SCIENTIFIC ADVICE ON CATCH LEVELS

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ABSTRACT

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—the replacement yield, the sustainable yield from a stock in equilibrium, the maintainable yield, and the catch for desired harvesting rate—are defined which correspond more closely to the biological reality.

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.

Various fishing research organizations are concerned with the setting of annual catch quotas or other measures for the management of the resources which are their responsibility. Agreement on the level of these quotas is more easily reached if they are determined by objective scientific criteria. 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.

At present there is not a single theoretical model for determining this catch that combines all the desirable features of (a) being readily understandable (at least in general outline) to the decision makers, (b) describing and predicting in a realistic manner, and to an acceptable degree of precision the events in every fish stock to which it may need to be applied, and (c) capable of being applied to a specific fishery without great demands in data and analysis. The models associated with Schaefer (1954) on the one hand and with Ricker (1958) and Beverton and Holt (1957) (in the simple form when no account is taken of fishery-induced changes in recruitment) on the other fail, for many important fisheries, to satisfy the second criterion. The density-dependent form of the Ricker-Beverton Holt approach is more satisfactory in this regard, but makes heavy demands on data and analysis. Despite these difficulties, and in the absence of a single uniformly acceptable model, some objective guidance can be given on the magnitude of the catches that can be taken from heavily exploited stocks, and such guidance is being used by many regional commissions [e.g., IWC (International Whaling Commission), Inter-American Tropical Tuna Commission, ICNAF (International Commission for the Northwest Atlantic Fisheries)] in framing regulations. This paper explores some of the bases of such guidance, in the hope of facilitating the future preparation of advice on desirable catch levels.

SUSTAINABLE YIELD

The concept of a sustainable yield as often applied in practice, and more particularly the idea of the maximum sustainable yield, is based on a simplified model of a natural animal population in which the population is treated as a single unit, ignoring the fact that there are individuals of different ages, etc.; it also ignores all disturbing influences on the population, other than removals by man. If such a population has been reduced below the limiting carrying

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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).

On the basis of this simple model, it is clear that if the annual removals by man (catch) are equal to the annual natural increase, 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 rate of natural increase and represents the yield which can be maintained indefinitely while also maintaining the stock size at the same level.

The rate of increase, as a proportion of the population, generally decreases as the population increases. The absolute value of this natural increase, and hence the sustainable yield, is small for very small populations 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 approximately 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 it will be equal to the MSY for population at or above this level. In the latter case harvesting the maintainable yield will involve for a short transitional period a change in population abundance as it is thinned out to the MSY level.

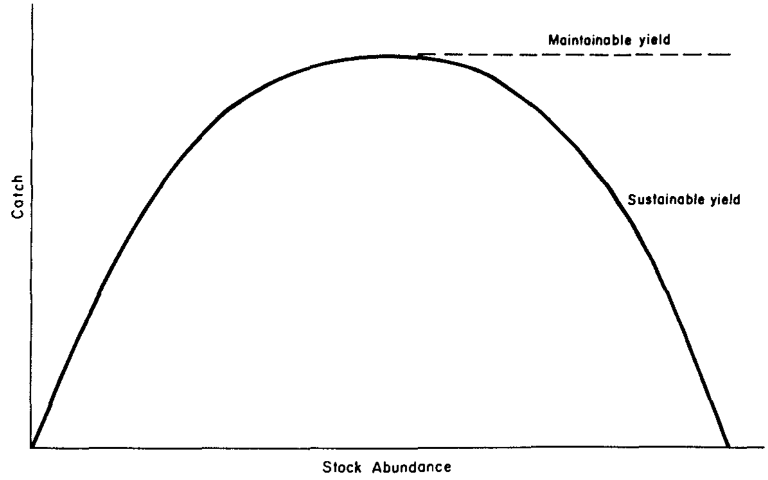

FIGURE 1.—Sustainable yield and maintainable yield as function of stock abundance.

