RESTRICTED

INTERNATIONAL COMMISSION FOR THE NORTHWEST ATLANTIC FISHERIES

Serial No. 2717
(B.g. 7)

ICNAF Res.Doc. 72/26
(also ICNAF SAC 72/25)

ANNUAL MEETING - JUNE 1972

SCIENTIFIC ADVICE ON CATCH LEVELS

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Introduction

Several International Commissions and other bodies are concerned with the regular setting of annual catch quotas, or other measures for the management and conservation of the resources which are their responsibility. Agreement on the level of these quotas is more easily reached if they are determined on some objective scientific criterion. Thus both the International Whaling Commission (in relation to baleen whales in the Antarctic), and the International Commission for the Northwest Atlantic Fisheries (in relation to the herring on Georges Bank) have asked their scientific advisers for guidance on the correct catch levels. Apart from the continuing difficulty in making precise assessments concerning any wild animals, this guidance is difficult to provide without some agreed basis on how the "correct" catch should be calculated. This note is intended to review some of the possible bases.

Sustainable yield

The concept of a sustainable yield, or maximum sustainable yield is based on a simplified model of a natural animal population. If such a population has been reduced below the limiting carrying capacity of its environment it will tend to increase. In the simplified case the rate of increase will depend solely on the abundance of the population (or the abundance of the exploitable part of the population).

If the annual removals by man (catch) are equal to the annual natural increase, clearly the size of the population will remain unaltered, and such a catch can be sustained indefinitely. For such a situation the sustainable yield can be defined as being equal to the net value (rate) of natural increase, and represents the yield which can be maintained indefinitely while also maintaining the stock size at the same level.

This natural increase, and hence the sustainable yield, is small for very small populations - at least in absolute value, if not as a proportion of the population - and is also small for large populations as they approach the limiting value. It will be greatest for some intermediate level of population which is the population abundance giving the maximum sustainable yield (MSY)(see Figure 1).

If the population is less than the level giving the MSY, no catch greater than the sustainable yield can be maintained for more than a short time. The population will be reduced each year, by an amount equal to the difference between the catch and the sustainable yield. The sustainable yield will in turn be reduced, leading to an ever faster reduction, which, if the amount caught is maintained by fishing harder and harder, will in a fairly short time lead to the "commercial extinction" of the stock.

On the other hand, if the population is above the MSY level, catches greater than the sustainable yield corresponding to that population level, can be maintained indefinitely, provided that they are not greater than the MSY. This is because, as these catches reduce the population toward the MSY level, the sustainable yield will increase. When the population is reduced to the level at which the sustainable yield is equal to the catch, then the catch can be maintained indefinitely without further change. The "maintainable yield" may then be defined as the largest catch that can be maintained from the population, at whatever level of stock size, over an indefinite period. It will be identical to the sustainable yield for populations below the level giving the MSY, and equal to the MSY for populations at or above this level.

Lag effects

The simplified description above does not in fact fit precisely the actual situation in the sea. Two main divergences may be mentioned; the fact that the net rate of natural increase will depend on past events as well as on the current abundance; secondly, there are many sources of variation, other than exploitation, in the abundance of populations. The first of these is particularly significant for whales, and the second for some fish populations, especially in temperate and sub-arctic waters.

For whales, the net rate of natural increase in the exploitable part of the population is usually expressed in numbers, and is the difference between the number of animals dying from natural - non-fishery - causes, which will be some fairly constant proportion of the number in the current stock, and the numbers of young animals - the recruits - entering the exploitable stock, which will be proportional to the numbers of mature animals alive some years previously. If the abundance of the stock is changing, the concept of a sustainable yield becomes complicated. Suppose the stock has recently been reduced, then the recruits during the year will have come from a parent population that is greater than the current mature stock. The number of recruits may then be appreciably greater than the number of natural deaths, so that quite a large catch could be taken, and still leave the population at the end of the year the same size that it was in the beginning. However, such a catch could not be sustained indefinitely, since the number of recruits in later years will decrease. For such a stock a number of different terms may need to be defined.

The replacement (actual) yield for a given year is the catch which, if taken, will leave the abundance of the population (or the exploitable part of the population) at the end of the year the same as at the beginning. This is specific to a particular year, and includes no concept of continuity. Even if the replacement yield is taken in one year, it is unlikely that the replacement yield in the following year will be the same, unless this population has remained at around the same abundance for some time (not less than the time span between birth and recruitment).

