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BEYOND MSY : A CONSIDERATION OF DEFINITIONS OF MANAGEMENT OBJECTIVES

J.A. Gulland
(United Kingdom)

Abstract

The concept of "Maximum Sustainable Yield" (MSY) has provided a useful guideline for resource management under the assumptions of a simple population model and simple objectives. This paper explores different guidelines under more realistic population models, taking account of the objectives set out in Article II of the CCAMLR Convention. The criteria will depend on whether the main concern is with recruitment or growth overfishing. Account also needs to be taken of the uncertainties associated with any assessment. Suggestions are made for the provision of advice to the Commission for the finfish and krill fisheries.

Résumé

Le concept de "production maximale équilibrée" (PME) a fourni un principe directeur utile pour l'aménagement des ressources dans l'hypothèse d'un modèle de population simple et d'objectifs simples. Ce document explore différentes lignes directrices d'après des modèles de population plus réalistes, tenant compte des objectifs exposés à l'Article II de la Convention de la CCAMLR. Les critères varieront selon que l'intérêt principal portera sur le recrutement ou la surexploitation au détriment de la croissance. Il faudra également tenir compte des incertitudes liées à toute evaluation. Certaines propositions sont avancées en ce qui concerne la présentation de suggestions à la Commission concernant les pêcheries de poissons à nageoires et de krill.

Resumen

El concepto de "Máximo Rendimiento Sostenible" (MSY) ha provisto una pauta útil para la administración de recursos bajo las suposiciones de un modelo sencillo de población y de objetivos simples. Este documento explora diferentes pautas bajo modelos de población más realistas, tomando en cuenta los objetivos establecidos en el Artículo II de la Convención de CCAMLR. Los criterios dependerán en si la mayor inquietud se encuentra en la sobrepesca de las poblaciones en restablecimiento o en aumento. También debe tomarse en cuenta las incertidumbres asociadas con toda evaluación. Se dan sugerencias para la provisión de asesoramiento a la Comisión para las pesquerías de pez aleta y de krill.

Резюме

Концепция "максимального устойчивого вылова" (MSY) являлась полезным руководящим принципом управления ресурсами - при наличии исходных посылок, присущих простым популяционным моделям и простым целям. В данной работе разрабатываются другие руководящие принципы при принятии более реалистичных популяционных моделей, учитывая цели, изложенные в Статье II Конвенции АНТКОМа. Критерии будут зависеть от того, что вызывает большее беспокойство: перелов особей пополнения или перелов молоди. Также надо учитывать и неопределенности, присутствующие в любых оценках. Делаются предложения по представлению Комиссии рекомендаций по промыслу плавниковых рыб и криля.

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J.A. Gulland
Renewable Resources Assessment Group
Imperial College, London, UK

INTRODUCTION

The traditional one-phrase definition of the objective of resource management has been the Maximum Sustained Yield (MSY). This has several advantages: simplicity, ease of comprehension, and reasonable correspondence to the behaviour of resources under exploitation. In the 1950s and 1960s it served a very useful purpose in bringing an understanding of the broad principles of resource management to administrators and industry. In later years it has come under increasing criticism. Economists have felt that it does not take enough account of economic and social factors, and have proposed alternatives such as Maximum Economic Yield (MEY). Biologists have felt that it uses too simplistic a concept of how natural populations behave, and that not enough account is taken of interactions between species and variability.

A number of alternative formulations have been offered. One with considerable practical implications is contained in the Convention for the Conservation of Antarctic Marine Living Resources. This gives, as an objective of the Commission, ensuring that the population does not fall below the level giving the greatest net annual increase (GNAI). Under the simplest conditions i.e. with all factors other than the direct impact of exploitation remaining constant, GNAI would probably be the same as MSY, and both provide clear guidance on the need for management. If the population is below the level giving MSY or GNAI, or which in the simple case is the same condition, if the amount of fishing is above the MSY or GNAI level, then management is needed. Under more realistic conditions they will differ. Also the criteria for management is less simple, because there is no longer a simple one to one relation between the amount of fishing and population abundance or between either and the rate of increase in the population.