The simplified description above does not in fact fit precisely the actual situation in the sea. Two main divergences may be mentioned: 1) the fact that the net rate of natural increase will depend on past events as well as on the current abundance and 2) there are many sources of variation, other than exploitation, in the abundance of populations. The most important of these for many fish species of commercial importance is natural fluctuations, especially in recruitment, caused by variations in environmental conditioning. Other causes of variation, e.g., changes in the availability or distribution of fish, will have significant effects on the success or otherwise of the fishery in a particular season, but will not be discussed here. The first of these is particularly significant for whales, and the second for some fish populations, especially in temperate and subarctic waters.

LAG EFFECTS

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 (nonfishery) causes, which will be some fairly constant proportion of the number in the current stock, and the numbers of recruits entering the exploitable stock, which will be closely proportional to the numbers of mature animals alive some years previously, at least at small to moderate population sizes. As the population approaches its equilibrium, unexploited level, the recruits will be less, or the mortality more, or both, than expected from a purely proportional relationship with population abundance. If the abundance of the stock is changing, the concept of a sustainable yield becomes complicated. If, for example, 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 yield for a given year is the catch which, if taken, will leave the abundance of 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 simple definition of the sustainable yield refers to an equilibrium situation and cannot strictly be used in a situation of changing stock size. When the population has been changing it may be convenient to define the (equivalent) sustainable yield as the sustainable yield from a population of the same abundance (or with the same abundance of the exploited phase), which has remained at this level of abundance for a long time. It is the value that would be obtained from reading off the yield corresponding to the abundance in a figure such as Figure 1. Hence if the catch taken is set equal to this sustainable yield, the population abundance will not, in general, remain unaltered.

It is evident that if the stock (or its exploitable phase) has recently been decreasing, and, as in the case of whales, the recruits are roughly proportional to the abundance of an earlier and larger parent stock, the replacement yield is greater than the 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 sustainable yield of either the parent stock size or the present stock size.

In a situation in which the stock is 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 stock is changing and is below the level of MSY, however, the maintainable yield is equal neither to the replacement yield nor to the sustainable yield corresponding to the abundance of either parent or present stock, but will be at a level between the 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 are below MSY level and 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 sufficient period of time, will ultimately lead to a rebuilding of the stocks, even though in the short term it may cause some decrease.

If the population is below the MSY level, setting the catch equal to the estimated sustainable yield will, as has been frequently pointed out, lead to an unstable situation. If the estimate used is only just too high the stock will start to decline, the gap between the catch and the actual sustainable yield will widen at an accelerating rate, and the stock will decline ever more rapidly until the catch is adjusted. As pointed out by Y. Fukuda (pers. comm.) this can occur, if there are natural fluctuations, even if the catch taken is exactly equal to the sustainable yield under average conditions. Suppose, for example, there is a poor year for reproduction, leading to reduced recruitment. Then the catch, if unchanged, will reduce the stock, and this reduced stock will have a smaller sustainable yield, even under average conditions. A fixed catch will then continue to deplete the stock at an accelerating rate. Similarly, a favorable if transient fluctuation and a fixed catch will result in a continuous increase in population to above the MSY level.

The significance of the differences among the various terms can perhaps best be illustrated with some hypothetical examples of different actions which might have been taken after the serious decline in the fin whale stocks in the late 1950's and early 1960's. For simplicity, it has been assumed that the stocks have been declining by 10,000 whales per year from a level of 120,000 in 1960 to 70,000 in 1965, figures which are roughly similar to the decline as estimated by the Scientific Committee of the IWC. Recruitment rate has been taken for the purpose of this example at 8%, recruitment age at 5 years, and natural mortality rate at 4%, which values were assumed to remain constant within the range of stock sizes of the examples (see Table 1).

TABLE 1.—Trends in population and catch of Antarctic fin whales, if, after 1965, catches were set equal to the replacement yield, or to the sustainable yield. (Thousands of animals.)