The term "sustainable yield", by definition, refers to an equilibrium situation, and cannot be used in a situation of changing stock sizes. The yield that might be taken can, however, be compared with the equivalent sustainable yield, which may be defined as the sustainable yield from a population of the same abundance (or with the same abundance of the exploited phase), which has been maintained at this abundance for a long period, and which hence is the value that would be obtained from reading off the yield corresponding to the abundance on a figure such as Figure 1.

It is evident that if the stock (or its exploitable phase) has recently been decreasing, and the recruits are the offspring of an earlier and larger parent stock, the replacement yield is greater than the equivalent sustainable yield of the present stock size. If, on the other hand, the stock has recently been increasing, the replacement yield is equal to the difference between the recruitment from a smaller parent stock and the natural mortality of the greater present stock, and may therefore be lower than the equivalent sustainable yield of either the parent stock size or the present stock size.

In a situation in which the stocks have remained above the level of maximum sustainable yield, the maintainable yield, as defined above, which is equal to the maximum sustainable yield, is not affected by recent changes in stock size. If the stocks are changing below the level of MSY, however, the maintainable yield is neither equal to the actual yield, nor to the equivalent sustainable yield of either parent or present stock size, but will be at a level between the equivalent sustainable yields of these two stock sizes. Maintenance of the catch at the level of maintainable yield will ultimately lead to an equilibrium situation with a stock size in between the original "parent" and "present" stock sizes.

It should be noted that if the stocks have recently been decreasing, the maintainable yield is lower than the replacement yield, whereas if the stocks have recently been increasing, the maintainable yield is the higher of the two. Any catch lower than the maintainable yield, if kept at the same level for a for a sufficient period of time, will ultimately lead to a rebuilding of the stocks, even though at short term it may cause some decrease.

It may be of interest to consider some of the recent stock and yield estimates of the Antarctic fin whales in the light of the above considerations.

Natural fluctuations

For fish, in the narrow sense, the lag effects are less disruptive to the simple model than natural fluctuations, among which changes in year-class strength are the most striking. Where differences in year-class are very large, it is likely that when a strong year-class enters the fishery the stock will increase whatever catch is taken (within practicable limits); when a succession of strong year-classes is replaced by a run of poor ones, the stock may decrease if even fishing is cut back virtually to nothing. In this situation it is difficult to talk about a sustainable, or maintainable yield.

However it is precisely in the situation of a declining stock, with strong year-classes being replaced by weak ones, that scientists are often asked for advice (e.g. regarding herring in sub-area 5 of ICNAF). Sometimes the advice is requested in general terms, allowing the scientists to describe the situation in detail, but leaving the decision as to the control measures (such as the level of catch quotas) to administrators. At other times the administrators cannot decide easily among themselves on the amount of catch that should be taken, and ask the scientists for an explicit figure of the "correct" or "desirable" catch. This requires some objective basis for determining this, analogous to the sustainable or replacement yield for whales.

The simplest case is when the abundance of recruits (strength of the year-class) is independent of the abundance of the parent stock. All that management can do is make the best use of whatever recruitment happens to occur. That is, to maintain fishing at whatever is considered the optimum position on the yield-per-recruit curve. The choice of the position of the optimum is not simply a biological matter, unless it is chosen at the level of the maximum yield per recruit - if this exists and occurs at a moderate level of fishing. Usually the optimum level will be that giving slightly less than the maximum yield per recruit, but at a much smaller fishing mortality. Unless there are marked density-dependant changes in mortality or growth this optimum will occur at some fixed value of fishing mortality.* For those few fisheries which are fortunate enough to have immediately available a measure of total effort which provides a measure of fishing mortality consistent from year to year, the optimum level of fishing can be defined at once in terms of total fishing effort, without the need for year to year adjustments.

Usually difficulties of standardization in a multi-national or multi-gear fishery, or changes in the effectiveness of a nominal unit of effort, will mean that the amount of fishing in each year will have to be controlled in terms of total catch. The scientists can, in principle, given adequate information, calculate what the value of this catch should be, taking into account the strength of the year-classes already present in the fishery, and those that will recruit during the year in question. This catch might be defined as the "catch for optimum harvesting rate".

