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Introduction

One main purpose of carrying out stock assessment studies is to advise governments on whether the current amount of fishing on a stock is too high or too low, and what adjustments in the amount of fishing would be needed to bring the fishery into a more desirable state.

In some rare situations the step of moving from the scientific work of assessment to the more general work of advice (with its economic, social and political implications) will present no difficulties. The assessment work will result in a curve relating to the amount of fishing (as measured in some acceptable manner), and the sustained yield, with a sharp peak (the MSY). It is clearly desirable to maintain the fishery at or very close to the peak. In practice matters are less simple. The yield curve may be fairly flat near the maximum, so that it is not clear exactly what the optimum point is. Also many assessments using analytical (age- or length-structured) models result in expressions of yield-per-recruit as a function of the amount of fishing (strictly fishing mortality), while the manager is interested in the actual yield. These considerations result in modifications in the way the scientific results are presented.

Objectives

The objectives of a fishery manager are varied, and can be inconsistent. Especially in developing countries, food production is clearly a major objective. This, however, does not necessarily mean maximizing the catch from a given stock. In terms of the total food supply to the country, it does not matter much, provided due account is taken of national customs, what species of fish are landed - or indeed whether the people get more protein to eat in the form of, say, chicken or meat rather than fish. The obstacle to greater food production is usually one of shortage of inputs (especially, in developing countries, capital and money for fuel and other operating expenses). Even if increased fishing on a moderately heavily fished stock would result in some increase in catch, this would be a misuse of resources, if the same resources could achieve a greater increase in food supply if applied elsewhere, e.g., in a less heavily fished stock. Thus, if managers are looking at a given stock in the context of the whole national economy (or at least the whole national fishery), achieving something like MEY (Maximum Economic Yield) is likely to result in a higher total supply of food than achieving the MSY. Thus, the pursuit of economic targets, rather than purely biological ones, which is being increasingly put forward as the proper objective in developed countries, can apply also in developing countries. These, of course, have other objectives, including increased earnings of foreign exchange (e.g., from exports of shrimp), or reducing demands for foreign exchange (e.g., for imports of engines or fuel), maintaining employment (especially in rural communities), protecting the interests of the small-scale artisanal fishermen and so on.

Few of these objectives will be best met by fishing exactly at the top of the yield curve. Usually a position on the left hand shoulder of the yield curve will serve most objectives rather better. Staying a little to the left of the peak can allow the costs of fishing to be kept down with only a very small reduction in total catch. The exact position of the optimum will vary between objectives. Even for a specific objective such as maximum net economic return, optima can vary from year to year, due to changes in, for example, the relative prices of fish and fuel and other costs. This implies that a specific position on the yield curve cannot be determined as the optimum target of management on biological grounds alone, but requires knowledge of the objective of management, and, for many objectives, the result of economic and other analyses. This can raise difficulties when the biologist comes to present his results to a manager, and explains why many results (e.g., from the use of production models) continue to be expressed in terms of estimates of MSY, and the amount of fishing (fishing effort or fishing mortality) corresponding to the MSY.

Biological considerations

The true curve relating the amount of fishing to the sustained yield seldom, if ever, resembles the simple, sharply peaked, curve of some traditional models (e.g., the parabola obtained from the Schaefer model) and in practice it may be difficult to determine clearly, particularly at the higher levels of fishing. The curve often has a rather flat top. At the left hand side, small increases in fishing give a significant increase in yield, but beyond that there can be a wide range of effort over which increasing amounts of fishing will result in some, but very small, increase in total catch. It must also be stressed that the yield curve represents average conditions. Because of environmental and other factors, actual catches (for a given effort) can vary from year to year about the average, and often these variations become larger at higher levels of fishing. It can therefore be very difficult to determine the location of the MSY, especially in relation to the amount of fishing. That is, it may be possible to determine that the greatest catch that can be taken from a stock is around 25,000 tons, but much harder to determine whether the greatest sustained catch would be taken with, say, 1.000 or 1.500 units of effort.

When the biological assessments are made using production models (e.g., by relating catch per unit effort to total effort), the results can, with the above qualifications, be used directly to determine MSY and related quantities, such as the effort at MSY. This is not true of most age- or length-structured models. The output from these models, except in their more complicated forms, is in terms of the yield-per-recruit, or some equivalent units. The maximum total yield, i.e., MSY, will occur at the fishing mortality F_{MAX} corresponding to the maximum yield per recruit only if the average recruitment does not change with adult stock size, at least at stocks corresponding to that level of fishing. This is unlikely to be precisely true, since at F_{MAX} the stock will be moderately heavily fished, and this is likely to have at least some effect on recruitment. That is the MSY is likely to occur at some value of fishing mortality, F_{MSY} less than F_{MAX}.

Choice of target

From the preceding sections it is clear that the fishery biologist does not have a simple task when asked for specific advice in terms of a single figure for the desirable amount of fishing (number of trawlers to be licensed, etc.) even after he has completed the biological assessments. To some extent he can pass the problem back to the managers by providing options, and spelling out the consequences of different options. In principle this is probably the most desirable procedure, but it cannot always be followed. The problem was met in particularly acute form by the scientific committee of ICNAF in the early 1970's. At that time most of the demersal stocks in the Northwest Atlantic were heavily fished, and control of fishing effort was needed. It was accepted that, for the reasons already mentioned, the control should preferably be set rather below F_{MSY}. However, because of the nature of the provision of advice and of taking decisions, it was almost essential that the target fishing mortality (and hence the target catch quotas) should be set in an objective and clearly determinable fashion, which was provided at that time only by F_{MSY}.

