EXPLOITATION OF FISH POPULATIONS

K. RADWAY ALLEN

Fisheries Laboratory, Marine Department, Wellington

This paper deals with some of the principles underlying the exploitation of fish populations, rather than with the history or condition of such populations in New Zealand waters.

The term "exploitation" implies the idea of making use of the population, and in fisheries is generally regarded as a process which should be continued indefinitely without destroying the population. Very intense exploitation leading to the complete destruction of the population, or at least its reduction to a level so low that further exploitation is not worthwhile, is rarely, if ever, deliberately practised in dealing with fish populations although it may sometimes occur unintentionally and as a result of mismanagement. In New Zealand the pilchard fishery in the Marlborough Sounds in the 1940's is probably an example of an intensive fishery which virtually wiped out a small localised population within about five years (N.Z. Marine Department 1942–51). Also excluded from this discussion is the exploitation of populations which are under more or less complete control and can be harvested in their entirety at any desired time: in other words, "farming". In commercial fish farming, where the product is harvested and marketed by the farmer, the distinction from the exploitation of wild populations is generally simple and clear-cut. In sport fisheries, on the other hand, the product is essentially the capture of the fish rather than the fish itself, and an almost continuous gradation exists. One can recognise, for example, the following series of situations:

1. Placing fish in a restricted area of water and maintaining them by artificial feeding until they are caught by anglers paying a fee for the privilege.

2. Placing fish of takeable size in natural rivers or lakes with the expectation that the majority will be caught by anglers within a few weeks.

3. Placing young fish in natural waters where they will feed and grow naturally for one or more years before becoming subject to capture.

4. In waters where a population maintains itself naturally, adjusting its level of abundance by either adding more fish or destroying or removing some of those already there, so as to obtain a desired result.

5. Increasing the carrying capacity of bodies of water by adding to the spawning areas, or the food supply, or the cover, or by removing predators.

All these involve some degree of farming, but all except the first two deal with wild populations and are therefore also subject to the principles discussed in the main part of this paper. The typical fishery, however, still contains no element of farming, but is concerned with a population inhabiting an area of water too large to be susceptible to measures of environment improvement and being exploited under conditions in which addition of fish to the population is not economically practicable.

In such a fishery the object of exploitation is to take a continuing crop from a wild population, and fisheries management has as its principal aim the raising of the crop to the optimum level at which it can be maintained. In doing this almost the only tool available is the adjustment of the amount and kind of exploitation. Definition of the optimum level of crop is not always easy; the simplest and most widely used is the maximum total weight of catch. This assumes that the value of a fish is directly proportional to its weight, but in practice this is often not true. In sport fisheries the value of a fish usually rises more rapidly than the weight. A number of polls of New Zealand anglers have shown that a large majority would prefer a catch weighing 5lb. composed of 2 fish of 2½lb. each, to a catch weighing 7lb. but composed of fish of only ½lb. each. In commercial fisheries, also, there is sometimes a preferred size which will bring a better price per lb. than either larger or smaller fish. This preferred size may occur at any point in the size range available for capture; an extreme case is probably presented by the New Zealand freshwater eels, which are now being commercially exploited, but which only find a market in about the 1lb. to 3lb. size range. In such situations the catch giving the greatest gross financial return may be produced under conditions rather different from those producing the maximum weight of catch, although the latter conditions are much less difficult to determine and usually provide the best basis for a useful working hypothesis.

In practice the immediate objective of a commercial fishery is the maximum net financial return rather than the maximum gross value. The conditions producing the maximum financial return are generally different from those giving the maximum total weight of catch and are still more difficult to determine since it is necessary to consider also the cost of production. The difference from the conditions giving the greatest catch is particularly large when the maximum weight is obtained by reducing the population to a fairly low level. In these circumstances the fishing effort required to obtain the optimum catch may be disproportionately high, so that costs of production rise correspondingly. This aspect of the problem has however so far received little attention.

In managing an exploited fish population the two main concerns are the maintenance of a sufficient breeding population, and the adjustment of the catch, as to both the quantity and the size and age of the individuals in it, so as to keep the catch at the optimum level. Historically, there has been a gradual swing in attention from the first to the second of these approaches, but it was early appreciation of the significance of the first factor which led to the formulation of the two great fallacies that are still firmly embedded in popular thought on the question — that it is necessary to protect fish during the spawning season — and that it is necessary to fix size limits so that every fish has a chance of spawning at least once before it is caught. Realisation that the value of a mature fish as a potential breeder is approximately the same during the previous season as at the spawning time, and of the high fecundity of many fish and the efficiency of their reproduction, is leading to the rejection of these principles as being of general application.