Often a precise optimum level of fishing mortality cannot be defined, or cannot be agreed upon. It is still possible to calculate the catches in each year which would be required to attain any prescribed value of fishing mortality. These values may be those which occurred at some previous time when it was believed that the fishery was in a better condition (in some general, unspecified sense) than the present, or some convenient figure, which the scientists believe approximates to the optimum condition. In this way the scientists, without pre-emptingthe administrators'duty to decide on the objective of management, can provide some figures derived in a reasonably objective way, on which it may be possible for agreement to be reached. An example of such calculations are those made by the Assessments Sub-committee of ICNAF for the cod stock at West Greenland. This stock undergoes moderately strong year-class fluctuations, and estimates have been made of the catches required to attain fishing mortalities of 0.8 and 0.6.

For most fish stocks there is a reasonable likelihood that changes in the abundance of the adult stock brought about by fishing will have some effect on the average level of recruitment, though the extent of such effects may not be known. When they are known, various catch rates can be objectively determined.

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* It may be noted that the optimum fishing mortality, exerted at a constant rate during the whole of its life, above the age at first capture, is the same for any strength of year-class, but slightly larger catches would be obtained by fishing less hard when the fish are young, and harder when they are old, i.e. concentrating catches more at the age when the biomass of the year-class is at its maximum. The fishing mortality in a particular year which leads to the greatest catch over a period will be mean of the best mortality for each year-class present, weighted according to their strengths. If the year-classes are equal, this will be equal to the optimum constant rate for a single year-class during its entire life. If there is a big variation in year-class strength there would be some theoretical advantage, other things being equal, in fishing slightly harder when the strongest year-class present is old (since they will not grow much more, but will suffer losses by natural mortality), and less hard when strong year-classes have just recruited. However the theoretical increases in yield are not likely to be great, and it is simpler to keep, as the objective, the same constant fishing mortality independent of year-class changes.

The management of salmon stocks generally corresponds to this situation. The relation between spawning stock (escapement) and subsequent recruitment is usually known, and normally has a maximum at some moderate to high level of spawning stock. Catches are adjusted to obtain some desired level of escapement. This might be the level giving - under average conditions - the maximum recruitment, though a more nearly optimum strategy would be to take a rather larger catch, such that the immediate gain in increased catch, would be more than the expected loss (with or without any discounting). In such a situation it is possible to define purely on biological grounds, a catch for maximum recruitment; and also, using both biological and economic considerations, a catch for optimum spawning (or optimum escapement). The nature of the salmon fisheries - the movement of the pre-spawning fish through the fishing area during a short season and the spawning and subsequent death of all those not caught - makes relatively easy the visualization of the catches as defined here, since they are equal to the number of fish arriving at the fishing grounds, less the escapement required for maximum recruitment, or the optimum escapement respectively. However, the same definition could apply to any fishery, though in practice it can only be applied in those few fisheries for which the stock/recruit relationship is well known. It may be noted that these definitions lead to very great fluctuations in the catch that should be taken. The population of the stock (run) that is harvested decreases rapidly with decreasing run, and falls to zero as soon as the size of the run drops below the target escapement.

Unfortunately, for most fisheries there is little firm information on the relation between adult stock and average recruitment. An obvious example of the resultant difficulties in defining objectively any specific catch quota is occurring for both the herring and haddock on Georges Bank (sub area 5 of ICNAF). For the haddock there has been an unprecedented run of poor year-classes (those of 1964 to 1970 inclusive), which, combined with exceptionally heavy fishing in 1966 and 1967, has reduced the stock to a very low level. Though the more recent of the weak year-classes (since about 1968) were associated with a low parent abundance, the earlier ones can form moderate to large stocks - in fact stocks of about the same abundance as those giving the very large year-classes of 1962 and 1963. Thus although it is highly probable that the decline in adult stock is among the causes of the run of poor year-classes, it is certainly not the only cause.

The ICNAF scientists have therefore pointed out that the sensible policy is to take action to build up the spawning stock, since this will almost certainly increase the probability of future year-classes being of average strength or better. However there is no guarantee that, even if in the extreme case catches are cut to zero, there will be any increase in recruitment compared with what would have occurred with unrestricted fishing.

This means that, since there is no good knowledge of the stock/recruit relation, there is no catch uniquely definable on scientific grounds as the best catch, though the optimum policy, for a stock at a low level, must lie between catching nothing (for the most rapid re-building of the adult stock), and fishing at the rate which makes the best use of those fish which have, in fact, recruited.