The solution of the ICNAF scientists was to establish a new target; that of $F_{0.1}$, where the slope of the yield curve is 0.1 of the slope at the origin. In other words, where the increase in total catch achieved by adding one unit of effort (or additional fishing mortality) is only 10% of that achieved by the first unit of effort, when the fishery was first started. The choice of 10% was arbitrary, though it has been found to give useful results.

In practice this approach can involve some ambiguity. Unless the stock-recruitment relation has been established - or at least it is known that average recruitment does not change significantly with changes in adult stock - the <u>true value</u> of $F_{0.1}$ is not easy to determine. What can be determined using one or other age- or length-structured model, is the value of what might be denoted as $F'_{0.1}$, i.e., the value of fishing mortality at which the increase in <u>yield-per-recruit</u> resulting from a small increase in fishing mortality is 10% of that resulting from the same increase in a very lightly fished stock.

The difference is probably not great. Both $F_{0.1}$ and $F'_{0.1}$ will correspond to objectively determined values of fishing mortality that match more or less closely most management objectives. The chief difference in principle is that while $F_{0.1}$ will definitely involve some trade-off between objectives, i.e., some loss of total catch in exchange for better economic returns, $F'_{0.1}$ could correspond to a fishing mortality equal to or above that giving the MSY, and thus involve no loss of catch. In such cases $F'_{0.1}$ will be, on virtually any criterion, a better management target than F'_{MAX}, the fishing mortality corresponding to the maximum <u>yield-per-recruit</u>. This could involve fishing at a rate well beyond the true MSY.

<u>Discussion</u>

The responsibilities of a stock assessment scientist do not end when he has assessed the stocks and produced, say, a curve of sustained yield as a function of fishing mortality. He has to report his results to the fishery administrator, and other users of his results in a form that they can understand and apply in their own tasks of deciding on fishery policy. In the ideal world there will be a continuing dialogue between scientists and administrators about their problems. In practice scientists will often need to summarize their results in one or two key numbers. In the past the MSY, and the effort corresponding to the MSY has served this purpose, and often, as a first approximation, served it well. There are disadvantages; the MSY focuses attention on the size of the physical yield as the only objective of fishery policies, when economic or social aspects can be equally important. Also, while the approximate level of the MSY can be determined reasonably well, it can be difficult to say, even approximately, at what level of effort the MSY will occur.

The concept of $F_{0.1}$ is put forward as a point of reference against which advice can be given in terms of both the likely level of catch, and the amount of fishing (fishing effort or fishing mortality). It has been used successfully in international fishery commissions, and in some national management schemes. While to some extent an arbitrary figure, it does allow the biological assessments to take some account of the direction of most economic and social pressures. In the form of $F'_{0.1}$ (i.e., the corresponding point on the yield-per-recruit curve), it is probably the most useful way of presenting results from some of the new techniques using length-structured models.

Appendix

Calculation of F_{MSY} and $F'_{0.1}$ from yield tables

The implications of using $F_{0.1}$ and related concepts, rather than MSY on advice were assessed using the yield tables of Beverton and Holt (1964). These give the yield per recruit, in arbitrary units, as a function of two basic parameters, C, the ratio of L_c (the length of first capture) to L_∞ (the asymptotic length) in the von Bertalanffy growth equation, and the ratio F/M, the ratio of fishing to natural mortality . Different tables are given for different values of M/K (the ratio of natural mortality to the parameter in the growth equation describing the rate at which the fish approaches its asymptotic length). This form of presentation is particularly appropriate when some of the new length-based modifications of the traditional age-structured models (e.g., those of Beverton and Holt) are being used, since these often give results in terms of the ratios of parameters, rather than absolute values.

Table 1 gives, for sets of values of C and M/K, the values of F/M corresponding to the maximum yield per recruit $(F/M)_{MAX}$ (shown by an asterix is the Beverton and Holt tables) and to the point where the marginal yield per recruit, is 10% of the value at very low fishing intensities, $(F/M)_{0.1}$.

The latter values are insensitive to variations in M/K, though increasing with increasing values of C, i.e., the larger the fish are, as a proportion of their maximum length, the more it pays to fish hard. The table also tends to confirm a rough rule of thumb that the optimum fishing intensity is around the point where fishing and natural mortality are equal.

References

Beverton, R.J.H. and S.J. Holt. 1964. Tables of yield functions for fishery assessment. FAO Fish. Tech. Pap. 38:49 pp.

Table 1. Target rates of fishing, expressed as the ratio of fishing to natural mortality according to different criteria (MSY or $F_{0.1}$), and different combinations of natural parameters.

	$(F/M)_{MSY}$				$(F/M)_{0.1}$			
C \ M/K	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
0.3	1.22	1.00	1.00	1.22	0.80	0.68	0.65	0.66
0.4	1.50	1.50	1.50	1.86	0.90	0.80	0.80	0.82
0.5	1.86	1.86	2.33	4.00	1.01	0.95	0.98	1.04
0.6	2.33	3.00	5.67	+	1.16	1.15	1.17	1.21

ESTIMATION OF NATURAL MORTALITY RATES FROM SELECTIVITY AND CATCH LENGTH-FREQUENCY DATA[a]

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In conventional catch curves, the logarithms of the relative abundances of successive age groups are plotted against age, in order to obtain an estimate of the total instantaneous mortality rate, Z, from the slope of the descending right hand arm of the plot. Values to the left of the descending arm of the graph, reflecting catches of incompletely retained fishes are ignored.

Pauly (1982, 1983) has described how length-frequency distributions can be converted to age-structured catch curves in which the observed frequencies in successive length groups are divided by the time required for a fish to grow through each length group and plotted against the estimated ages of the mid-

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