I. GENERAL CONSIDERATIONS

Recruitment Overfishing

A fish population is usually thought of in two parts. For the first few months or years of life, as eggs, larvae or juveniles, the fish are too small to be caught by normal fishing gear, and these fish are not included in the stock as commonly thought of. At some point, the age of recruitment, the fish become big enough, or change their distribution or behaviour, and become accessible to fishing. Though the point of recruitment is not always clear cut, and the boundary between pre-recruits and recruits is somewhat subjective and can change if there are big changes in fishing practice, the distinction is an important one that exists for all fish except perhaps for a few sharks and rays that are large at birth. Except where explicitly stated otherwise this paper will be concerned only with the exploited stock.

Following Russell (1942) the change in the population can be written as R+G-M-C, where

R is the recruits to the stock,

G is the growth put on by the fish that have already recruited

M is the losses due to natural mortality

and C is the catch.

In this formulation all quantities are expressed as weight i.e. the use of M is different from its normal use as a coefficient. In the normal usage the losses due to natural mortality can be written as M*P, where P is the population biomass. In the steady state, the change in population is zero, i.e. R+G-M-C=0, or C=R+G-M. In this familiar expression it is clear that net natural increase and sustainable yield are the same, and the MSY and GNAI points are identical. To explore how they may differ in more complex situations the components of the right hand side need to be examined separately.

R is not affected by current events in the recruited stock, but will depend on the size of the adult stock (which will be related to, but not necessarily identical to, the recruited stock) some time previously when the fish recruiting were spawned, and also on events in the pre-recruit stage. There are substantial arguments, and an equally substantial literature, on the relation between recruitment and adult stock. It is generally agreed that the relation between the abundance of adults and the average or expected recruitment from that stock can be described by a curve similar to those of Ricker (1954) or Beverton and Holt (1957) (Figure 1), but that there is great variation about the average curve. The main arguments concern the position of a given stock on the curve and the relative attention that should be given to the roles of stock size and environmental factors in determining recruitment.

The Ricker curve has a maximum, but this will rarely be the point corresponding to MSY or GNAI. The difference is most easily seen for the simple case of salmon, in which recruitment, catching, spawning, and death follow in quick succession, with no appreciable influence of growth, or of natural death until after spawning. In this case the net increase per generation, or sustainable yield from a brood, will be the difference between the recruitment and the parent stock i.e. the difference between the stock-recruit curve in Figure 1 and the straight line of equal stock and recruitment. Provided that the recruitment is greater that S_{opt}, the spawning stock corresponding to this maximum, the objective of GNAI will be met by taking an amount R-S_{opt}, so that the escapement (i.e. recruitment less catch) will equal S_{opt}. If environmental conditions vary, so that recruitment varies, even when stock is maintained at S_{opt}, then catches will vary. It can be argued that they are not being sustained, and that MSY is equal to the minimum catch, occurring after poor environmental conditions. It may also be noted that the policy corresponding to GNAI is uniquely defined in terms of stock size, i.e. escapement should be maintained at S_{opt}, but if environmental conditions are varying there is no unique rate of fishing that gives GNAI. Good recruiting year-classes can be fished harder than weak ones.

Growth Overfishing

These last conclusions, that GNAI can be determined in terms of biomass but not fishing rate, are reversed in the case of a fish stock like some North Sea demersal stocks, where it appears that, to a first approximation, recruitment is independent of adult stock, and management is a matter of achieving the right balance between growth and natural mortality. For a period after a brood of young fish recruits, the growth of the individuals exceeds losses due to natural mortality, and in the absence of fishing the total biomass of the brood will increase. As the fish get older, growth slows down, and at some point - the critical age of Ricker (1948) - losses will exceed growth, and having reached a maximum, the total biomass of the brood will decline. The net natural rate of growth (which may be positive or negative) will depend on its age structure. A stock with mostly young fish will tend to increase and one with mostly old fish will decrease.

If recruitment does not vary, then the age structure will be determined by the level of fishing. The effect of fishing on the natural rate of increase can be derived from the earlier equations in the form $C = R + G - M$, or in terms of yield per recruit (recruitment in this case being measured as total weight of recruits) $C/R = 1 + (G-M)/R$.