A catch that can be objectively defined, which will often lie in this range, and which may also be a reasonable catch to take for the benefit of the fishery, is the replacement catch. This can be defined, in exactly the same way as before, as that catch which will ensure that the stock at the end of the year is the same as that at the beginning of the year. The stock in question could be the spawning stock, or the total fishable stock, and its magnitude could be expressed either as weight or numbers. (The use of numbers makes calculations easier and clearer.)

For example recent reports of ICNAF's Assessment Sub-committee have set out the changes in the numbers in the Georges Bank haddock stock, separating additions through recruitment, and removals by fishing and natural mortality. Thus during 1970 there were 16 million recruits, and some 3 million fish died through non-fishing causes, i.e. a net natural increase of 13 million fish, which was about twice the catch in numbers (ca 5.3 million). However because the deaths (through both fishing and natural causes) were mainly of large fish (average age in U.S. landings was [illegible] years, of 2.4 kg weight), the deaths (in weight) were much larger than the weight of recruits, though this was almost balanced by the growth of the survivors. Thus the catch of 12 000 t was about equal to the net natural additions, i.e. the catch was equal to the replacement catch, in weight, though less than the replacement catch in numbers.

The replacement catch varies very greatly. Thus between 1968 and 1969 the natural deaths in the Georges Bank were 5 million fish and the recruits only 1 million; the stock, in numbers, could only be maintained by introducing 4 million fish onto the grounds, i.e. a replacement catch of minus 4 million fish. Conversely, when a very strong year-class recruits to the fishery the replacement catch would be large, and require a fishing effort well in excess of that giving the optimum mortality. The variation in the replacement catch, defined in terms of weight, will be less severe. Even so it is clear that the replacement catch cannot be used blindly as the determinant for the catch to be taken in any particular season. It will, however, provide some sort of guide as to whether the proposed action will improve things (proposed catch is less than the replacement catch), or allow them to get worse. Unfortunately it is not a perfect guide. For example the average condition of the stock, over a period, will only be maintained if, when a strong year-class is entering the fishery, the opportunity is taken to build up the stock to balance the occasions when poor year-classes occur.

Regulations, such as catch quotas, based on a catch defined in terms of a particular harvesting rate would seem to form a better guide. Though the optimum mortality cannot be determined unless the form of the stock/recruit relation is known, an optimum rate (for any given economic or social policy) can be calculated on the assumption of constant recruitment. If the stock is at a low level, the optimum rate, if recruitment is affected by the abundance of adult stock, must be somewhat less. Therefore an upper bound can be set on the desirable level of catch. Further, various assumptions can be made concerning the form of the stock/recruit curve, and the corresponding relation between fishing mortality and total yield calculated. The scientific advice could then be presented in four columns, the first would list the possible objectives, and assumptions that could be made about recruitment, the second and third columns would then give the fishing mortality necessary to achieve the objective, and the corresponding catch in the forthcoming season. For example, for a purely hypothetical stock the information could be given as follows:

Objective	Recruitment	Optimum F	Catch
Maximum physical yield	constant	1.2	110 000 t
" " "	moderately density-dependent	0.9	84 000 t
" " "	strongly density-dependent	0.6	59 000 t
Maximum economic yield 1/	constant	0.8	76 000 t
" " "	moderately density-dependent	0.7	68 000 t
" " "	strongly density-dependent	0.5	50 000 t

1/ For a certain set of assumptions on costs and prices

While this still leaves a wide choice open - a range of over two-fold - the more extreme values might be ignored, so that the real choice may not be large, and the information provides a useful basis for determining management action.

Economic considerations

The definitions of the target catch have been made largely on biological grounds. It is not the aim of this note to discuss the various objectives that may be taken into account when setting regulations. However it should be stressed that, under nearly any circumstance, it will be more desirable to fish at a rate somewhat below the level giving the maximum sustainable yield, rather than at the maximum.

Also, in a depleted stock calculations can be made of the replacement yield, or equivalent sustainable yield, but this should not imply that these are the proper objectives. Rather action should be taken to rebuild the stock (especially of whales, where the recruitment is nearly proportional to the adult stock). This is done most rapidly by cutting the catches to zero for a period. The optimum strategy between this (making the greatest present sacrifice for the maximum long-term benefit), and merely maintaining the situation (making no present sacrifice) will be determined by a number of factors, mainly economic. This will include the relative values placed on present and future catches, alternative employment for the excess men and equipment in the present fisheries, etc. For example it would be much easier to stop for a period the off-shore herring fishery on Georges Bank, since the vessels concerned can easily switch to other fisheries, than to do the same for Antarctic whales.

