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Item 10: Types of scientific information required for a fishery conservation programme

and

Item 11: Types of conservation measures applicable in a conservation programme

In accordance with the advice of the group of experts convened by the Secretary-General to assist him in the preparation of this Conference, technical papers on certain items of the provisional agenda were invited from a number of authorities. The Secretary-General accordingly has the honour to communicate the following paper by Dr. Milner B. Schaefer, Director of Investigations of the Inter-American Tropical Tuna Commission, La Jolla, California, United States of America. A summary of this paper is available in English, French and Spanish as A/CONF.10/L.1 (Summary).

TYPES OF SCIENTIFIC INFORMATION REQUIRED FOR A FISHERY CONSERVATION PROGRAMME, AND TYPES OF CONSERVATION MEASURES APPLICABLE IN A CONSERVATION PROGRAMME

by

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(44p.)

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Figure 1.

PART I

TYPES OF SCIENTIFIC INFORMATION REQUIRED FOR A FISHERY CONSERVATION PROGRAMME

A. Introduction

1. The natural resources upon which mankind depends are of two kinds. In one category are the resources, such as mineral deposits and fossil fuels, of each of which there is only a fixed amount on this planet. The amounts of such resources are irreversibly diminished by exploitation. The conservation of such resources consists in using them as carefully and with as little waste as possible, so as to secure the greatest current benefits to mankind, and to save as much as possible against future needs.

2. The second category of resources are those which renew themselves. Such resources may be exploited by man without reducing their maximum usefulness in the future. To preserve such resources for the future, it is not necessary to refrain from using them, but only to use them in such a fashion that they remain capable of continuing to yield maximum benefits to man in the future. Of this category of resources, the living resources of the sea are outstanding examples.

3. Populations of fishes, and other organisms, tend to remain in balance with their environments. Over a reasonably long period of time, the losses from the population must be balanced by accessions to the population, otherwise the latter would become extinct. When, however, the percentage rate of loss is increased, by whatever means, the percentage rate of accession to the population changes, also, so that the population again comes into balance. It is the <u>resiliency</u> of a population of organisms, its ability to compensate for increased mortality, which makes it possible to survive increases in the populations of its predators. This same phenomenon is the biological basis of fisheries since, from the standpoint of the fish, a fishery is simply an increase in the predation rate. It is the compensatory reaction of the fish population to the mortality produced by fishing which makes a fishery possible, so that the population comes into balance under the environmental conditions which include this predation by man. It is theoretically possible to impose so much fishing on a population

as to drive it down below the level at which such compensatory reaction can bring it into balance again - to drive it below its threshold level for survival. I know, however, of no instance where this has been accomplished in a purely marine fishery. It appears that the threshold level is almost always well below the population level to which it is economically possible to fish. We may, I think, agree that for nearly all populations of organisms in the sea we need not be concerned with protecting them against being driven to such low levels that they can never recover. The question is, rather, from among the wide range of fishing intensities between zero and the maximum that is economically possible, to choose that which is most desirable, both as being most beneficial to mankind at present and as avoiding any diminution of the benefits which are obtainable, on a sustained basis, in the future.

4. A conservation programme consists, then, in controlling man's predation in such a fashion as to maintain man's benefit from the resources continually at the highest sustainable level.

5. It is, in general, considered desirable to maximize the total production in a form useful to man, or, in other terms, to maximize the total catch of commercial sizes of fish. This general objective must, however, be subject to modification in some degree in particular fisheries. One of the results of increased fishing intensity is the decreased average age and size of the individuals of the fish population, so that an increased total catch is accompanied by a greater share of smaller fish. Since different sizes of fish are, in some fisheries, not equally desirable in the market, a compromise must be reached between maximum total poundage and the most desirable size composition of the catch. In some fisheries, of course, it is possible to control the sizes of fish captured independently of the intensity of fishing, but in others this is not practicable, in which case changes in the quality of the catch go hand-in-hand with changes in the level of the average total catch.

6. Other economic considerations must also sometimes be taken into account. Where, as in the case of a number of the clupeoid fishes, they may be used by man in different forms (e.g. as human food, or as fish meal for animal feeds) the relative desirability of such uses needs to be considered. Further, it is not always considered desirable to maximize the sustainable total yield, regardless of

the effort expended in making the harvest. In some cases, economy of fishing effort may be of at least temporary importance, even though the total yield is thereby somewhat diminished. Indeed, it has been asserted by Gordon (1953),[1] and implied by Burkenroad (1951), Beverton (1953), and others, that it may be most desirable to maximize the net economic yield.

7. The function of scientific investigation, in relation to the problems of fishery conservation, is to provide the factual information on the basis of which man can control or modify his predation on the populations constituting the fishery resource so as to maximize the harvest, both with respect to quantity and quality, or otherwise control the harvesting to desirable ends. This involves the determination of the effects of man's predation on the abundance and composition of the populations of fish, and on the resulting quantity and quality of the catch. It also involves determining what courses of action may be taken to control the activities of the fishermen so as to produce desired changes in the fish populations and in the catch.

8. These, as will be seen, are matters of some complexity. One of the principal complicating factors is that the changes in man's predation are not the only causes of changes in the fish populations. Variations in the fish's natural environment operate simultaneously, affecting the abundance and composition of the populations, and also the ease of capture, or availability to the fishermen. One of the important and difficult tasks of the fisheries scientist is to take account of such effects arising from "natural" causes, and so reach a correct estimate of the effects of fishing alone.

9. The factors determining the standing crop and harvest of a fish population under exploitation by man, and their interrelationships, have been diagrammed on the accompanying chart, Figure 1.[2] It may be seen that we are concerned with the mutual interactions of a considerable number of factors. To manage a fishery completely it would be necessary to understand in their entirety all of these interrelationships. However, it is possible to achieve a useful measure of control with less than perfect understanding.

1/ See bibliography (page 40 ff.) for this and subsequent references.

2/ See Figure 1 at the conclusion of this document.

10. As indicated in the diagram, and as will be developed in more detail below, we may consider the understanding of a fishery and the ability to manage it at three levels. At the first level we may simply develop the relationships between the amount of fishing, the quantity and quality of the catch, the quantity and quality of the population, and the rate of natural increase of the population (which may be taken as the harvest on a continuing basis). This treats all the environmental factors as random variables, and so lacks precision. It also gives us no insight into the factors making up the natural rate of increase. This procedure is, however, often adequate to determine whether a greater average harvest may be obtained by restrictions on fishing, and so to indicate when conservation management is required.

11. At the second level, we undertake to measure separately the three components (reproduction, growth, and natural mortality) which determine the rate of natural increase, and how each of these is related to the abundance and age composition of the population. This provides an improved understanding of the fundamental nature of the fish population, and so makes possible more precise management of the fishery. The environmental factors are, again, treated as random variables, so that we are able only to regulate for average environmental conditions.

12. Finally, at the third level, we shall obtain a full understanding of the environmental factors - both physical and biological - influencing the population, and so achieve the capacity for full management of the fishery. This ideal stage is far from being realized for any of our fisheries, but is an ultimate goal of fishery science.

B. <u>The extent of separation into independent populations</u>

13. One of the important aspects of a fishery resource is the natural biological units into which it is divided. Characteristically, a species of animals is constituted of groups of lower taxonomic order, which are the basic units from the standpoint of conservation. These basic units are not always capable of clear definition, since the extent of separation into such units is not always clear in the species itself. However, these units, which we refer to here as populations, or stocks, have certain properties by which they may be characterized.

14. A population of organisms is a homogeneous group of members of the same species, which interbreed freely among themselves, and which occupy a continuous environment, and so are able freely to intermix and thus maintain their homogeneity. As a result of inbreeding, the members of the population are genetically more similar to each other than to members of other populations of the same species. Since there is this high degree of genetic similarity, and since the population lives in a continuous environment, which is often to some degree different from that of other populations, there commonly occur anatomical differences of either genotypic or phenotypic origin by means of which the members of the population may be identified.

15. These divisions of a species into populations are not always complete and clear cut. It frequently happens that there are biological barriers (regions not suitable for the existence of the members of the species) geographically separating regions of suitable environment. The members of the species within one such region are clearly independent of those of other regions. Within such a region, however, there often exist populations of the same species which are only partially independent, since, although they tend to intermix and interbreed with the other members of their own population, they do intermix and interbreed to a greater or lesser extent with members of other populations. In such a situation the populations are only semi-independent. D'Ancona (1954, Chapter 2) contains an excellent review of these matters.

16. One of the important characteristics of a population is that it tends to respond as a unit to changes in population magnitude, whether induced by natural causes or by fishing. To the extent that the population is independent of other populations, therefore, its responses to exploitation by man are independent of those of other populations.

17. It is quite obvious that knowledge of the extent of separation of a resource into independent or semi-independent populations is one of the important categories of scientific information with respect to conservation. Conservation is, essentially, applied population dynamics, and the basic unit in population dynamics is the population.

18. Conservation measures will be most efficient if applied to each population individually. This, however, is not always possible, either because of lack of

knowledge of the detailed population structure of a resource, or because it is not always feasible, in practice, to regulate each of many populations separately, particularly if they are not very discrete in their distribution in space or time. In these circumstances, an aggregation of population units may be successfully treated as a conservation management unit. An example of such a situation is offered by the North Pacific halibut (Hippoglossus stenolepis). The members of this species along the American coast to the north and west of Cape Spencer were shown by the scientists of the International Fisheries Commission to be distinct from the stocks to the south of Cape Spencer, and successful management regulations were established, based on this geographical division. Subsequently, it has been discovered that, within each region, there are sub-populations which appear on the fishing banks at different times of year, and improved harvesting of the resource has begun, based on this improved knowledge of the population structure. (Dunlop and Bell 1952).

