of eggs produced will not greatly effect the number of recruits, i.e. at reduced stock levels there may be sufficient improvement in the survival from eggs to recruits to balance the reduced initial number of eggs. This improved survival to the recruit stage may be caused by reduction in direct competition for food between the young or by reduced adult predation. On the other hand, heavy fishing, especially on the spawning schools, must reduce very greatly the numbers and sizes of mature fish and the numbers of eggs produced. A situation such as the lack of sufficient production of recruits to the haddock fishery of the southern Grand Bank since 1955-56 makes one wonder whether, especially at the northern and southern outposts of a species, it is not dangerous to reproduction to reduce the mature population beyond a certain size or to reduce the production of eggs below a certain level. It is possible that larvae produced from some sizes and ages of parent females may have enough physical and physiological differences to provide higher survival than those produced by other sizes and ages. A wide range of sizes of females will produce different sizes of larvae, offering a better range of possibilities for survival when food size immediately after hatching is a factor. A wide range of sizes of fish sometimes extends the spawning time by as much as 2 months, as in the Labrador area where the small mature cod spawn in March and early April and the large cod in May and June, and also greatly extends the horizontal and vertical area over which spawning or larval extrusion occurs. These factors provide for the stock a great margin of safety which is decreased when the spawning stock is reduced to a few younger year-classes. Because of the great natural fluctuations in survival of young even when the spawning populations are large, this field is a very difficult one for research and precise answers cannot be expected very quickly. In any case the answers would very likely be different for each stock and situation and would vary with changing water climates.

Interspecific and Intraspecific Competition, Utilization of Food and Predator Control

A population change from a majority of one fish species to a majority of another in the same area can presumably occur in the sea as it does in lakes. A fishery specializing in the catching of large predator fishes but with no fishery or a small fishery for food fishes provides the possibility of a reversal in species abundance. On the southern Grank Bank, for example, the numbers of capelin are controlled by predation by larger fishes, especially cod, and by haddock feeding on their eggs during the capelin spawning season. The numbers of launce are also kept in control by groundfish feeding on them. The predation pressure on these food species has been greatly lifted in recent years both in the offshore and near shore areas by the great decrease in the standing stock of large groundfish, especially cod. Because there is no offshore and only a small inshore commercial fishery for capelin and none at all for launce, increases in the numbers of these species are difficult to measure, but capelin were reported to be unusually abundant on the Grand Bank in 1963 and in the inshore area of southern Labrador in 1964. A great abundance of capelin and launce is likely to produce increased food competition for and predation on very young groundfish.

Other possible effects may favour the cod but be unfavourable to the fishermen. In the inshore region an overabundance of capelin compared with cod will greatly reduce the effectiveness of all line fishing in June, July and early August. These well-fed cod may grow faster and, if not caught in the usual amounts by the inshore fishery, will be relatively more numerous offshore in winter and spring. Thus the trawl fisheries will profit.

Interspecific and intraspecific competition and interaction provide a field for research almost untouched in the ICNAF area at present and some of these studies of interspecific competition are very difficult to develop in the absence of a large fishery for the food fishes.

In fish population work it is usually assumed that, when the stock of old mature fish is reduced by the increasing fishing effort, the younger fish increase in number and by turning more of the food into muscle rather than into eggs and milt and body maintenance provide a greater surplus for the fishery. In other words what is assumed (but not known) to be a surplus of eggs and milt becomes a surplus of flesh. It is a common observation, however, that the size of food eaten by fishes increases with increase in fish size and to make good use of all the food of various sizes present requires a balanced population of fish and not one reduced to a small fraction of its size range and consequently feeding on a small size range of food. If, by the removal of the larger fish of a species, the standing stock of small fish of the species increases considerably, there will be greater competition than before for the sizes and kinds of food on which these fish depend. This may result in lower growth rates, as occurred with the large year-classes of Grand Bank haddock between 1949 and 1956. It is also probable that for cod, the dominant species over most of the ICNAF area, only a balanced population including a fair proportion of large and very large fish is likely to control the numbers of adult predators of other species and competitors for food. This field is wide open for study. However, as more and more of both predators and food fishes are used commercially the predator population will not be so much affected by the interspecific competition between predator and food fishes and the populations of these two groups should again reach a balance.