The general policy to be followed by the management body - to aim for the maximum physical yield from a given stock, or some lesser physical yield but with greater economic benefits, to rebuild a depleted stock quickly, or merely prevent its further decline - must be determined by that body taking all factors into account and cannot be decided purely on biological grounds. What can be determined by objective scientific calculations is the actual procedure to be followed - specifically the catch to be taken in each season - to implement the chosen policy. This note has been concerned purely with a discussion of this second step.

Summary

The sustainable yield, or maximum sustainable yield, has been used to provide, on an objective scientific basis, target figures for the catches to be taken from a heavily exploited stock that is under regulation. The simple concept of sustainable yield does not, however, provide a completely adequate guide when the biological system is complex. Certain other quantities are defined which correspond more closely to the biological reality:

> The replacement yield (or actual yield) is that catch which will leave the abundance of the stock at the end of the year the same as it was in the beginning.
>
> The equivalent sustainable yield from a given stock is the sustainable yield from an equilibrium stock of the same abundance.
>
> The maintainable yield is the yield that can be taken from the stock indefinitely over a long period. It may cause some initial changes in the stock.
>
> The catch for desired harvesting rate is the catch that would be obtained by exerting a particular desired fishing mortality during the season in question.

One or other of these will provide a better guide for management, depending on the nature of the divergence from the simple model. In whale populations the major divergence is the lag between changes in adult stock, and changes in recruitment; replacement yield or maintainable yield are the most useful. In many fish stocks fluctuations in year-class strength are more important: catch for desired harvesting rate may be better.

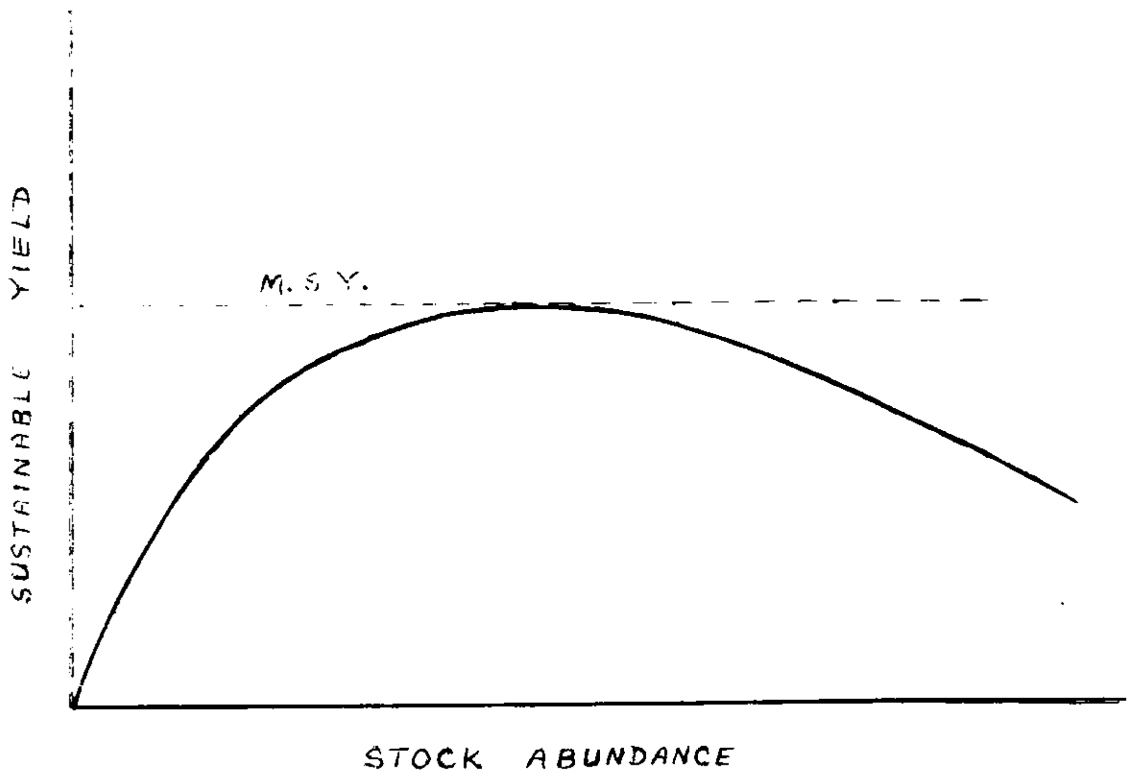

Fig. 1.