Many commonly exploited fish, such as the gadoids (Parrish 1956) and herrings in the sea and sunfishes and perches (Langlois 1954) in freshwater, are so prolific that protection of the breeding stock is unnecessary. This is shown by the fact that variations in the strength of year-classes are often due to the effect of environmental conditions on the survival of young fish and not to the quantity of eggs produced. In fish such as the Salmonidae which are less prolific and often have only limited areas suitable for spawning, it may be necessary to pay more attention to the preservation of the breeding stock. This aspect has been of great importance in the Pacific salmons. Here the most important aspect of management is the adjustment of the fishing effort in the inshore waters and river mouths to ensure that the desired quantity of spawners can pass through and reach the spawning grounds upstream. The primary objective is, of course, to ensure that a sufficient number of spawners pass upstream to provide adequately for the next generation. But studies aimed at determining this quantity have also shown that there is an optimum, and not merely a minimum escapement, which should be aimed at since in these and other Salmonidae the efficiency of reproduction may be reduced as the number of spawners in a given area increases. Above a certain level the reduction in efficiency may lead to an actual decrease in the numbers of the next generation (Hunter 1959, Thompson 1962). This decrease in efficiency may be due in different circumstances to various factors, such as the destruction of the eggs of early spawners by those coming later, competition for food or territory between the fry when they begin to feed, and intraspecific predation among the fry.

Provided that the number of spawners is adequate to maintain recruitment, the object of management becomes the adjustment of exploitation so as to produce the optimum catch. The phenomenon on which this method of management depends is the variation with time in the total weight of the survivors of any group of fish, and its basic tool is the adjustment of the size range over which fish may be caught, in accordance with the rate of exploitation. The variation in the weight of the group arises from the relation between the growth rate and the mortality rate. In any year class the growth-rate is initially higher than the mortality rate so that the combined weight of the survivors rises; later however the growth rate falls below the mortality rate, and the combined weight consequently falls until it reaches zero when the year-class has died out. There is therefore a time when the weight of the year-class is at its peak value, and the heaviest possible catch would be obtained if the entire group were harvested at this time. This, of course, is not practicable in fishing as distinct from farming, and some of the fish which have reached the age at which cropping begins will always die natural deaths. To obtain the heaviest catch, exploitation must therefore begin sometime before the year-class has reached its maximum weight, and the less efficient the exploitation the earlier it must commence. It can be shown that the heaviest catch is obtained when the ratio of the number of fish caught to the total number reaching takeable size is the same as the ratio of the weight of a fish at the limiting size to the average weight of all the fish caught (Allen, 1954). For example, in a fishery in which one quarter of the fish reaching takeable size were caught (the other three-quarters dying natural deaths), and the average weight of the fish actually caught was 1lb., the maximum total weight of catch would be obtained if the smallest fish which could legally be caught weighed ¼lb. If it were found later that a higher proportion of the fish were being caught it would be necessary to raise the minimum size at capture until the ratios were again equal.

Figure 1 illustrates the form of the relation between the minimum size at capture (L), the proportion of fish reaching takeable size which are ultimately caught (R), and the weight of the catch. The curves (A, B and C) corresponding to various minimum sizes show that for any minimum size the heaviest catch is obtained with an appropriate value of R and that higher or lower values give smaller catches. The enveloping curve shows the catch obtainable for successive values of R when the minimum size is continuously adjusted to the optimum value. It is evident that the weight of the catch increases with R, until, as stated earlier, the maximum catch is obtained when R equals unity and all fish are caught as they reach takeable size. It follows that the yield from a fishery cannot be reduced by overfishing as long as the size limit or other conditions allow adequate reproduction and the minimum takeable size is kept at the appropriate value for the intensity of the exploitation.