Calculation of yield per recruit as a function of the growth and natural mortality coefficients, and as function of the two main characteristics of the fishery - the age at first capture (which may be greater than the age of recruitment if selective gear is used) and the fishing mortality - is a standard procedure (Beverton and Holt 1957). Typical results for North Sea plaice for two ages of first capture are shown in Figure 2. Apart from a constant, these curves are identical with the curves of $(G-M)/R$. For low age at first capture there is a clear maximum, which under conditions of constant recruitment corresponds to MSY and GNAI, and under these conditions will also correspond to specific values of fishing mortality and stock biomass. If recruitment varies due to environmental factors then to a close approximation this value of fishing mortality will, if sustained, give a greater yield than any other sustained fishing mortality, and can be considered as giving GNAI (but not strictly MSY because the yield is not sustained at the same level). However the corresponding stock size will vary in proportion to changes in recruitment. A more accurate calculation will show that the long term yield can be achieved by a fishing mortality that varies about the constant recruitment optimum, being lower when a strong year-class has just recruited and higher when it is old. This will bring the average age of the fish caught closer to the critical age, but the practical difference is likely to be small.

More Complex Situations

Few stocks present cases of pure recruitment or growth overfishing. Even when there is little indication of stock size affecting recruitment over the range of stock sizes so far observed, it is clear that if stock is sufficiently reduced, there will be a fall in recruitment. Thus the absence of a maximum in the yield per recruit curve of Figure 2 for a high age at first capture does not reflect the behaviour of the total yield (or net natural increase) which will fall off at sufficiently high values of fishing mortality.

If environmental conditions are constant, the two approaches are readily combined. The yield per recruit approach can be used to determine the adult stock that will result from a given recruitment under any given fishing pattern (fishing mortality and age at first capture). The resulting lines, giving stock as a function of recruitment, can be plotted in a stock and recruitment diagram (Figure 3). The point where the line for a given fishing pattern cuts the stock-recruit line gives the equilibrium recruitment and stock for that fishing pattern, and hence, by multiplying the yield per recruit by the equilibrium recruitment, the total yield. The fishing pattern that gives the maximum yield is then readily determined. Under these constant conditions, and ignoring the possibility of changing the age at recruitment, unique values of stock size and fishing mortality can be determined corresponding to this maximum, which corresponds to MSY and GNAI. The necessary steps in this have been set out in more detail by Sissenwine and Shepherd (1987).

In practice the recruitment will vary, possibly quite greatly, independently of any changes in adult stock. The difficulties that this causes in determining the underlying relation between mean recruitment and adult stock are well known. In addition it invalidates any simple application of the concepts of GNAI or MSY. The greatest yield that can be sustained is one corresponding to full exploitation of the weaker year-classes - but a much less than full exploitation of the stronger ones. The net natural increases may be negative, even in the absence of fishing when strong year-classes are being replaced by weak ones. Conversely, the stock may increase when a strong year-class recruits, even when it is being heavily exploited.

In the simplest form of this situation, in which the stock-recruit relation is known, it is possible to work out optimum strategies according to various economic or other criteria (see Clark 1985 Chapter 6). Unfortunately these procedures do not in general satisfy criteria such as those of CCAMLR, nor do they deal with sources of uncertainty other than those that Clark refers to as "gambler's uncertainty", i.e. to take a simple example, the uncertainty as to the value that next year's recruitment will take from a (known) probability distribution about a (known) stock-recruit relation.

Possible Criteria Under Variability and Uncertainty

The previous section suggests that if a stock could suffer from both recruitment and growth overfishing, and its recruitment varies considerably, it is not easy to define, still less determine, policies that would satisfy general conservation criteria such as those demanded by CCAMLR. A possible way forward might be to apply separately the criteria relevant to the two types of overfishing, i.e. to ensure that the fishing mortality does not rise above the level causing growth overfishing (or a reduced yield per recruit), and the adult stock does not fall below the point where recruitment begins to fall appreciably.

Considerations of this kind lay behind the original concept of objectives such as $F_{0.1}$ (Gulland and Boerema 1973). These give a point on the yield per recruit curve which is objectively defined, and can be estimated reasonably precisely. In the conditions of the north Atlantic in the early 1970s, with consensus being vital, but countries seeing their interests corresponding to very different levels of fishing, $F_{0.1}$ enabled the scientists in ICNAF to give clear advice on target levels of fishing mortality. This was not possible using MSY, because it gave either an unreasonably high value (if recruitment effects were ignored, and only the yield per recruit curve was used) or could not be estimated (if recruitment effects were taken into account).