19. In the case of the Pacific salmons of the genus Onchorynchus, which spawn in rivers and streams, the fish tend to return for spawning to the streams in which they were born, thus to each stream corresponds a population. During the period of time spent in the sea, however, several populations of the same species are present in the same sea region. The major fishery along the American coast takes place on the adults as they return toward their spawning rivers, and it has been found that in some cases different populations pass through the fishery at different times, making it possible to control the amount of fishing on separate populations.

20. For the most effective management of a resource, we need to know, in as much detail as possible, and for a number of reasons, the populations into which it is separated, and also the distribution of these populations in space and in time. We need to be able to refer the catches obtained by the fishermen to the populations from which they are taken. In attempting to elucidate, the effects of various physical and biological environmental factors on the size and quality of the populations, we need to be able to collect pertinent data on the geographical location of the populations at various stages of their lives. The important investigations of the life history and ecology of the fishes, which will be discussed subsequently, need to be related to particular populations. Finally,

in order to obtain the maximum harvest from the resource, management measures need to be applied, as far as practicable, to the separate populations, so as to maximize the harvest from each of them.

C. The geographical ranges and magnitudes of the populations constituting the resource

21. As has been pointed out above, the basic unit for conservation management is the population. A fishery for a given species may depend on several populations, which are independently affected by man's predation, and may also be independently affected by other (environmental) factors. The quantitative scientific investigation of a fishery resource, having the objective of providing the technical information upon which effective conservation may be obtained, needs, therefore, to be conducted in such fashion as to provide the information needed for the conservation of each of the populations constituting the resource.

22. We need to know, first of all, the geographical range of the resource, and the ranges of any populations into which it may be separated. Such knowledge is necessary in the first instance in order to determine the region of the sea within which it is necessary to conduct scientific investigations. This is of great practical importance in determining the requirements of ships, men, and money needed for the investigations; in determining to what extent the fisheries of more than one nation may be involved, which will have an important bearing on the arrangements for the scientific investigations; and in the detailed planning and execution of the research. This kind of knowledge becomes equally important, of course, in determining over what area of jurisdiction regulations need to be applied to control man's predation on the resource effectively in order to reap the maximum sustainable harvest. It must be understood that both the scientific investigations and the subsequent management measures need to be extended over whatever area of the sea corresponds to the range of the populations in question. Since the ranges of the populations of different species of animals supporting the commercial fisheries are not co-extensive, it will, in general, be found that the jurisdictional areas must differ for different fisheries.

23. The situation in the North Pacific with respect to halibut, salmon and albacore tuna is a fairly good illustration. The range of the halibut populations

of the American West Coast extends northward and westward from California along the coasts of the United States, British Columbia, and Alaska, out along the Aleutian Islands and into the Bering Sea. There is, apparently, no intermixing with the halibut populations on the Asiatic side in the vicinity of Hokkaido and the Kurile Islands. Investigation and management of the American halibut fishery involves, therefore, only an area of jurisdiction off the coasts of the United States, British Columbia, and Alaska. On the other hand, the several species of Pacific salmon, spawning in streams on the American continent, range far offshore from their home streams, just how far not being known at present, and presumably intermingle in the offshore feeding areas with members of populations of Asiatic origin. Even more far-ranging are the albacore tuna of the North Pacific. Recent studies indicate that some of the fish subject to capture along the United States west coast migrate completely across the ocean to Japanese waters, and are fished in mid-ocean and in the coastal waters of Japan. Competent investigation and management of this resource will, of necessity, cover the entire North Pacific Ocean.

24. It is, of course, of the utmost importance to determine the magnitudes of the populations constituting the resource, in relation to the amount being harvested, in order to determine whether or not the current rate of fishing is large or small, and thus to have a basis of judging whether any conservation action is required. Where the degree of predation by man is so low that the losses from the stock of commercial sizes due to fishing are small in relation to the losses due to natural causes, there is no need for conservation measures. Where, on the contrary, the rate of fishing is high, it becomes important to proceed further to determine whether it may have exceeded or be about to exceed the fishing intensity corresponding to the maximum sustainable yield.

25. It is important to note the distinction between the magnitude of the standing crop of commercial sizes of fish - that is, the total amount of fish of commercial sizes in the sea at any time - and the productivity of the population - that is, the amount which can be harvested on a sustainable basis. "Productivity" as used here is equivalent to the "rate of natural increase of population" on the diagram (Figure 1), and also to the term "equilibrium catch" employed in a later section (p. 27). The maximum standing crop will, on the average, exist in a virgin

population on which there is no fishing, and for which the productivity, in the sense employed here, is zero. When a fishery is first applied, the standing crop, on the average, decreases and the productivity increases. With increasing intensity of the fishery, the productivity increases for a time as the standing crop decreases. Eventually a point is reached, at some intermediate level of fishing intensity, where the productivity is maximum, after which it falls off with increasing intensity of fishing.

26. The relationship between size of standing crop and rate of natural increase, or productivity, is different for different kinds of organisms. Some species, such as the dogfish shark (Squalus suckleyi) of the North Pacific, are very long-lived and slow growing and have a low fecundity, so that the productivity is always small in relation to the size of the standing crop. The opposite extreme is exemplified by many tropical species, as, for example, the tropical anchovy (Cetengraulis mysticetus) used for tuna-bait in the Eastern Tropical Pacific, which grows very rapidly, has a high rate of reproduction, and a short life, nearly all of the members of the population being in their first and second years of life. In such species the productivity is large in relation to the size of the standing crop.

27. In considering the "magnitude" of the populations constituting the resource we are concerned both with the size of the standing crop and the productivity. As will be discussed further in a later section, the determination of the effect of fishing on the resource rests largely on the study of the relationships between intensity of fishing, population abundance (size of standing crop), and its productivity.

D. Pertinent facts respecting the life history, ecology and behaviour of the fish constituting the resource

28. The purpose of scientific investigation of a commercial fish population is to evaluate quantitatively the effects of man's exploitation on the amount and quality of the population, and of the catch, and also to provide a factual basis for effective conservation action, if such action is found to be required. Since changes in the size and composition of the population, and of the catch, are

caused not only by the amount of fishing, but also by variations in various features of the physical and biological environment, it is desirable to obtain some understanding of all of the causes of changes in the population and in the catch, and of the manner in which such changes are produced. This should enable us to arrive at estimates of the effects of exploitation on the resource, and to determine what changes in the fish populations are not due to exploitation.

29. Research on these matters requires study of a number of aspects of the biology, ecology, and behaviour of the fish constituting the resource. I have attempted in Figure 1 to construct a diagram indicating the interrelationships of factors which determine the standing crop and yield of a population under exploitation by man. To each of the several factors indicated on this diagram correspond categories of information which must be known in order to determine their interrelationships on a quantitative basis. This method of categorizing the information required may serve as a basis of more detailed discussion of the pertinent biological facts.

1. Facts respecting the composition of the population and the catch

30. The yield of a fishery at any time is dependent on (a) the magnitude and composition of the population of fish of commercial sizes (which is also called the "stock"), (b) the intensity of fishing (quantity of fishing effort employed), and (c) the availability of the fish to the fishermen (i.e. the relative share of the stock which can be captured by an average unit of fishing effort).

31. It is obviously important to obtain, on a continuing basis, measurements of the amount of fishing effort employed, the magnitude of the catch, and the magnitude (at least the relative magnitude) of the stock.

32. It has also been found by fisheries scientists that it is of very great value to determine, on a continuing basis, the size and age composition, and sometimes the sex composition, of the stock for a number of reasons, among which are:

(a) Fishing, even if not selective, affects not only the magnitude of the stock but also its size and age composition, since, by increasing the mortality rate, the longevity, and, therefore, the average age and size of the fish in the stock, are reduced.

(b) Continuing data on the age and size composition of the stock provides part of the information for inferring certain vital statistics of the population - the rates of mortality, rates of growth, and relative rate of recruitment (relative magnitude of year classes entering the stock).

(c) Evidence of fishery-independent changes in the stock due to variable success of reproduction is obtainable from the variation in year-class strength - the occurrence of the so-called "dominant" year classes.

33. The composition of the stock is usually inferred from the composition of the catch by the application of ancilliary information as to the intensity of fishing, and as to the selectivity of fishing, by size, age, and sex, which may be due to the selective action of the type of fishing gear used, the differential distribution of the fish on the fishing grounds, or other "availability" factors.

2. Facts respecting the availability of the fish to the fishermen

34. In order to infer the magnitude and composition of the stock from the success of fishing (catch per unit of fishing effort) and the composition of the catch, one must apply adjustments for variations in the "availability" of different categories of fish to the fishing effort. "Availability" is employed here, as by Marr (1951), to mean the degree (in percentage terms) to which a group of fish is accessible to the efforts of the fishery. It is well known that availability varies from time to time, place to place, and among different components of the population. Various statistical devices may be employed to discount the effects of availability in the absence of sufficient information to apply correction factors. This, however, causes a loss of precision in the results, and it is therefore of value to obtain knowledge of those facts respecting the biology and behaviour of the fish which are important in this connexion.

35. The availability of the fish is dependent to an important degree on the geographical distribution of the fish with relation to the location of the fishery. It is, therefore, important to determine the seasonal changes in distribution due to migration. Such migrations often differ for different age, size and sex categories of the population. In the case of the sardine of the American west coast for example, the larger and older fish perform extensive feeding migrations northward from the spawning centres off California, while the smaller and younger fish do not. Many species of fish perform migrations to particular areas during their spawning season, so that the sexually maturing adults are removed from the fishing area (as in the case of the Pacific sardine), or come into it (as in the

case of the North Pacific herring). Some kinds of fish do not perform any large migrations causing major shifts in the geographic distribution of the population, but they do move about to a greater or lesser degree in a "random" manner, in search of food, or for other purposes. The immature halibut of the southern fishing grounds off Canada and the United States offer one example of this sort of movement (Thompson and Herrington 1930). In such cases the extent of such "random" movements may be an important factor in availability.