	Catch = replacement yield				Catch = sustainable yield			
Year	Stock	N[1]	R[2]	Catch	Stock	N[1]	R[2]	Catch
1960	120				120			
1961	110				110			
1962	100				100			
1963	90				90			
1964	80				80			
1965	70	2.80	9.60	6.80	70	2.80	9.60	2.80
1966	70	2.80	8.80	6.00	74.0	2.96	8.80	2.96
1967	70	2.80	8.00	5.20	76.88	3.08	8.00	3.08
1968	70	2.80	7.20	4.40	78.72	3.15	7.20	3.15
1969	70	2.80	6.40	3.60	79.62	3.18	6.40	3.18
1970	70	2.80	5.60	2.80	79.66	3.19	5.60	3.19
1971	70	2.80	5.60	2.80	78.88	3.16	5.92	3.16
1972	70	2.80	5.60	2.80	78.48	3.14	6.18	3.14

[1] N = numbers dying from natural causes = 4% of current stock.
[2] R = numbers of recruits = 8% of adult stock 5 years earlier.

If from 1965 onward, catch quotas had been introduced equal to the replacement yield, the stock would have been maintained at the level of 70,000 whales, and the quota would have been 6,800 whales in 1965, declining by 800 per year to 2,800 whales in 1970, after which the number would have remained at this level.

If, on the other hand, the sustainable yield had been taken every year the catch quota would have been 2,800 in 1965, slowly rising to 3,190 in 1970, then declining to 3,130 in 1973 and stabilizing at about 3,140 thereafter, at which time the stock size would practically have stabilized at 78,560 whales.

The highest constant annual yield which could have been taken from 1965 onward—the maintainable yield—would have been about 3,125 whales, which would have led to a stock size of about 78,200 whales by the mid-1970's (Figure 2a).

For the purpose of demonstrating the effect of increasing stock size, the effects of different catch quotas have been calculated for the situation in which the stock has risen from 70,000 to 80,000 whales over a 5-year period (say, from 1965 to 1970) by 2,000 whales per year. Catch quota equal to the replacement yield, which would maintain the stocks at 80,000 whales, would have been 2,400 whales in 1970, increasing by 160 whales per year to 3,200 whales in 1975, after which the figure would remain constant.

If the sustainable yield had been taken, the catch quota in 1970 would have been 3,200 whales, decreasing to 3,120 in 1974 and thereafter stabilizing at around 3,130, and a stock size of around 78,310 whales.