With reductions or increases in the size of fish, the different size requirements of food can presumably have considerable effect on the size constitution of the invertebrate fauna. When most of the larger invertebrates are not used for food because of the reduction in the numbers of large predators, a predominance of large invertebrates may occur, resulting in less room on the bottom for the quantities of smaller invertebrates which may serve as food for the smaller fish now on the fishing ground. The American plaice of the Grand Bank slopes, for example, at their larger sizes eat great quantities of adult sand dollars, Echinarachnius parma, which grow to a size of about 7 to 8 cm and carpet the sea bottom in sandy areas. As the numbers and sizes of large plaice are reduced by heavy fishing, it cannot be expected that the larger sand dollars can be eaten in quantity, so that in time they may cover much of the area to the probable detriment of the smaller sand dollars, which can be utilized by the smaller plaice, or to the detriment of other bottom organisms which may be utilized by cod and plaice. A similar case could be argued, based on the utilization of large crabs, such as the very numerous Chionoecetes opilio, by large cod but smaller sizes by smaller cod. Presumably, if very great numbers of the larger crabs were present, the smaller crabs might become less numerous. The diet of the wolffish will provide many such examples but these fish are not usually very numerous even in the virgin condition.

Eumetric Fishing

The eumetric yield curve shows the relation between catch and effort (fishing mortality) when the size (age) at first capture at any given level of effort is adjusted to give the maximum catch (only yield per recruit at present) for that effort.

With increasingly high fishing intensities population dynamics theory usually finds it possible to reason, using such data as growth, fishing and natural mortality and catch per recruit, that the size at first capture (i.e. the mesh size in trawl fisheries) should be gradually increased to obtain the best weight of fish from the fishery. The result under any intensity of fishing is to increase the stock of larger fish beyond that which would have occurred if the sizes at first capture had been smaller.

Apart from the gain from the growth and survival of the recruits already present, there may be several consequences which cannot be assessed before the size at first capture is actually considerably increased or decreased.

In the actual cases studied in the ICNAF area, of which the Georges Bank haddock has received the greatest attention, it is usually the case that the period of intensive background study before the change has been far too short for any close comparison of the new with the old situation. It is probable that this will be the case in most other experiments in introduction of new laws, because there is usually scientific and administrative and sometimes industry pressure for the change. None of these groups is noted for patience. They all want to see some improvement within their lifetimes. At the present time, even under favourable conditions for study, because of the many unknown or poorly known factors and the estimated small differences in long term landings under the old and the new regulations, there is small likelihood of scientific proof of the benefits to quantities landed of small changes in mesh and other fisheries regulations.

Under any given intensity of fishing, raising the size at first capture should increase the number of fertilized eggs produced, which under conditions of heavy fishing may be favourable or at least provide a safety factor. There is the possibility that these extra eggs are not needed, or even that, at certain very high levels of egg production, they may be detrimental. The results will vary greatly with the stock, the place of spawning, and the related current systems which in some cases may disperse and lose the eggs from the fishing ground and in others conserve and retain them on the ground.

For some stocks an increased abundance of larger fish will probably reduce the numbers of adult food fishes and of other competitors and predators of the smaller sizes of fish in the stock which it is desired to increase. This may result in more young surviving the larval stages and some increased survival later. Increasing the catching size may provide advantages to the stock by using a wider variety and size of food. As a probable disadvantage greater numbers of protected larger fish remain on the ground, and, if the protected sizes are large enough, the condition found in virgin fisheries may be approximated. In this situation the recruitment of large numbers of younger fish to the fishable sizes may be suppressed by competition and sometimes predation by the older fish of the same species, so that the expected number of recruits may not appear. Since, when size limits are raised, the quantities of fish in the sizes immediately below and adjacent to the recruit sizes may be considerably increased, additional competition for food may reduce the growth of these fish.