36. The bathymetric distribution of the members of the population is important to those fisheries which operate at fixed depths in the sea, and this distribution is sometimes subject to variation with age, size or sex of fish, and with season of the year. The smaller sizes of yellowfin tuna (Neothunnus macropterus), for example, occur near the surface of the sea and are thus accessible to capture by surface-fishing methods, while the larger sizes occur to a lesser extent near the surface and are found at depths down to at least 80 fathoms, where an entirely different kind of gear is required to capture them. An example of seasonal variation in bathymetric distribution is offered by the cod in Greenland waters. Rasmussen (1954) reports that during July and August the cod leave the bottom and form shoals in the upper strata of the sea.

37. The capture of a number of species of fish, such as the herrings, sardines, anchovies, and mackerels, by the use of surrounding nets of various kinds depends on the aggregation of the fish into compact schools which can be surrounded by the net. Variations in the aggregation habits of the fish, i.e., the sizes of the schools and their compactness, have important effects on the degree of success of capture. Commonly, the aggregation habits change with the age and size of the fish, with the state of sexual maturity, and with seasonal changes in the physical and biological factors of the environment. It is less clear whether the amount of fish in the stock, i.e. the population density, also influences the aggregation habits.

38. The capture of many kinds of fish is accomplished by the use of baits or lures, and thus the success of capture depends importantly on the feeding habits

of the fish, which vary with age, state of sexual maturity, and with physical conditions such as temperature, etc.

39. Variations in the physical environment have been shown, in one fishery or another, to influence directly or indirectly all of the above-mentioned factors involved in making the stocks of fish more or less available to the fishermen. The investigation of the influences of changes in the physical environment on the distribution, migration, aggregation, behaviour patterns, etc., of commerical fish species is, therefore, an important aspect of the scientific investigation of fisheries, as illustrated, for example, by several papers in the symposium of the International Council for the Exploration of the Sea (I.C.E.S.) on "Fisheries Hydrography" (Lucas, et al 1952).

3. Components of the rate of natural increase of the population

40. As noted previously, the catch made from a fish population during any year depends on the size of the population and on the amount and effectiveness of the fishing effort applied. The amount of the catch which can be taken without changing the size of the population depends, however, on the amount of the natural increase of the population. If the fishery, during a year, takes only that amount of fish which represents the excess of increase due to reproduction and growth over the losses due to deaths from natural causes, the net change in the stock is zero. The excess of increase due to reproduction and growth over loss due to natural deaths, per unit of time (usually a year), we term the rate of natural increase. What we seek to do in a conservation programme is to balance the rate of catch with the rate of natural increase, averaged over a suitable period of years, and further to establish this balance at the level most beneficial to man. In general, we try to achieve that balance which will provide the maximum average catch.

41. For the most effective conservation management of a population, it is desirable to have knowledge concerning the biology and ecology of the fish pertinent to each of the three components (reproduction, growth, natural mortality) making up the rate of natural increase.

4. Facts respecting additions by reproduction (recruitment)

42. Basic information in this category includes the facts on the spawning habits of the fish. We usually wish to know the age and size at first maturity, in order to determine to what extent the fishery operates on sexually immature members of the population. The type of reproduction, particularly with reference to the protection afforded the eggs and young, is important. This ranges from ovo-vivaparous reproduction, in which the young are protected until some time after hatching, to completely pelagic spawning, where the eggs drift freely in the sea and are at the mercy of the environment and of predators from the instant of deposition. Determinations of the fecundity (number of eggs spawned by females of different sizes) and frequency of spawning (number of spawnings per female per year) are valuable in assessing the reproductive potential of the population; they are also of value in determining the absolute size of the adult population by the method of determining the total eggs spawned, from net hauls, and dividing by the mean number of eggs spawned per adult.

43. The determination of the areas of spawning and the season of spawning is of importance, both as a basis for the quantitative estimation of the adult population by the method noted above, and as a basis for studying the effects of environmental factors on the survival of eggs and larvae.

44. The importance in fisheries management of studying the early life history of marine fishes rests on the observation, made many years ago by Johan Hjort and his co-workers in Norway, that the success or failure of most broods of such species is determined very early in their life. The phenomenon of large variations in success of reproduction exhibited by many marine fishes has been demonstrated to be very often due to variations in their environment during their early life, before reaching commercial size. Elucidation of these relationships requires rather comprehensive knowledge of the biology of the fishes during their larval and juvenile stages. Pertinent aspects of the early life history include: rates of development and growth of larvae and juveniles; food and feeding habits of larvae and juveniles; behaviour, including aggregation habits and tropisms of larvae and juveniles; spatial and temporal distribution of larvae and juveniles; migrations of juveniles.

45. Important also in conservation regulations is the determination of "nursery" areas - regions of the sea inhabited by the sub-commercial sizes which may profitably be afforded protection from the predation incidental to fishing for commercial sizes of the same or other species.

46. Of special relevance to the problem of conservation management is the determination of population density effects on the amount of recruitment to the commercial stock, or, in other words, the relationship between the size of the spawning population and the number of their progeny which survive to commercial size. The importance of density-dependent mortality among the young stages of fishes, in comparison with density-independent mortality, and the form of the relationship between spawning stock and number of recruits is one of the more controversial and difficult aspects of current fishery research. Ricker (1954) has recently published an illuminating dissertation on this problem.

47. The elucidation of the relationships between the properties of the environment and the success of reproduction is an important line of study for the fish populations (such as the herrings of the North Atlantic and North Pacific) in which there are large year-to-year variations in the recruitment, little related to the size of the spawning stock. Such variations are, apparently, due to variations in the properties of the environment operating in several ways. It is believed that for a good many fishes, at least, there are critical stages in their development when the lack of some element - such as suitable food when first starting to feed - may result in very large mortality. This need not, however, be always true, or even true in general, since slight changes in mortality rates over a long period of development can produce the same result.

48. The physical environmental factors may affect the strength of year classes either through direct effects on spawning and survival or through indirect effects on the food and other means of existence. Direct effects of the physical environment will include such matters as the direct relation between temperature and salinity on the location and amount of spawning, the deaths of eggs, larvae or juveniles due to lethal temperature conditions, and their transport by currents to sea areas adverse for survival. Indirectly, the physical environment may affect the survival of young through affecting the production of suitable food, or through limiting the space containing suitable temperature or oxygen, or through other factors generally included in the term

"means of subsistence". Such effects may be even more indirect, acting through the encouragement of the development of populations of competitors or predators upon the young stages, or through the provision of conditions for the favourable growth of pathogenic organisms.

5. Facts respecting additions to the stock by growth

49. The number of fish in a population is added to only by reproduction. The weight of the stock is, however, also increased by the growth of its individual members.

50. We wish to learn how much weight is added per unit of time to the members of the stock at different ages - the age-growth relationships - because this is one piece of information important for the determination of the most profitable size at which to harvest the fish in those fisheries where the size of capture is amenable to direct control. It is also important in fisheries where such control is not possible because, even in this event, there may be a most profitable average size, which in turn is related to the intensity of fishing, which can be controlled.

51. The rate of growth of fishes is a function not only of the age of the fish but also, when there is competition for food, of the density of the population. This has been rather well demonstrated for some fresh water fishes (see for example Beckman 1941, 1948). It has also been indicated that for some, at least, of the demersal fishes of the North Sea and North Atlantic, the growth among the youngest age groups is greater at lower population densities. It is to be noted, however, that the gain in growth is not sufficient to compensate for the losses due to fishing of undersized fish of these species (Maurice, et al 1932).

52. The growth of fishes is, again, directly affected by the properties of the physical environment. It has been shown both by statistical studies and by laboratory experiments, for example, that temperature has a direct effect on the growth rate.

53. Variations in the physical environment may also affect the growth of members of a fish population through affecting the food supply. In order to investigate this for a particular species of fish it is necessary first to obtain information on what the fish eat, that is, the kinds of organisms the fish feed on and any changes in feeding habits with size and age. It is further necessary to determine

whether food is, in fact, a limiting factor on the growth of the members of the population, that is, whether there is ever any shortage of food.

54. In the event that it is shown that the supply of food does, in fact, become limiting on the growth of the population, it is of further interest to determine whether the food supply is also related to the density of the population, that is, to determine whether grazing by the fish population effectively modifies the standing crops of food organisms. The above cited examples of an inverse relationship between growth and population-density would lead one to infer that such grazing effects are sometimes of importance, but direct measurements would be desirable.

55. Where several species of fish feed on the same food, the sizes of the populations of competing species may affect the food supply, and thus the growth of the members of the fish population under study. Whether this occurs to any important degree in the sea is, perhaps, a moot question.

6. Subtracting from the population by deaths from causes other than fishing

56. The balance between additions due to reproduction and growth and losses due to "natural" deaths determine the rate of natural increase of the population.

57. We are concerned, first of all, to determine the general level of natural mortality, or its inverse, the longevity, of the commercial sizes of fish in the population because this, with similar knowledge of the reproduction and growth rates, gives a first approximation to the rate of natural increase.

58. For most kinds of animals, including fishes, the mortality rate is not constant, but changes with the age of the fish. The measurement of the age-specific mortality rates is difficult for populations of sea fishes, but where possible to measure it is of great value, because this, together with the age-specific growth rates, determines whether it is more profitable to leave fishes of a given age in the sea or to harvest them. So long as the gain by growth is greater than the loss by death, poundage will be gained by deferring their capture, but beyond this age, poundage will be gained by harvesting them.