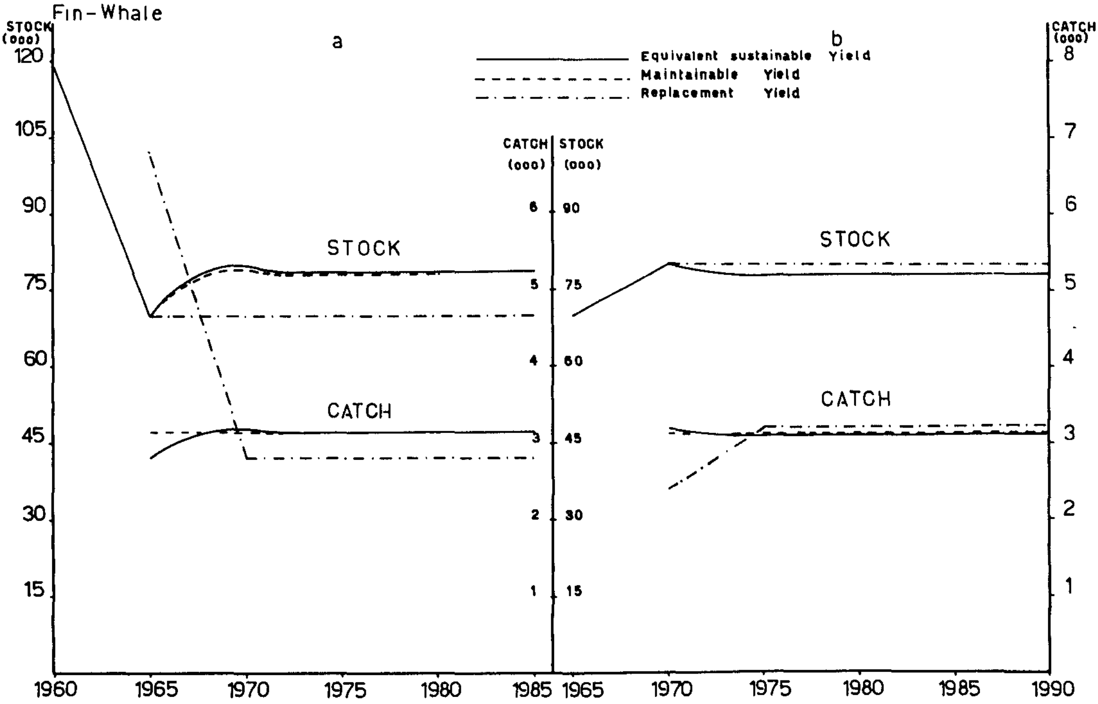

FIGURE 2.—Examples of catch level and stock size resulting from regulating catches of fin whales at the level of equivalent sustainable yield, maintainable yield, and replacement yield respectively, in the case that the regulations were introduced a) after a constant decline in the stock (in the example assumed to have taken place from 1960 till 1965) and b) after a constant increase in the stock size (in the example assumed to have taken place from 1965 till 1970). Parameters used in these models are specified in the text.

The maintainable yield would in this case have been 3,134 whales, leading to a stock size of about 78,360 whales in the later 1970's (Figure 2b).

These examples demonstrate some general features. Firstly, they show that catch regulations based on replacement yield, equivalent sustainable yield or maintainable yield will all lead to an equilibrium situation in which the stock size and permitted catch reach a stable level. In the case in which the stock has recently been changing, regulation based on replacement yield will maintain the stock at the level at which it was at the start of this regulation, but catches regulated at the level of sustainable yield or of maintainable yield will lead to a different stock level. If the stock had recently been declining, the long-range stock level and yield would then be rather higher than that based on taking the replacement yield, and if the stocks had recently been decreasing, the long-range equilibrium would be reached at a somewhat lower stock size. Although there are some differences in catch level between regulations based on sustainable yield and on maintainable yield in the first years after introduction, the long-term effects of these two criteria for regulation are very similar.

It would thus seem that replacement yield, which maintains the stock at the same level, but requires changing quotas in the first years, and maintainable yield, which is the highest catch that can be maintained indefinitely from the stock size available, but will lead to a change in stock size in the first years, will provide the best guide for whaling management decisions in situations in which stock sizes have recently been changing.

Any scientific advice on these matters should be clearly defined. Part of recent confusion about frequently changing estimates of permissible yield by the Scientific Committee of the IWC has been due to insufficient definition of the terminology as outlined above.

Finally, it may be noted, from the arguments given above, that the rate of increase of population depleted well below its level of MSY, but completely protected thereafter, is less than the net recruitment rate in an equilibrium situation. For example, for recruitment rate 8%, recruitment age 5 years, and natural mortality rate 4%, the net recruitment rate in equilibrium situation is 4%, but the rate of increase in recovering, unfished, population in any year would be about 3% of the stock size in that year, or about 3.5% of the size of the parent stock (the stock size 5 years earlier).