An opportunity for the study of some of the factors involved arises when any increase in mesh size occurs which produces a considerable change in the size of fish caught, when any considerable increase in fishing intensity occurs with consequent reduction in standing stock, when an unusually strong year-class appears, progressing in size from year to year, or when an area is closed to fishing for some time.

Maintenance of Customary Migration Patterns

As standing stocks and sizes of fish are reduced by increasing fishing effort and a greater proportion of the population is caught at the smaller mature and the immature sizes, the average patterns or extent of migration may change. Off Labrador, for example, the larger cod spawn a month or two later than the smaller cod and the elimination of the larger cod is almost certain to produce differences in the average pattern of after-spawning feeding migration.

The spreading of feeding fish after spawning provides the great inshore Newfoundland cod fishery in which the hungry pelagic cod follow the spawning capelin to the shore. Previous to this the cod live during winter and spring in deep water. As cod become scarcer, a greater proportion of them may be able to find food in the offshore wintering or deep water areas and may not need to move to the inshore areas for feeding. The immature part of the population may not move as far offshore in winter as the spawning fish nor migrate as freely in summer as the hungry spent fish. On the other hand the offshore deepwater spawning and the pelagic inshore capelin-feeding movements may be such inherent and instinctive parts of the cod behaviour that great differences from the present migration patterns will not be noted. It is fairly certain, however, that there will be some differences in migration patterns as the size constitution and numbers change.

Grand Bank haddock, when stocks were great, migrated in May-June across the bank from their winter-spring abode on the southwestern slopes and occupied in summer the shallow water of the Southeast Shoal. There in July and August they fed on capelin eggs and on the spawning capelin. During the past several years with stocks greatly reduced no concentrations have been found in the former shallow-water areas of abundance and they have been relatively more plentiful in summer on the slopes of the bank.

These changes, if they occur, may not affect maximum yield of the whole stock but may affect the quantities caught by different countries or different sections of the industry.

Hydrography

Far too little is known about current direction and strength over a great part of the continental shelf, especially in the bank areas. This and the related sea temperature information for the spawning months and for several months afterward are necessary if drift and survival of fish larvae and fry are to be understood.

Changing Water Climates

The whole recorded knowledge by biologists and hydrographers of the periodicities in changes in water climates and their effect on the abundance of fish stocks is of too brief duration for adequate forecasting or prediction either of the temperature cycles to be expected or of their effects on the size and constitution of fish populations.

Productivity

The productivity of the area needs much more and continuing study and the linkages between chemical productivity, plankton and bottom fauna productivity and fish productivity revealed. Otherwise natural changes in fish productivity, whether produced by changes in water climate, current directions or volume transport or by chemical changes in the sea will not be understood and reasoning about them will be incorrect.

Total Maximum Yield

It is apparent to all that a greater weight of rabbits orfield mice or lemmings could be obtained than of the foxes which feed on them and that if the maximum amount of meat is necessary it is better to eat the rabbits and the other rodents than to eat the foxes. Similarly with fishes it is apparent from available food conversion rates that for fis it is at least several times more productive of food poundage to eat the grazers on the plankton such as herring and capelin than to eat the final predators of these fishes such as the cod. It may be possible that the argument is similar for using small cod at the plankton eating or mainly pre-fish-eating stages. At the present time, however, it is usually the fish predator and bottom feeder and large fish which are desired by most nations fishing the ICNAF area and which bring the highest market prices. Consequently such arguments regarding grazers and fish predators must remain academic until more fish protein could be profitably utilized and these plankton feeders or smaller fish are desired in quantity by more nations. It will be necessary, however, to study and provide information for many fishes on food preferences, species competition for food and on utilization of various foods and their conversion into usable fish flesh.