59. Variations in the mortality of adult sea fishes related to environmental factors are probably, in general, of less importance than those which occur during the early stages of life when the young fish are more at the mercy of their environments. Such effects may, however, be important in some instances.

It appears, for example, in the case of the California sardine, that there are rather significant differences in the natural mortality rates of adults in different years. The properties of the environment can, presumably, cause mortality of adults either directly or indirectly, as indicated in our diagram. Little data on these matters are available for the sea fishes.

7. Discounting of environmental effects

60. It has been indicated in the foregoing that changes in the properties of the environment can have noticeable effects on the rate of natural increase of the population and can also, through affecting the availability of the stock to the fishing gear, influence our measurements of the relative abundance and quality of the population, based on the commercial catch.

61. We are, primarily, interested in determining the effects of man's predation under average environmental conditions. It is necessary for us, then, to take suitable account of the variations in environmental factors. Short term environmental effects which may be considered as random variables may be averaged out by statistical methods if we have a sufficiently long series of measurements. For this purpose, the series of data being considered must be long relative to the length of the periods of environmental changes. This condition is often encountered in practice.

62. On the other hand, there sometimes exist long-term environmental changes which influence the commercially important marine fishes. In such cases, where the series of data is short in comparison with the period of such changes, they cannot be regarded as random variables, and some understanding of their effects is required so that they may be suitably discounted in getting at the effects of man's predation. Such long-term effects of changes in the environment have been shown, for example, to be of importance in fisheries for North Atlantic cod, mackerel, lobster, capelin, and other species (Tåning 1953, Templeman and Fleming 1953).

E. Effects of intensity and kind of exploitation on the resource, and current status.

63. We have considered in the foregoing section the kinds of biological and ecological information which are required for evaluating the effects of man's exploitation on the fish population and on the sustainable catch. We will attempt in this section to review some of the methods which have been employed in making quantitative estimates of these effects, with particular reference to determining whether or not in a particular fishery the catch could be increased by measures to control man's predation.

64. An outstanding common characteristic of populations of organisms is that they are self-regulating; they remain at some more or less fluctuating level of abundance over hundreds, or thousands, of years, neither increasing without limit nor declining to zero, in spite of rather great changes in their surroundings. This obviously requires that a population react to changes in its environment in such fashion that the losses from and accessions to the population come into balance under the changing conditions. As we have noted in the introduction, this resiliency of population is the biological basis of any sustained fishery.

65. It has been pointed out by Nicholson (1933, 1954a,b), Ricker (1954), and others that, although the level of abundance of a population can be affected by any element of its environment, only those elements which are responsive to changes in population density, and in turn modify the population change, are involved in the salf-governing mechanism of the population. We may conveniently designate the elements involved in this self-regulating system as <u>controlling elements</u> and the remainder as <u>modifying elements</u>. The reactions of a fish population which compensate for the mortality due to man's predation, and make a sustained fishery possible, must, of course, involve controlling elements.

66. It is not <u>necessary</u> that we isolate the elements involved, but only that we determine quantitatively the relationships between intensity of fishing, the size and composition of the population, and the amount and quality of the catch that the population will sustain; although an understanding of the mechanisms concerned is of obvious value, both in understanding the dynamics of the fishery and in applying conservation measures.

1. The concept of equilibrium catch and maximum equilibrium catch

67. The basic problem of fishery management has been very simply and clearly formulated by Russel (1931), who stated the matter, essentially, as follows:

68. If P_1 represents the weight of the population of catchable sizes of fish at the beginning of some period of time (say a year) and P_2 represents the weight of the population of catchable sizes of fish at the end of the period,

$$P_2 = P_1 + A + G - M - C \qquad (1)$$

where:

A is the amount by which the stock of catchable sizes of fish is increased in weight by recruitment of new individuals during the year (additions by reproduction);

G is the increase in weight of the stock by growth during the year;

M is the loss in weight of stock by natural deaths during the year; and

C is the weight of the annual catch.

Putting (1) in a slightly different form,

$$P_2 - P_1 = A + G - M - C \qquad (2)$$

69. We see that this states the obvious fact that the change in weight of the stock is equal to the additions to the stock of recruitment and growth, less the subtractions by natural mortality and fishing. Obviously, when C is greater than A + G - M, the stock decreases; when C is less than A + G - M, the stock increases; and when C is exactly equal to A + G - M, the net change is zero.

70. The sum of the three terms (A + G - M) is what we have referred to above as the rate of natural increase. The catch when C = A + G - M, we may call the equilibrium catch, because it is the catch when the population is in equilibrium with its environment, including predation by fishing.

71. It is clear that, under the same environmental conditions, except for the amount of fishing, the equilibrium may be established at various levels of stock. Indeed it may be established at any level of stock between the maximum possible stock (when there is no fishing) and the threshold level for survival. The problem, then, reduces to estimating (A + G - M), the rate of natural increase (which equals the equilibrium catch) for various values of P (and corresponding values of fishing intensity). Since the several terms are interconnected

biologically, and some or all of them are determined by the density-connected controlling elements of the environment, there will, in general, be some maximum value for the equilibrium catch, the establishment of which is the primary objective of fishery conservation.

72. Because both the controlling and modifying elements of the environment are subject to variations unrelated to the magnitude of the fish population, the stock is, even under constant fishing intensity, never, in practice, in equilibrium, but fluctuates about some average level corresponding to average environmental conditions. By taking a suitably long series of observations, however, it is possible to deal with the average condition, and to estimate the average maximum equilibrium catch and the fishing intensity corresponding thereto, in the absence of sufficiently detailed knowledge of the operation of all environmental factors to permit them to be taken account of by other than statistical procedures.

73. Although the estimation of the fishing intensity which will produce the maximum equilibrium catch is a central objective, a somewhat lesser objective may be more easily attained, and be of great immediate importance, that is the determination of whether the intensity of fishing is above or below the level corresponding to maximum equilibrium catch. This does not necessitate estimation of the equilibrium catch over a wide range of fishing intensities, but only the determination of whether an increase from the existing intensity will result in a decrease or an increase in the equilibrium catch. In the latter case, the population is being underfished (so far as maximum sustainable yield is concerned), while in the former it is being overfished, and conservation action is indicated.

74. The preceding discussion has been predicated on the assumption that under uniform conditions of environment (including fishing) the fish population tends to stability, that is under a given set of environmental circumstances the population will tend to remain at a fixed level. Most populations of sea fishes are believed to be of this sort. There are, however, some kinds of organisms - notably certain kinds of insects - where the nature of the intraspecific competition leads to sustained oscillations in the size of the population, i.e. the rate of natural increase tends to be some periodic function, (Nicholson, 1950, 1954b). It appears that this type of population may sometimes

occur among fishes, for example some of the population of salmon of the genus Onchorynchus. It has been shown by Nicholson (1954a, b) that this type of population, under a given set of conditions oscillates periodically about a constant mean value which is determined by the conditions of the environment. If, therefore, we deal with the mean values, averaged over one or more cycles, of the population and of the factors making up the natural rate of increase, equation (2) above and the subsequent treatment applies. In this case there will still exist some level of sustained fishing intensity and corresponding mean population which corresponds to the maximum sustainable mean catch.

75. There is, however, the possibility that for oscillating populations the sustainable mean catch might be greater if the fishing intensity were continuously varied than if held at some constant level; on the other hand it might be less. I do not believe this has been investigated for any marine organisms, and, indeed, I am not acquainted with any literature bearing on this matter for any organism. In the absence of information regarding oscillatory fish populations, I shall deal here only with those kinds of populations which may be regarded as tending to stability. As noted above, most, at least, of our sea-fish populations are believed to be of this kind.

76. As noted in the introduction, and as indicated on the diagram, we may go about investigating the effects of man's predation at three levels, of increasing complexity, but leading to increasing understanding of the dynamics of the fishery, and consequently increasing possibility of efficient conservation management.

2. Investigations at level I

77. At the first level of investigation we may simply obtain, over a series of years which encompasses various levels of fishing intensity, measurements of fishing intensity, size and composition of the population, and size and composition of the catch, and, on the basis of these, infer the effects of fishing on the stock and catch, and arrive at an estimate of the current status of the fishery in comparison with the condition corresponding to maximum sustainable yield.

78. The amount of the catch may be determined from landing statistics, and its composition from examination of representative samples of the landings. The

relative abundance of the stock can be measured by the catch per unit of fishing effort, properly corrected for differences in gear which may be employed. The most precise estimates of this sort require also corrections for variations in availability, but where these are lacking the factor of availability may be treated as a random variable, if the series of data is sufficiently long, and if there is, in fact, no systematic, long-term change unconnected with the fishery activities. To compute absolute abundance from relative abundance usually requires data from marking experiments, although this can also sometimes be inferred from the changes in catch and relative abundance.

79. In addition to the measurement problem resulting from variations in availability to the fishing gear, there may also arise a problem in changing efficiency of gear, due to improvements of existing gear, or shifts to new kinds of gear, over a series of years. Various statistical devices for taking these into account have been developed, and are sufficiently well known to require no detailed discussion here.

80. Inferences of effects of fishing on the stock and catch, and the current status of the fishery, from the evidence of historical records of changes in relative abundance and catch in relation to changes in fishing effort, have proven most useful in practice. Several good examples come immediately to mind:

81. The data on the plaice fishery of the North Sea, summarized in several publications of the I.C.E.S. (for instance Figure 3 of Graham 1954) indicate clearly that the intensity of fishing is sufficiently great to have had a marked effect on the stock, and that the intensity reached before World War II was above that corresponding to the maximum yield. For this, and some other North Sea and North Atlantic fish populations, the respites from fishing during the two World Wars provided a large variation in fishing intensity, the effects of which on the stock are unmistakable (Clark, et al 1948).