NATURAL FLUCTUATIONS

For fish, on the other hand, the lag effects on the average 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 classes 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 even if 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, when strong year classes are being replaced by weak ones, that concern about the management of the stock is likely to be greatest, and when scientists are often asked for advice (e.g., regarding herring in subarea 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 that in which 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 happened to occur, that is, to maintain fishing at whatever level is considered the optimum position on the yield-per-recruit curve. In the simplest situation the curve of yield per recruit as a function of fishing effort will have a clear maximum, for which the corresponding fishing mortality can be reasonably easily determined. This fishing mortality might then be considered as being one possible value of the optimum fishing mortality. However, in practice the yield curve will be quite flat in the neighborhood of the maximum. This may make determination of the position of the maximum difficult and will certainly mean that obtaining the absolute maximum (e.g., moving from the effort giving 99% of the catch to that giving 100%) will require a disproportionate increase in effort and hence in costs (Gulland, 1968a). Given particular values of the price of fish and costs of exerting unit fishing mortality, a mortality which will maximize the net economic yield can be calculated, and might be considered the optimum for the given economic situation. Different economic conditions will result in somewhat different optima, but for most conditions the optimum will lie within a fairly narrow range. It is, therefore, possible to define a target of the desirable fishing mortality in the middle of this range which will receive general acceptance, or at least, especially for a heavily fished stock, a minimum target at the upper end of this range. Whatever the precise objectives and economic conditions of any individual country participating in a fishery, the reduction of the amount of fishing to this target level should be desirable.

A more objective method of calculating a limiting value to desirable fishing mortality may be derived from considering the marginal yield, i.e., the increase in total yield achieved by adding one extra unit of effort (Gulland, 1968b). The marginal yield will be equal to the slope of the tangent to the curve of catch against fishing effort. It will always be less than the catch per unit effort, which is the slope of the line joining the point in the curve to the origin. The economic optimum, i.e., the greatest net economic return, occurs when the value of the marginal yield is equal to the marginal costs of a unit of effort. At the point giving the maximum physical yield the marginal yield will be zero. Clearly from any practical viewpoint, it would be undesirable to increase the amount of fishing beyond the level at which the value of the marginal yield is small compared with the costs of the extra unit of effort required to produce that yield. The question then arises as to what might be considered as small. An arbitrary figure, which has in fact been used in connection with the herring on Georges Bank (ICNAF, 1972) is a marginal yield equal to one-tenth of the original catch per unit effort in the very lightly exploited fishery. This is illustrated in Figure 3. The two straight lines through the origin show catches per unit effort

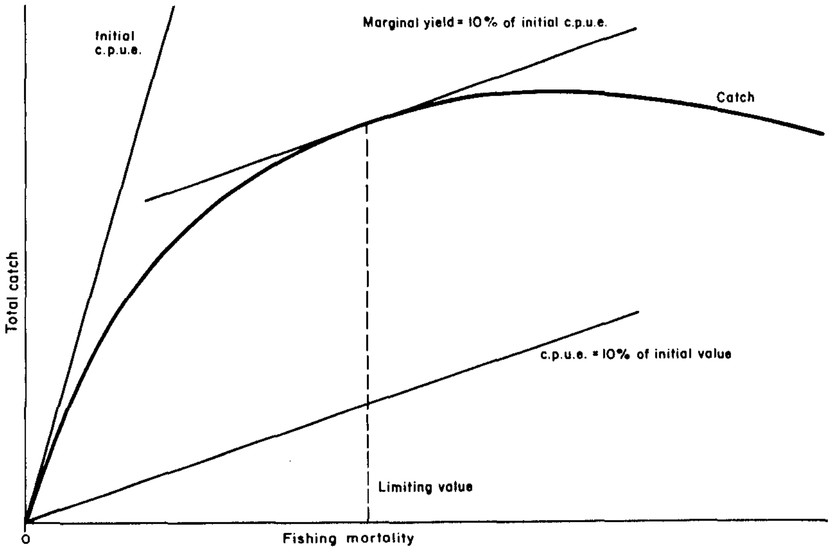

FIGURE 3.—Determination of an economic optimum position at which the marginal yield is 10% of the initial catch per unit effort.

in the nearly unexploited fishery—the tangent to the catch curve at the origin—and a catch per unit effort of 10% of this value. The limiting point beyond which any increase in fishing would certainly not be worthwhile—assuming a marginal yield of 10% of the initial catch per unit effort is not worthwhile—is where the tangent to curve is parallel to this 10% line. The selection of 10% is arbitrary but once the 10% figure is accepted the corresponding catch can be calculated objectively. Thus it can be used to provide a Commission or other management body objective guidance based on scientific grounds.