Conclusions

We may conclude therefore that at present scientists can arrive at some approximations for ICNAF fish stocks with regard to the yield per recruit and some approximations of what kind of mesh, fish size and yearly catch would produce the maximum sustained yield per recruit under various fishing intensities. However, with the brief period of very heavy fishing pressure on most of the species and the short period and lack of variety and coverage of essential factors by research operations, it is not usually possible to know the magnitude and size composition of a population which will give the maximum sustained yield, and consequently it is not possible to set a figure, based on adequate scientific evidence, for the maximum sustained yield.

Major errors of judgement are possible if a calculation of yield per recruit is accepted as a basis for maximum sustained yield. In the Assessment Committee report for June, 1964 it is concluded, on the basis of yield per recruit, that in 1962-63 the yield of haddock from Division 3NO was probably a little below maximum. At the same time, from lack of successful year-classes since 1955-56, this fishery has declined rapidly since 1962 and will remain at a low level until good year-class survival occurs. The main unknown questions here are what conditions lead to successful survival and how large a spawning population is necessary and of what size constitution to ensure a very successful year-class when hydrographic and food conditions are favourable.

Catch per unit effort, however, is the factor which directly affects the fishing enterprise and with improved statistics this information can be made readily available. If a great or increasingly great amount of fishing effort is applied to the fish population without corresponding increases in size at first capture the total catch will eventually fall below its maximum level and, by the reduction of the number of year-classes available, become gradually more fluctuating as it comes to depend more and more on the new recruits to the fishery.

Even if the appropriate researches are greatly intensified a very long period of biological and statistical information on a fishery will usually be necessary to arrive at close approximations of maximum sustained yields. For the highly fluctuating haddock population of the southern Grand Bank it may be possible to have some reasonable opinions in another 50 years. For Georges Bank haddock, which have had a longer period of study and whose year-class fluctuations are not so great, some tentative conclusions on maximum sustained yield may be made in a shorter time.

For redfish, many ages and slow growth and heavy concentrations on a restricted slope area are involved, and the fishery developed rapidly to a high level, but usually in each newly exploited area catch per unit effort and total catch and total effort fell quickly. Over most of the area much more time and research effort and the application of fairly intensive fishing must elapse before approximations can be made of sustained yield of most redfish stocks.

Cod have usually a smaller number of year-classes in the fishery than redfish, but the number is great enough that one year-class does not usually control the major part of the fishery as it often does for haddock.

The total catch of cod in most subareas has been levelling off in recent years in spite of increasing effort. For Subarea 2 it is much too early for consideration because the great offshore fishery in this subarea developed very recently. For Subareas 1, 3 and 4, if, in spite of increasing effort, the catch continues to level off for another 10 years or more, it may then be reasonable to suppose that, unless water climate changes significantly, it should be possible to maintain a sustained catch of the sizes being taken, approximately equal to that of the level period.

Some action beyond mesh regulations will obviously be necessary to obtain the combination of approximate maximum sustained yields and adequate economic returns from the ICNAF fisheries. From a biological point of view the picture is so complex as to be in the field of experiment. It is thus desirable before great changes in regulations are made to make special and where possible co-operative efforts to fill in as much of the missing data necessary to estimate the probable effects of these changes as can be obtained in a reasonable time. Even with these additional efforts, for most ICNAF fish stocks in the near future biologists will generally be able to supply at the most only more or less reasonable opinions on real sustained yield. Consequently, it will be necessary to proceed on a somewhat pragmatic basis, using biological-mathematical-statistical calculations that appear reasonable and where necessary arguing to some degree from analogy with better known fish stocks. For each major stock it will be necessary to study the responses of the stock to the fishery, and to estimate as precisely as possible the most desirable quantities and sizes of fish in the standing stock. It will then be necessary to produce, on the basis of available knowledge, a figure for sustained yield to be aimed at, regulating on this basis, and allow time and the accumulation of new information and theory to indicate advance or retreat from the previous position. The tempo of fisheries research and of statistical recording should be increased and, where necessary, changed in direction to follow more closely the effects of the fishery and of nature on the fish population.