82. A similar series of data on the Icelandic cod (Graham 1954) indicated that this stock, on the contrary, shows no signs of approaching the maximum desirable level of exploitation.

83. In the well known example of the Pacific halibut (Thompson and Bell 1934, Thompson 1952), the historical series through 1930 indicated that the intensity of fishing had reached, particularly on the oldest fishing grounds, a level well

above the maximum desirable, and that the stock had declined to a point where the sustainable harvest was well below the maximum. Acting on this information, the harvest was regulated by the International Fisheries Commission, with subsequent rebuilding of the stocks, and eventually some increase in total harvest as well.

84. The simple examination of such time series is, in many cases, adequate to indicate whether a stock is underfished or overfished, and, thus, whether conservation measures are required. It is also possible, however, from reasonably long historical series of data on abundance, catch, and fishing intensity to make quantitative estimates of the effect of changes in fishing intensity on the stock, and to estimate the equilibrium catch at various levels of population, and the maximum equilibrium catch. The method employed here consists, essentially, of considering the rate of natural increase, that is the <u>sum</u> of the terms (A + G - M) to be some single valued function of the mean population.

$$A + G - M = f(\bar{P})$$

and (from equation 2 above)

$$P_2 - P_1 = \Delta P = f(\bar{P}) - C \quad \ldots\ldots\ldots\ldots\ldots (3)$$

85. If we further assume, as is usual in fisheries research, that the catch per unit of fishing effort is proportional to the mean population encountered by the fishery during the year (is a measure of the relative abundance of the fish), and that the instantaneous rate of fishing mortality is proportional to the number of units of fishing effort, we have

$$\Delta P = f(\bar{P}) - k_1 F \bar{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and

$$k_1 \bar{P} = U$$

where F is the total number of units of effort applied during the year, $\bar{P}$ is the mean population, U is the catch per unit of effort, and k_1 is a constant.

86. If on theoretical grounds, or on a sufficient basis of empirical experience, we can specify the form of $f(\bar{P})$, we can employ (4), or an equivalent formulation, to estimate quantitatively the relationship between fishing, population, and sustainable catch. Büchman (1938) and Graham (1939) have discussed some of the theory of this approach. Graham (1935) has applied it in a rough way to the estimation of the equilibrium catch of the demersal fish stocks of the North Sea,

as has Baerends (1947). Recently the writer (Schaefer 1954a, b) has further developed the theory and methodology, and shown applications to the Pacific halibut and sardine fisheries.

87. In the interpretation of historical series by the foregoing methods, it is assumed that all of the influences of environmental factors other than fishing, as well as measurement errors, may be regarded as random variables. It is necessary, therefore, to employ fairly long series of data for such investigations, for two reasons: (1) Even if the environmental effects mentioned are truly random, the greater the amount of data, the greater the precision of the statistical estimates; (2) If there exist cyclic variations, it is necessary that the series of data be long enough with respect to the period of significant cycles for such variations to be treated as quasi-random.

88. If there do exist, unknown to the investigator, long-term trends or long-term cycles, in the environmental influences, there is the possibility that the changes in population due to such trends or cycles may be attributed to changes in fishing effort, whereas they may not in truth be so. Certainly some caution needs to be exercised in this direction.

89. Determination of the size and age composition of the catch (and stock) over the same series of years, offers one means of determining whether the observed changes may be due to fishery-independent factors. Where the controlling factor is the intensity of fishing, there occur, along with changes in the magnitude of the stock, changes in the age composition, systematically related to changes in fishing intensity, (see e.g. Clark et al., 1948). Such series also make possible the empirical determination of the relationships between intensity of fishing and quality of the catch, which, as we have pointed out before, may be an important secondary consideration in a conservation programme.

3. Investigations at level II

90. An alternative approach to applying equation (4), or an equivalent formulation, to the determination of the relationship between intensity of fishing and equilibrium catch is to estimate the individual terms for recruitment, growth, and mortality, and combine them to estimate equilibrium catch.

91. The pioneer worker Baranov (1918) was the first, so far as I know, to employ this method. He assumed that the number of fish recruited annually to

the population is constant for all sizes of population. He assumed growth to be age-specific but independent of size of population (he took the length to be directly proportional to the age and the weight proportional to the cube of the length). He assumed the percentage of natural mortality to be constant, and the instantaneous rate of fishing mortality to be proportional to the fishing intensity. Under these assumptions, he computed the equilibrium catch for populations of fish, having a specified rate of increase of length with age, for various values of natural mortality rate and fishing intensity.

92. Thompson and Bell (1934) computed the equilibrium catch in a fishery for various rates of fishing mortality, assuming numbers of recruits constant and percentage rates of growth and mortality constant. They also computed the changes in the population and yield which would occur in the halibut fishery, assuming numbers of recruits constant, percentage rate of natural mortality constant, growth to be age specific (using average age-weight data from samples of the catch) but constant at each age, and instantaneous fishing mortality rate to be proportional to number of units of gear actually fished. The mortality rates employed in the calculations were in the vicinity of those inferred from tagging experiments. With these simplifying assumptions, they found the calculated changes in abundance and catch corresponded rather well with the actual changes over the period of years examined.

93. Parrish and Jones (1953), studying the haddock of the Faroes and the North Sea, have computed equilibrium catch, assuming numbers of recruits constant; percentage rate of natural mortality constant (using in different calculations a range of rates within which falls the average value for the fishery in question, inferred from the available data); growth rate to be age-specific, following a mathematical form due to Bertalanffy, but constant at each age for all population densities (curve fitted to average data from samples of the catch); and the instantaneous fishing mortality rate to be proportional to the amount of gear fished. It is shown that the present fishing intensity in both areas is above that corresponding to maximum equilibrium catch.

94. Beverton (1953) has made similar calculations, based on the same assumptions and similar methodology to those of Parrish and Jones, for the plaice and haddock fisheries of the North Sea. He has also made calculations of the variations in yield of this fishery, taking into account the effect of variation

in age of recruitment, due to regulation of size of mesh of net. He shows that the equilibrium yield might be increased from its present condition by a decrease in intensity of fishing, an increase in mesh of net, or both.

95. This approach, combining the estimates from current data of recruitment, growth rates, and natural mortality rate, is adequate to indicate when a fishery has been overfished, and to indicate the direction regulation needs to take. Since this does not take into full account the density effects on these factors, and also neglects the age-specificity of natural mortality rates, the estimates of equilibrium catch at fishing intensities much different from the current one becomes increasingly poor. This has been recognized by some authors. Ricker (1944) points out that the assumption that certain of the rates remain constant when the fishing effort changes do not correspond to reality, so that such calculations cannot be valid over a very large range of population sizes. Parrish and Jones (1953) say, "Of course, these curves are not valid over their whole range, since with increase in stock density, there will possibly be some decrease in growth rate and increase in natural mortality rate, so that the ordinates to the left of the curve [lower fishing intensity] are probably over estimates".

96. Since recruitment must decrease, also, at very low levels of population, the values computed for very high fishing rates are, doubtless, also over-estimates.

97. Beverton (1953) notes that "... the model can establish the main dynamic properties of a fishery and can indicate the first steps which are required to regulate it, but for making accurate predictions of the regulation required and of its probable effects, it is necessary to take other factors into account. Of particular importance here is the variation of the parameters with population density... Introducing phenomena of this kind makes the model more realistic and gives it the properties of 'self-compensation' which are characteristic of natural populations...". He has made, for both haddock and plaice, calculations showing the effect of taking into account density effects on the growth rate and natural mortality rate.

98. In determining the average values of recruitment, growth, and natural mortality, fisheries scientists normally employ data from the catch and from tagging experiments over a series of years. It is implicitly assumed that any

environmental influences behave as random variables, which will average out over the series. This, as in the investigations at level I, is a possible source of error, if in truth there is a non-random trend of such factors. The measurement of the elemental rates, however, makes it easier to detect such environmental effects than the simple consideration of the catch-statistical data alone.

99. Calculations disregarding age-specificity of natural mortality, and disregarding density effects on recruitment, growth, and natural mortality, limit the usefulness of the calculations to fishing intensities and population sizes near to those for which the rates have been measured. It is desirable, therefore, that, where possible, the changes of natural mortality with age, and the density effects on all three factors be determined and incorporated into the calculations. The age-specific mortality rates can be calculated from sufficiently detailed samples of age composition in several successive years. The determination of density effects, however, requires determination of rates at different population densities, which are often difficult to obtain, since the fishery tends to maintain the population density at some rather constant level, depending on economic factors. Such changes in population density as those resulting from respites from fishing during the major wars offer one sort of opportunity for such determinations. Lacking this, as a practical procedure, it is probably necessary to proceed step-wise with management regulations, approaching the condition of maximum sustainable yield by a series of successive changes in regulations.

4. Investigations at level III

100. Investigations at levels I and II give, primarily, information for controlling the fishery so as to give the greatest sustainable yield under average environmental conditions, and the methodology of investigation treats variations of such conditions as random variables to be eliminated by suitable statistical procedures. Our understanding of the dynamics of the fishery will, obviously, be more precise, and therefore, more useful to effective conservation action, if we understand and measure the effects of the environment on the population and catch, along the lines indicated in an earlier section. Such knowledge will also make it possible to establish a regulation of the fishery

under which the harvest would be increased during periods of abnormally high rate of natural increase, and decreased during periods of abnormally low rate of natural increase, thus obtaining a greater total production than is possible under regulations based on average conditions.