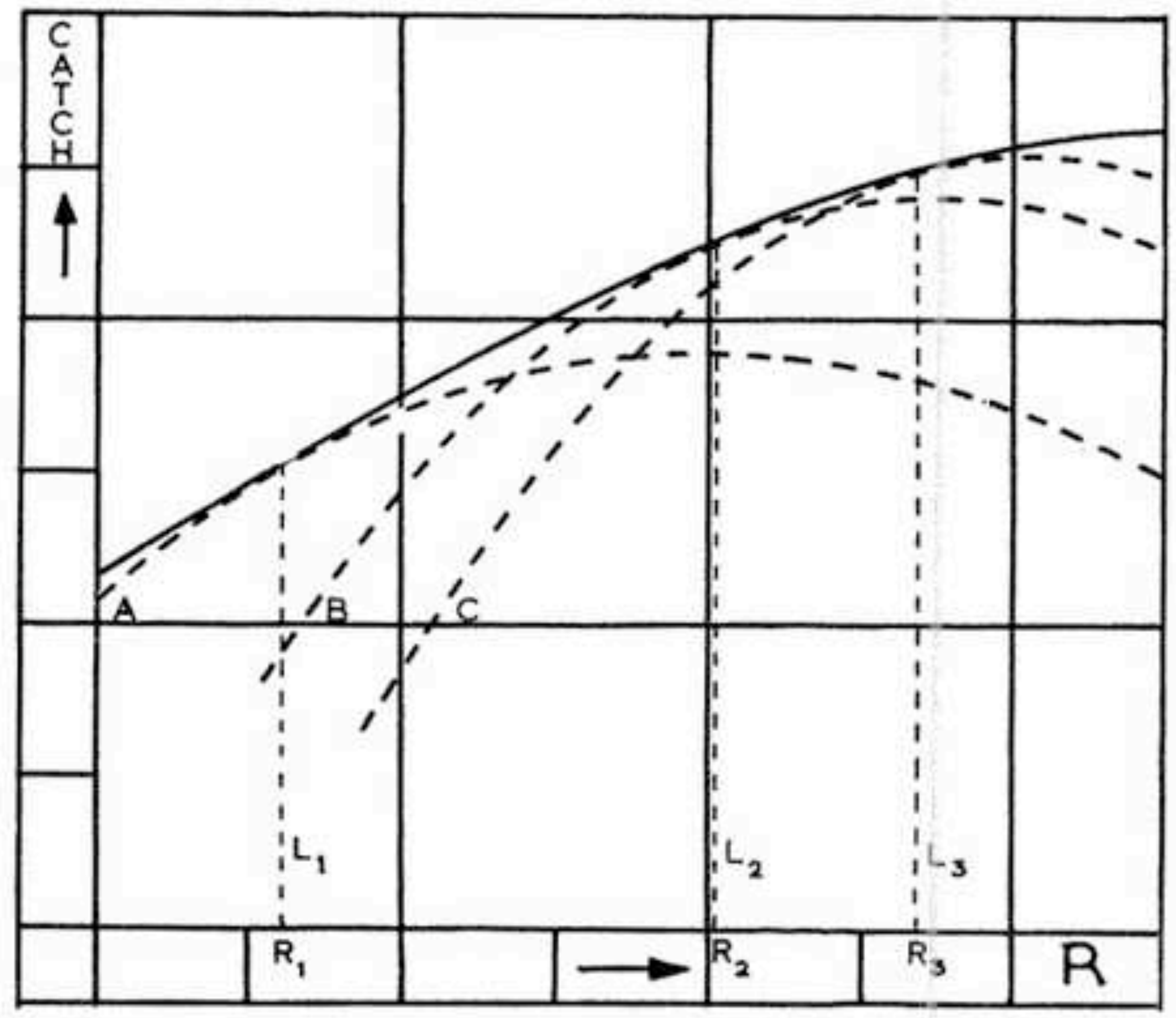

FIGURE 1. *Hypothetical case illustrating the relation between the weight of catch, size-limit, and proportion of takeable fish caught (R). The three broken curves (A, B, C) show the weights of catch obtained for successive values of R when the population is fished with size-limits L_1, L_2, L_3 where these are the optimum size-limits corresponding to rates of exploitation R_1, R_2, R_3, respectively. The solid enveloping curve shows the maximum catch which can be obtained (i.e. with optimum values of the size-limit) for all values of R. (after Allen* 1954).

This discussion has, so far, assumed that the optimum catch is the heaviest. If it is taken to be that of greatest gross value, no essential change is involved as precisely similar calculations can be employed substituting values for weight at all points. If however the optimum catch is that giving the greatest net financial return, it is necessary to assess also the abundance of the stock corresponding to any given exploitation rate and minimum size and to attempt to estimate from this the catch per unit effort and so the costs of production. This will involve considerably more elaborate calculations.

Successful application of these principles in practice requires the fulfilment of several conditions. These include:

1. Sufficient information must be available to enable the optimum minimum size to be determined.
2. The fish must be susceptible to capture over a sufficient part of the life-cycle, to include the stage at which exploitation should operate to obtain the optimum catch.
3. It must be practicable to restrict the taking of fish to the size range that is theoretically desirable.

Estimation of the optimum minimum size requires, basically, knowledge of the growth rate and of the rates of mortality due to natural causes and to capture. Determination of the growth rate is frequently fairly simple, but estimation of the mortality rate is usually complex and various indirect methods have to be used to meet different situations. The biological characteristics of the population must also be known to determine the extent to which different sections of the fishery operate on the same or different populations, and whether fish move into and out of the fishery at different stages of their life history. Attempts to deal with these complications have led to the building up of a large body of mathematical theory and techniques, some of which may ultimately prove of value in the study of the population dynamics of animals other than fish (Ricker 1958, Beverton and Holt 1957).