Unless there are marked density-dependent changes in mortality or growth this target will be achieved by exerting some fixed rate of fishing mortality. 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 in principle 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 total 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 the 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 middle-aged (since they will not grow much more but will suffer losses by natural mortality), and less hard when the 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 change. From an economic standpoint the optimum level of fishing mortality will increase slightly when strong year classes are present, because then it becomes more worthwhile to squeeze out an extra 1 or 2% of the maximum yield. For those few fisheries for which the investigators 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 multinational or multigear 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 magnitude of this catch should be, taking into account the strength of the year classes already present in the fishery, and those that will be recruited 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 estimate the catches in each year which would be required to attain any prescribed value of fishing mortality. These mortalities may be those which occurred at some previous time when it was believed that the fishery was in 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 preempting the 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, as set out in Table 2 (from ICNAF, 1970).

It may be noted that for virtually all patterns of mortality, there is a drop in predicted catch from 1969 to 1970 and again from 1970 to 1971, due to the entry of weak year classes into the fishery.

TABLE 2.—Catches (thousands of tons) of cod from the West Greenland stock in 1970 and 1971 corresponding to different values of fishing mortality (in parentheses).

1968	1969	1970	1971
382	225	178	159(0.6)
(0.8)	(0.6)	(0.6)	203(0.8)
		224	143(0.6)
		(0.8)	182(0.8)

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, they can be incorporated into the calculations to obtain the catch rates corresponding to different objectives.

The management of salmon stocks generally corresponds to this situation. The relation between spawning stock (escapement) and subsequent recruitment is usually claimed to be known and has a maximum at some intermediate level of spawning stock. The 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).[2]

The nature of the Pacific salmon fisheries—the movement of the prespawning 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 be applied only 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. Very large catches may be taken from good runs, but the allowable catch would fall to a very low level, or even zero, when the run is poor, and little, if at all, above the required escapement. The proportion 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 to or 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 (subarea 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 came from 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

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[2] This outline of the scientific rationale of salmon management ignores the great practical difficulties of management of any specific salmon fishery—the mixture at sea of fish from several different stocks, the difficulty of obtaining accurate measures of the incoming run before the start of the very short season, etc. These are outside the scope of the present note.

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 the 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 rebuilding of the adult stocks) and fishing at the rate which makes the best use of those fish which have, in fact, been 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 nonfishing 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 cases) were mainly of large fish (average age in U.S. landings were 6.6 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 tons 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 when the natural deaths in the Georges Bank were 5 million fish and the recruits only 1 million, the stock, in numbers, could be maintained only 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 is recruited 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 be maintained only 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, i.e., less than the replacement catch should be taken when strong year classes are being recruited. Also, the practical application depends on obtaining good and early estimates of the strength of the incoming recruitment.

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 recruitment is affected by the abundance of the adult stock and the stock is at a low level, the optimum rate 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; the second would give assumptions that could be made about the recruitment; the third and fourth 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 and recruitment	*Optimum* F	*Catch* (tons)
Maximum physical yield:		
Constant	1.2	110,000
Moderately density-dependent	0.9	84,000
Strongly density-dependent	0.6	59,000
Maximum economic yield:[1]		
Constant	0.8	76,000
Moderately density-dependent	0.7	68,000
Strongly density-dependent	0.5	50,000

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[1] For a certain set of assumptions on costs and prices.

While this still leaves a wide choice open—a range of over twofold, 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.

REBUILDING DEPLETED STOCKS

A special problem arises when advising on the management of badly depleted stocks, especially one (e.g., of whales) in which recruitment is closely dependent on the abundance of the adult stock.

For such a 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. 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 offshore herring fishery on Georges Bank, since the vessels concerned can 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.

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