101. The necessary quantitative knowledge of the influence of variations of elements of the physical environment on the fish stocks is not available for such ideal management of any of the sea fisheries, but is the ideal which fisheries research should hope to attain eventually. This must involve, however, measurements of all important factors in the ecological system, as shown schematically on our diagram. We must measure quantitatively the direct effects of the physical environment on recruitment, growth, mortality, and availability of the stock to the fishery. We must also measure the indirect effects through the modification of the food supply and the living space. Since a population of a given fish species is a part of an ecological system including populations of other species which compete with it, or prey upon it, the environmental effects on such other populations will affect the survival and growth of the population of the species harvested by man. Finally, in some instances, the fishery may destroy members of competing and predatory fish populations, either because they are of commercial value, or because they are captured and killed incidentally, even if not landed. The study of the effects of fishing on predators and competitors is, thus, an important kind of investigation in such circumstances.

102. Since the ecological system is exceedingly complex, the investigations at level III usually become complex also. Only in a few places have such detailed studies been attempted on an adequate scale. The investigations of the demersal fishes of the North Sea, and the investigations of the sardines and related pelagic species off California, are perhaps two of the best examples of progress along this line. In both of these cases a great deal has been learned, serving partly to show how much more needs to be found out. The information developed by investigations at this level are, however, of use in the conservation programme even though they may be incomplete. Partial information of the relationships indicated at level III is of value to the analyses at levels I and II.

F. Relationships to other species being exploited simultaneously

103. Very often a fishery does not depend on a single species of fish, but is supported by two or more species which are captured in the same areas at the same seasons, sometimes even being taken simultaneously from shoals composed of a mixture of species. For example, trawl fisheries commonly capture a mixture of marketable species. Again, in the tuna fishery of the tropical Eastern Pacific (Schaefer 1954c) two species of tuna are taken in the same areas and seasons with the same gear.

104. In such circumstances it would, of course, be desirable to maximize the sustainable catch of each of the species. Whether this is capable of attainment will depend upon the effects of a given amount of fishing on the stock and yield of each species, and upon whether species selectivity can, in fact, be practised in the fishery.

105. First of all it is desirable to determine the effects of fishing on the stock and yield of each species, and its current status in relation to the maximum equilibrium catch. If, as may often occur, some species are being underfished while others are overfished, it will be desirable to curtail fishing on the overfished species, while allowing it to increase in those that are underfished, if this be possible.

106. The possibility of selective control will depend on the biology and behaviour of the several species. Investigation may show that the different species are differently distributed by area or time, and the pattern of fishing can be modified accordingly. For those species, such as the tunas, which are located by visual means, it is important to determine to what extent the different species school each according to its own kind, because if mixed schools are of infrequent occurrence selectivity may be exercised in the fishing operation. It may also happen that gear modifications (such as regulation of mesh-size of trawls) will make possible the selective escapement of one species.

107. Where it is not possible, on these or other bases, to fish selectively, it will, in general, still be possible to control the fishing to obtain the maximum sustainable aggregate catch of all the species. Beverton (1953), for example, has noted that for the trawl fishery of the North Sea "for any given fishing intensity there is a mesh size which enables the greatest combined yield

to be obtained, although this combination of fishing intensity and mesh size might not be eumetric for any one of those species alone".

108. Here, again, it will sometimes be necessary also to consider some of the economic aspects of the fishery. Where several species are caught simultaneously, and they have quite different values in the market, it may be desirable to manage the fishery so as to obtain somewhat less than the maximum sustainable aggregate catch in order to secure a more desirable species composition. The same types of biological information are, however, required for both purposes - in either case the necessary conservation measures must be based on scientific knowledge of the dynamics of the fish populations concerned.

PART II

TYPES OF CONSERVATION MEASURES APPLICABLE IN A CONSERVATION PROGRAMME

109. When scientific investigations, of the types discussed above, have shown that curtailment or modification of man's predation on the fish population will increase the quantity or quality of the catch, various kinds of regulatory measures may be put into effect. The kind of regulations imposed will depend on the effects which it is desired to obtain, the nature of the fish population, the characteristics of the fishery, and economic and social factors pertinent to the particular circumstances.

A. Control of level of fishing intensity to obtain maximum average sustainable catch

110. When the investigations have shown that there exists, or is imminent, a condition of overfishing (i.e. an intensity of fishing such that the sustainable catch is less than it would be at a lower intensity), the sustainable catch may be increased by curtailing the amount of fishing. This may be accomplished in several ways.

111. The most straightforward method is directly to limit the amount of fishing effort employed in the fishery. This may be accomplished by limiting the number of fishermen or vessels which are permitted to engage in fishing, or by allowing all who wish to do so to fish, but limiting the amount of fishing time or amount

of fishing gear per person or vessel. Limiting the number of persons or vessels which can fish has the effect of giving a property right to those who are permitted to fish, which is contrary to public policy in many countries. Limiting the total fishing intensity by regulating the amount of fishing of each person who wishes to engage in the fishery has the same effect on the fish population and the catch, but has the possible disadvantage that total cost of harvesting the yield is greater, so that the net economic yield is less.

112. Administratively, it is usually easier to limit the amount of fish which are permitted to be caught and landed than to limit the amount of fishing effort directly. Limitation on fishing intensity is, therefore, often obtained indirectly by means of quotas, or limits, on the permitted landings. This technique has been employed successfully in the Pacific halibut fishery, among others. Where a single annual quota is imposed for a given geographical region, as the abundance of fish is rebuilt, the permitted catch will be obtained in a shorter and shorter time, so that the fishery will tend to be concentrated in a short season. If, within the region there are several sub-populations which become available to the fishery at different times of the year, this results in the fishery bearing on them unequally. Such a condition is apparently the case for the Pacific halibut (Dunlop and Bell 1952). In this event, it becomes necessary to establish separate catch quotas for different time intervals in order to obtain full utilization of all the sub-populations. The Pacific salmon offer other examples of resources which are composed of several populations, which are available to capture at different times in the same fishing area, and for which limitations on permitted catch need to be applied separately to different time periods to obtain the desired fishing intensity on each of the several populations.

113. Limitation on fishing intensity is, also, often obtained by establishing closed seasons during which no fishing is permitted, usually choosing those seasons when the fish are most amenable to capture. This seems, of course, to be economically inefficient.

114. A similar type of indirect limitation on fishing intensity may be obtained by closing to fishing certain areas where fish are most amenable to capture. Where closed areas have the sole object of curtailing fishing intensity, and not of protecting certain classes of fish, this type of control may, again, be

less economically desirable than others, if the areas chosen are those where fish are particularly amenable to capture.

115. A popular method of controlling intensity of fishing without becoming involved in limiting the number of persons engaged in fishing, or establishing direct catch limitations, is to employ regulations to limit the efficiency of the fishing gear. This may involve complete prohibition of certain kinds of gear; prohibition of the use of ancilliary equipment, such as electronic devices for locating fish shoals, or the addition of power to sailing craft; limits on the size of vessels permitted to engage in the fishery; or limitations on the fishing gear itself, such as limits on the lengths of gill-nets or purse seiners, or limits on the maximum breadth of trawl nets.

B. Protection of fish the conservation of which will result in greater average catch or more desirable quality

116. As has been noted in Part I, the total sustainable yield from a fish population may be increased by permitting the fish to remain in the sea as long as the increase in weight by growth exceeds the loss in weight by natural deaths. Harvesting fish at larger sizes will, in some cases, also produce fish of more value in the market. In such cases, and where it is practicable to do so, regulations to protect the smaller sizes of fish are desirable. This may be accomplished in several ways.

117. Regulation of fishing gear to permit differential capture of specified sizes of fish is a practical method in fisheries employing gill nets, trawl nets, and similar gear, since regulating the size of mesh of the nets allows fishes below specified sizes to escape capture. This type of regulation is being used, for example, in the trawl fisheries of the North Sea and of certain parts of the Northwest Atlantic.

118. It is also practical in some instances simply to prohibit the landing of fish below a specified size. For this to be practicable, the nature of the fish and the fishing method must be such that (a) the fishermen can avoid capturing the small fish, or (b) the small fish can be returned to the sea after capture without resulting in a large percentage of deaths.

119. Where the small fish occur in different geographical areas (often called "nursery" grounds) than the large fish, the small fish may be protected from capture by closing such areas to all fishing.

120. It may happen that, within the area where fish are available to the fishing gear, small fish occur in certain seasons of the year and large fish at others. In such cases, closure of the fishery during the season when the small fish predominate is an effective means of achieving this kind of control.

C. Differential harvesting of sexes

121. It may happen that the ratio of sexes occurring in nature is such that there is a surplus of one sex in relation to the requirements for reproduction. In this event, the fishery may be managed so as to fish one sex more intensely than the other, by taking advantage of differential distribution, behaviour, or morphology of sexes.

122. It may also happen, conversely, that the unregulated fishery bears unequally on different sexes, disturbing the normal sex ratio necessary for efficient reproduction. In this case regulations to correct the imbalance are in order.

123. The only example which comes readily to mind of this sort of thing is the sockeye salmon. For some populations of this species in Alaska, it has been indicated (Pacific Fisherman 1950) that there is a normal surplus of males, and that these may be differentially captured by regulation of the sizes of mesh of gill nets used to catch them. It has been shown, likewise, that the gill net fishery for Fraser River sockeye salmon (Peterson 1954) is selective toward the males, the degree of selection being related to the mesh size of the nets; here it has not been indicated whether or not this is desirable.

D. Regulations designed to ensure adequate recruitment

124. Regulatory measures are frequently employed with the object of ensuring that the recruitment to the fishable stock is maintained.