The second condition is satisfied in many fisheries. These include commercial trawl fisheries such as those for some gadoids and flatfish and also many freshwater sport fisheries such as those for sunfishes, cyprinids, etc., although even in those there is commonly a minimum size below which fish will not be caught. It does not however apply in fisheries where for biological or geographical reasons only fish of a particular size range are caught, such as the traditional inshore commercial fisheries for Pacific salmon which only take returning mature migrants. In many trout fisheries in New Zealand where the fish are large and fast growing small fish are not caught even though present, and consequently the optimum size limit can have no practical effect (Allen and Cunningham 1957).

Application of the optimum minimum size in practice requires either methods of fishing which do not take fish below the limit, or the return unharmed of any undersized fish caught. The first alternative can be achieved with reasonable accuracy in many net fisheries both trawl and set net, where the mesh to be used can be laid down correctly for the particular species concerned. It breaks down however in some mixed net-fisheries where the catch may be composed of a variety of species having different optimum mesh sizes. As undersized fish taken in the nets are often dead or moribund at capture, and so cannot be returned it may be virtually impossible to operate such a fishery under optimum conditions. Size limits can sometimes be more accurately applied in hook-and-line fisheries, both commercial and sporting, if fish are handled individually alive so that any undersized can be immediately returned. Even here however it may be difficult to return the fish in good condition, as, for instance, when they have been brought up from deep water. It is likely that this occurs in the line fishery for groper in New Zealand.

This discussion has so far assumed that the growth rate of the fish is independent of the population density. This is not invariably true. If they are not independent, perhaps due to competition for food, then the simple theory requires modification. In general, there is little evidence of variations in population density due to fishing pressure affecting growth rate in commercial marine species, but this may occur in some freshwater sport fisheries, particularly for trout (Allen 1951).

When intra-specific competition for food does occur, the amount of food produced at the next lower trophic level imposes an overall limit on the yield obtainable from a fishery, although the yield must inevitably be much less than the amount of food available from the lower level. Two factors contribute to the difference: the efficiency of conversion of food into the bodies of the fish; and the efficiency of cropping of the fish population by the fishery. Efficiency of conversion increases with the rate at which the fish are growing and therefore generally tends to diminish as the fish become older; it rarely exceeds 20%. Efficiency of cropping is reduced both by the loss of fish which die from natural causes before reaching the age at which they begin to be caught, and by natural mortality after this age. In the presence of competition, therefore, both efficiency of conversion and efficiency of cropping are increased by reducing the age at which fishing is started and both therefore tend to cause the optimum size limit to be less in the presence than it is in the absence of competition.

REFERENCES

ALLEN, K. R., 1951: The Horokiwi Stream — a study of a trout population. *Fish. Bull. Wellington, N.Z.* 10.

ALLEN, K. R., 1954: Factors affecting the efficiency of restrictive regulations in fisheries management. I. Size limits. *N.Z. J. Sci. Tech.* 35, B: 498–529.

ALLEN, K. R., and CUNNINGHAM, B. T., 1957: New Zealand Angling — 1947–1952. *Fish. Bull. Wellington, N. Z.* 12.

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

HUNTER, J. C., 1959: Survival and production of pink and chum salmon in a coastal stream. *J. Fish. Res. Bd. Canad.* 16: 835–886.

LANGLOIS, T. H., 1954: *The western end of Lake Erie and its ecology.* J. W. Edwards, Inc., Ann Arbor, Mich.

N.Z. MARINE DEPARTMENT, 1942–51: Annual Reports of the New Zealand Marine Department for the years 1942–1951 inclusive.

PARRISH, B. B., 1956: *The Cod, Haddock and Hake;* in *Sea Fisheries — their investigation in the United Kingdom.* Ed. M. Graham. Edward Arnold Ltd., London.

RICKER, W. E., 1958: Handbook of computations for biological statistics of fish populations. *Fish. Res. Bd. Canad. Bull.* 119.

THOMPSON, W. F., 1962: The relationship between numbers spawning and numbers returning in Pacific salmon. *H. R. MacMillan Lectures in Fisheries, Univ. of British Columbia,* 1962: 213–225.

THE EXPLOITATION OF BIRDS

BERNARD STONEHOUSE

Department of Zoology, University of Canterbury

In comparison with fish or mammals, birds offer little scope for large-scale exploitation. Although for centuries they have provided food, feathers, oil, nitrogen-rich guano and sport for man's use and enjoyment, the volume of products obtainable by periodic harvesting from even large populations of birds has seldom attracted more than local interest. Attempts to satisfy wider markets, e.g., to provide plumage for millinery, have invariably led to disaster; primitive and civilised man alike have frequently been misled by the apparent abundance and stability of breeding colonies and migrating flocks. Even when the need for conservation has been fully recognised, the temptation to over-exploit has seldom been resisted, and the history of man's exploitation of birds is a sorry and almost consistent record of devastation.

Populations cropped closely for food but otherwise protected by resident humans have generally fared better than those open