125. For some populations, of which, again, the Pacific salmon offer a ready example, it has been indicated by research that there is an optimum size of the spawning population which will produce the maximum resulting harvest, so that regulation takes the form of restrictions on fishing to permit the optimum number of fish to "escape" to the spawning grounds. This type of regulation, depending

upon the relationship between spawning stock and resulting recruitment being the predominately important factor determining the rate of natural increase, has little application to most purely marine populations.

126. Minimum size at first capture, obtained by any one of the means mentioned in (B) above, chosen so as to minimize the capture of sexually immature fish, has been justified on the basis that so long as the fish are given maximum opportunity to spawn at least once, adequate recruitment will be assured.

127. Protection of young fish by closure of "nursery" areas is also sometimes considered to be a means of assuring increased recruitment to the stock of adult fish, quite aside from the augmented weight of catch to be obtained by allowing the small fish to gain additional weight by the excess of growth over natural mortality, when such exists.

128. Protection of adult, spawning fish, by prohibition of fishing in spawning areas or during spawning seasons, with the aim of thereby increasing the number of progeny, is a widely practised type of regulation which, except in special circumstances, has little or no inherent advantage over restriction on fishing at any other period. The widespread belief in the effectiveness of this type of regulation probably arises from a presumed analogy with the conservation of various land animals which care for their young during a protracted time, and the protection of which, therefore, is necessary to the survival of their young. Since the majority of commerically important fishes give their young little or no post-natal care, refraining from catching them during the spawning season will produce but few more progeny than refraining from catching an equal number some months earlier. The only net increase will be due to the spawners having survived a certain natural mortality in the intervening period. If the stock is equally accessible to capture during both periods (i.e., if a unit of fishing effort catches the same percentage of the existing total adult stock during the spawning period and during the non-spawning period), there will be no gain at all in eggs produced, from applying the same fishing effort during the non-spawning period rather than the spawning period, because the percentge of the initial stock surviving to spawning will be exactly the same, whatever the time at which the fishery is applied.

BIBLIOGRAPHY

Ancona, U. d'

1954 — The struggle for existence. Translated by A.C. and R.F.J. Withers. Leiden, E.J. Brill, 1954. 274 p. (Geschriften van de Prof. Dr. Jan van der Hoeven Stichting voor Theoretische Biologie van Dier en Mensch, verbonden aan de Universiteit Leiden. Series D. Bibliotheca Biotheoretica, no. 6)

Baerends, G.P.

1947 — De rationeele exploitatie van den zeevischstand, in het bijzonder van den vischstand van de Noordzee. 's-Gravenhage, Rijksuitgeverij, 1947, 80 p. (Verslag en Medebeelingen van de Afdeeling Visscherijen [van het] Ministerie van Landbouw, Visscherij en Voedselvoorziening, nr. 36) English translation: Rational exploitation of sea fisheries with particular reference to fish stock of North Sea. Washington, Government Printing Office, (1950) 102 p. (U.S. Fish and Wild Life Service, Special scientific report: Fisheries, no. 13)

Baranov, F.I.

1918 — On the question of the biological foundation of fisheries. Izvestiia, Nauchnyi Issledovatel'skii Ikhtiologicheskii Institut 1:81-128, 1918. Text in Russian.

Beckman, W.C.

1941 — Increased rate of growth of rock bass, Ambloplites rupestris. Transactions of the American Fisheries Society (New York) 70:143-148, 1941.

1948 — Changes in growth rates of fishes following reduction in population densities by winter-kill. Transactions of the American Fisheries Society (New York) 78:82-90, 1948.

Beverton, R.J.H.

1953 — Some observations on the principles of fishery regulation. Journal du Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 19:56-68, 1953.

Bückmann, A.

1938 — Uber den Höchstertrag der Fischerei und die Gesetze organischen Wachstums. Bericht der Deutschen Wissenschaftlichen Kommission für Meeresforschung (Berlin) 9, heft 1:1-47, 1938.

Burkenroad, M.

1951 Some principles of marine fishery biology. Publications, Institute of Marine Science, University of Texas (Austin) 2, No. 1:179-212, 1951.

Clark, R.S. and others

1948 Contributions to special scientific meetings 1947. The effect of the war on the stocks of commercial food fishes. Rapports et procès-verbaux des réunions, Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 122:1-62, 1948.

Dunlop, H.A. and Bell, F.H.

1952 New problems in regulation of Pacific halibut stocks. Journal du Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 18:167-171, 1952.

Gordon, H.S.

1953 An economic approach to optimum utilization of fishery resources. Journal of the Fisheries Research Board of Canada (Ottawa) 10:442-457, 1953.

Graham, M.

1935 Modern theory of exploiting a fishery, and applications to North Sea trawling. Journal du Conseil Permanent pour l'Exploration de la Mer (Copenhague) 10:264 274, 1935.

1939 The sigmoid curve and the overfishing problem. Rapports et procès-verbaux des réunions, Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 110:17-20, 1939.

1952 Overfishing and optimum fishing. Rapports et procès-verbaux des réunions, Conseil International pour l'Exploration de la Mer (Copenhague) 132:72-78, 1952.

1954a The state of the northern stocks of cod. Rapports et procès-verbaux des réunions, Conseil International pour l'Exploration de la Mer (Copenhague) 136:48-50, 1954.

1954b Half a century of fishery biology in Europe. Proceedings of the Gulf and Caribbean Fisheries Institute, 6th annual session (Coral Gables, Florida): 70-81, 1954.

Kesteven, G.L.

1946 A procedure of investigation in fishery biology. Melbourne, 1946, 31p. (Council for Scientific and Industrial Research, Bulletin No. 194)

Lucas, C.E. and others

1952 Contributions to scientific meetings 1951. Fisheries hydrography. Rapports et procès-verbaux des réunions, Conseil International pour l'Exploration de la Mer (Copenhague) 131:1-113, 1952.

Lundbeck, J.

1954 Gedanken zur Frage der Bildung und Veränderung natürlicher und genutzter Tierbestande, inbesondere vom Standpunkt der praktischen Fisherei. Archiv für Hydrobiologie (und Planktonkunde) (Stuttgart) 49:225-257, 1954.

Marr, J.C.

1951 On the use of the terms abundance, availability and apparent abundance in fishery biology. Copeia (New York) No. 2:163-169, 1951.

Maurice, Henry G. and others

1932 The effect upon the stock of fish of the capture of undersized fish; reports of the proceedings of a special meeting held on 24 June 1932, at Copenhagen. Rapports et procès-verbaux des réunions, Conseil International pour l'Exploration de la Mer (Copenhague) 80: various paging, 1932.

Nicholson, A.J.

1933 The balance of animal populations. Journal of animal ecology (Cambridge) 2:132-178, 1933.

1950 Competition for food among Lucilia caprina larvae. Proceedings, 8th International Congress of Entomology, Stockholm, 1948 (Stockholm) 277-281, 1950.

1954a An outline of the dynamics of animal populations. Australian journal of zoology (Melbourne) 2, No. 1:9-65, 1954.

1954b Compensatory reactions of populations to stresses, and their evolutionary significance. Australian journal of zoology (Melbourne) 2, No. 1:1-8, 1954.

(Pacific Fisherman)

1950 The fruits of research; first revelation of scientific data from fisheries institutes' research made to U.S. salmon industry. Pacific Fisherman (Seattle, Wash.) 48:17-20, April 1950.

Parrish, B.B. and Jones, R.

1953 Haddock bionomics, 1. The state of the haddock stocks in the North Sea, 1946-1950 and at Faroe, 1914-50. Edinburgh, Her Majesty's Stationery Office, 1953. 27p. (Scottish Home Department, Marine Research, 1952, No. 4)

Peterson, A.E.

1954 The selective action of gillnets on Frazer River sockeye salmon. New Westminster, B.C., 1954. 101p. (International Pacific Salmon Fisheries Commission, Bulletin No. 5)

Rasmussen, B.

1954 On the Norwegian long-line fishery for cod in Greenland waters. Rapports et pròces-verbaux des réunions, Conseil International pour l'Exploration de la Mer (Copenhague) 136:63-64, 1954.

Ricker, W.E.

1944 Further notes on fishing mortality and effort. Copeia (New York) No. 1:23-24, 1944.

1954 Stocks and recruitment. Journal of the Fisheries Research Board of Canada (Ottawa) 11:559-623, 1954.

Russell, E.S.

1931 Some theoretical considerations on the overfishing problem. Journal du Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 6:3-20, 1931.

Schaefer, M.B.

1954a Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. La Jolla, Calif., 1954, 56p. (Inter-American Tropical Tuna Commission, Bulletin, Vol. 1, No. 2)

1954b Fisheries dynamics and the concept of maximum equilibrium catch. Proceedings of the Gulf and Caribbean Fisheries Institute, 6th annual session (Coral Gables, Florida): 53-64, 1954.

1954c Report on the investigations of the Inter-American Tropical Tuna Commission for the year 1953. Report, Inter-American Tropical Tuna Commission (La Jolla, Calif.): 18-50, 1953. (Spanish text on p. 51-87)

Sette, O.E.

1943 Studies on Pacific pilchard or sardine (Sardinops caerulea): 1. Structure of research program to determine how fishing affects the resource. Chicago, 1943. 27p. (U.S. Fish and Wildlife Service, Special Scientific Report, No. 19)

Tåning, A.V.

1953 Long term changes in hydrography and fluctuations in fish stocks. Annual Proceedings, International Commission for the Northwest Atlantic Fisheries, 3:79-86, 1953.

Thompson, W.F.

1952 Conditions of stocks of halibut in the Pacific. Journal du Conseil Permanent International pour l'Exploration de la Mer (Copenhague) 18:141-166, 1952.

Thompson, W.F. and Bell, F.H.

1934 Biological studies of the Pacific halibut fishery. 2. Effect of changes in intensity upon yield and yield per unit of gear. Victoria, B.C., 1934, 49p. (International Fisheries Commission. Report No. 8)

Thompson, W.F. and Herrington, W.C.

1930 Life history of the Pacific halibut. 1. Marking experiments. Victoria, B.C., 1930. 137p. (International Fisheries Commission. Report No. 2)

Westenberg, J.

1948 Rationele visserij. Chronica naturae (Batavia) 104:289-302, 1948.

1953 Overzicht van de ontwikeling der visserijtheorie. Statistica (Hengelo, Netherlands) 7, No. 2:71-95, 1953.

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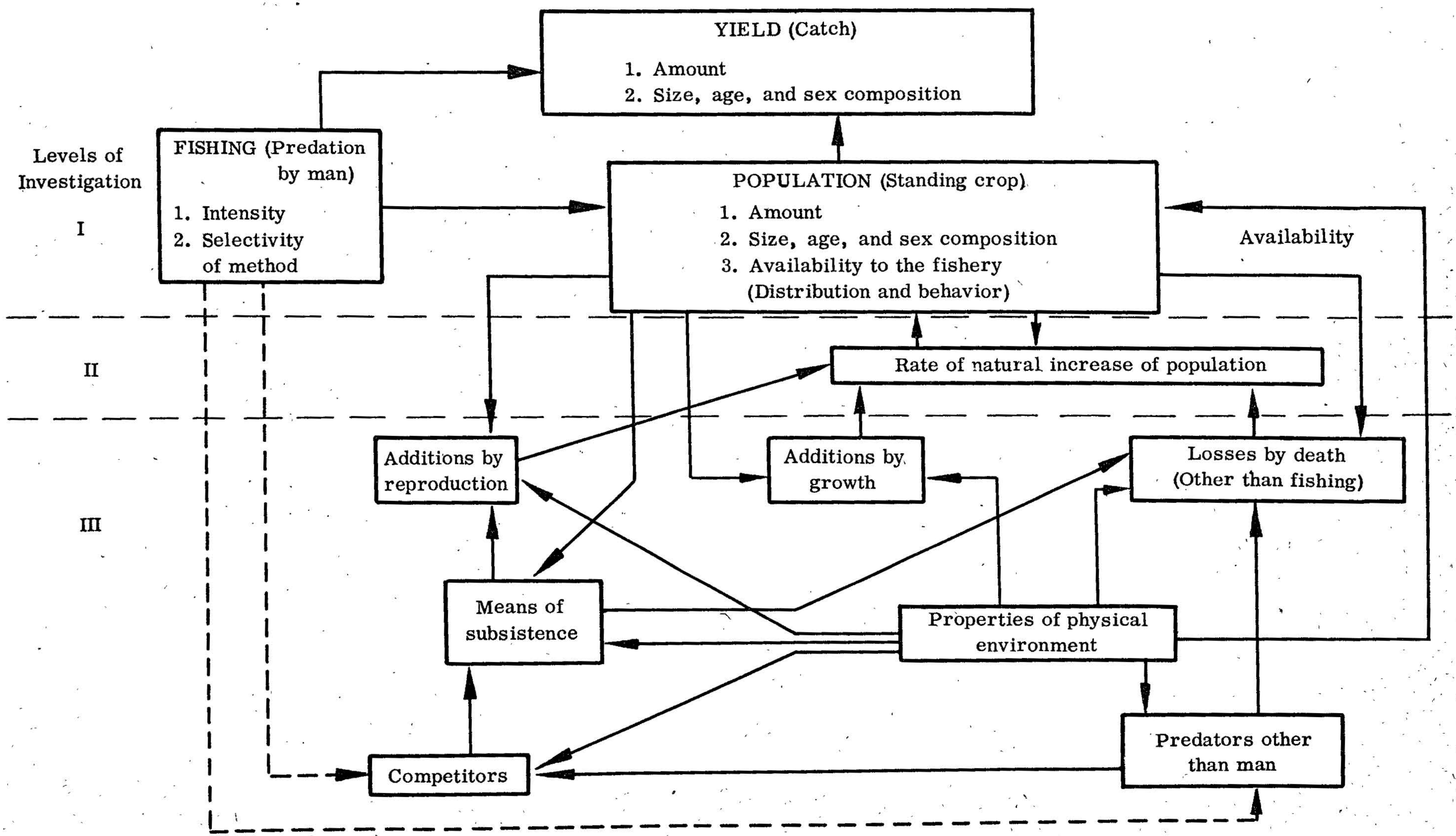
Figure 1

DIAGRAM OF INTERRELATIONSHIPS OF FACTORS DETERMINING THE STANDING CROP AND YIELD OF A POPULATION UNDER EXPLOITATION BY MAN

(Arrows indicate direction of cause-effect relationships)



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Items 10 and 11 of the
provisional agenda

INTERNATIONAL TECHNICAL CONFERENCE ON THE CONSERVATION OF THE LIVING RESOURCES OF THE SEA

Item 10: Types of scientific information required for a fishery conservation programme

and

Item 11: Types of conservation measures applicable in a conservation programme

In accordance with the advice of the group of experts convened by the Secretary-General to assist him in the preparation of this Conference, technical papers on certain items of the provisional agenda were invited from a number of authorities. The Secretary-General accordingly has the honour to communicate a summary of the following paper by Dr. Milner B. Schaefer, Director of Investigations of the Inter-American Tropical Tuna Commission, La Jolla, California, United States of America; the full text is being issued in English as document A/CONF.10/L.1.

TYPES OF SCIENTIFIC INFORMATION REQUIRED FOR A FISHERY CONSERVATION PROGRAMME, AND TYPES OF CONSERVATION MEASURES APPLICABLE IN A CONSERVATION PROGRAMME

by

Milner B. Schaefer

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55-05698

SUMMARY

1. The living resources of the sea renew themselves and may therefore be used continually without being destroyed. It has been found, however, that unwise use of these resources lowers the long-term benefits which might be derived from them, and conservation consists in controlling their use so as to maintain man's benefits at the highest sustainable level. In general, it is considered most desirable to obtain the largest catch possible of the commercial sizes, although in some instances this objective has to be modified by economic and other considerations.

2. The purpose of scientific investigation of fisheries is to provide information on the basis of which man can control his predation on the fish populations 1/ constituting his commercial resources so as to get the largest sustainable catch or otherwise to increase his benefits from the resource above those which would be obtainable without control. This requires determination of the effects of fishing on the abundance and composition of the fish populations and on the resulting quantity and quality of the catch. Various kinds of scientific information are needed for this purpose.

3. In planning or conducting investigations prior to establishing a conservation programme, and also in carrying it out, one must first determine the extent to which any one kind of fish constituting a commercial resource is separated into independent or semi-independent populations because the population is the fundamental unit for conservation management.

4. There is need to determine the geographical ranges of the populations because both investigations and conservation measures need to extend over the whole sea area occupied by the populations to be conserved, and these areas will differ for different resources. The size of the "standing crop" - the average quantity in the sea of fish of commercial sizes - and its

1/ A "population" of organisms is defined in the body of the paper as a homogeneous group of members of the same species, which interbreed freely among themselves, and which occupy a continuous environment, and so are able freely to intermix and thus maintain their homogeneity.

productivity, in relation to the amount being currently harvested, provides a basis for judging whether or not conservation measures are needed.

5. Changes in the abundance and composition of a population, and in the catch, are caused not only by the amount of fishing, but also by variations in the physical and biological environment. In order fully to understand the manner in which these changes, whether connected with fishing activities or not, are produced, it is desirable to investigate in detail the interrelationships of the several biological and ecological factors which determine the standing crop and yield of a population under exploitation by man. These interrelationships are shown schematically in Figure 1.

6. When the amount of fish removed from a population by fishing is equal to the rate of natural increase of the population, the population will remain unchanged, and the catch under such circumstances may be called the equilibrium catch. An equilibrium condition may be established for any population size between maximum abundance, when there is no fishery, and a "threshold" (minimum) abundance below which the group could not survive. There will be some level of fishing intensity, and a corresponding level of population, for which the equilibrium catch is at a maximum. The basic problem of fishery conservation is to determine the condition of the fishery corresponding to the maximum equilibrium catch, and to find out how the current condition compares with it.

7. This problem may be studied at three different levels, of increasing complexity but permitting increasingly precise conservation management. At the first level, we determine, on the basis of historical observations covering different degrees of fishing intensity, the average relationships between fishing intensity, size of population and size of catch, treating the effects of environmental factors unconnected with the existence of a fishery as random variables. At the second level, we measure separately the three components (reproduction, growth, and natural mortality) of the rate of natural increase, and how each of them is related to the abundance and composition of the population. At the third level, we seek to obtain full knowledge of the effects of all

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important environmental factors, both physical and biological. Useful conservation measures can be worked out on the basis of the less complex investigations, with increasing precision of control as knowledge at the other levels is developed.

8. For those fisheries which simultaneously fish members of several species, it may be possible to maximize the sustainable yield of each independently, or it may only be possible to maximize the aggregate catch of the several species, depending on whether their biology and behaviour is such as to permit selective fishing.

9. Management measures which may be applied in a conservation programme are of several general kinds:

a. measures for the direct or indirect control of fishing intensity so as to obtain the maximum equilibrium catch;

b. protection of particular classes of fish, the conservation of which will result in greater average catch or more desirable quality;

c. measures designed to assure adequate recruitment, and

d. differential harvesting of sexes to achieve a desirable sex ratio in the spawning population.

For each of these, there are a number of procedures available, which are discussed.

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