As Shepherd (in press) points out, $F_{0.1}$ does not take stock-recruitment effects explicitly into account, and thus, he suggests, sweeps this problem under the carpet. This is only partly true. One of the objectives of the original proponents was to make it less likely that the adult stock declined to the point at which recruitment might be affected seriously. In the case of most ICNAF stocks this was probably achieved, but, although using $F_{0.1}$ can make recruitment overfishing less likely, it is neither a sufficient nor a necessary condition for doing this. It may also be noted that because recruitment effects are not dealt with, $F_{0.1}$ may not necessarily be the point based on economic criteria that it is often supposed to be. That is, unless recruitment is not affected, the marginal yield (as opposed to marginal yield per recruit) will not be exactly 10% of the marginal yield at very light fishing.

Despite these shortcomings $F_{0.1}$ does provide one leg of a management policy that will satisfy conservation criteria of e.g. CCAMLR. Ensuring the F does not exceed $F_{0.1}$ will prevent growth overfishing and discourage recruitment overfishing. What is needed is a second leg that goes further in preventing recruitment overfishing. This will chiefly be a matter of maintaining an adequate adult stock, which has been the top priority in managing marine mammals.

Because of their low fecundity and low mortality in the pre-recruit phase (perhaps 50% compared with 99.999% or more for fish) recruitment among marine mammals is more nearly proportional to adult stock than is the case for fish. Also, though the determination of the stock-recruit relation is not easy, some estimate of its general form and hence of the form of the relation between stock and net recruitment can be obtained. From this, the point of maximum net recruitment (MNR, which will be equivalent to GNAI or MSY) can be determined. If net recruitment rate (i.e. net recruitment as proportion of adult stock) declines linearly from a maximum at very low stocks to zero when the stock is at the carrying capacity of the environment, then MNR will occur when the stock is at 50% of the maximum. There is a belief, with some observational support, mostly from large terrestrial mammals (Fowler 1981) that the recruitment rate is fairly constant until the stock comes close to carrying capacity. In that case MNR or MSY will occur at a population size of more than 50% of maximum.

Where there are formal commitments in terms of MSY or similar criteria, e.g. in the International Whaling Commission, or under the U.S. Marine Mammal Protection Act, there have been considerable discussions over the precise location of the maximum. The IWC has used a value of 60%. In the U.S. the requirement of Optimum Sustained Population (OSP) has been interpreted as being a range of population sizes from that giving MSY (usually taken as 60-70% of maximum) upwards.

For fish, there is as yet no simple rule of thumb about how big the stock should be, though it is clear that for many stocks MNR occurs at population levels well below the unexploited level. For example MNR for the four stocks illustrated in Figure 12 of Cushing (1977) lie between about 50% (for salmon) and 25% (for cod) of the largest stock in the data series, the MNR for plaice being indeterminate but certainly less than 30% of the biggest observed stock. Bearing in mind that all these stocks have been heavily fished so that, with due reservations for the temporary effects of the occasional very large year-class, the observed levels of abundance are well below the original, unexploited, levels, it appears that keeping these stocks at 50 or 60% of the unexploited level would be unnecessarily cautious.

In practice, fisheries management has often erred in the opposite direction. Lacking any general guidance on what size of adult stock is needed, controls on fishing with the aim of preventing recruitment overfishing have not generally been introduced until enough data has been accumulated to determine empirically the stock-recruit curve for the stock in question. This determination usually requires observations at low levels of stock and of recruitment, i.e. the onset of the recruitment overfishing which a good management policy should prevent. Though scientists have warned about the possible onset of recruitment failure e.g. in relation to several herring stocks in the 1970s (Saetersdal 1980), or to the Peruvian anchovy just before the collapse (Anon 1972), these were seldom acted on. This failure was mainly because the recruitment collapses were possibilities or probabilities, rather than certainties, and the management practices of those times did not call for action until the need for action was fully proven. The relative scarcity of serious cases of recruitment overfishing is not due to good management, but because in many fisheries the fishing effort has not reached the critical level for economic reasons (the fishery ceases to be profitable) or because controls are applied to control the more easily demonstrable growth overfishing.

A better awareness of the risks, and new management principles, such as the CCAMLR Convention, have reduced some of the difficulties of acting on probabilities without conclusive proof, but the scientific problems of knowing when action is becoming desirable (i.e. when the stock is likely to fall, in the absence of action, below the MNR level), remain. There is little chance, for the typical stock with considerable natural variation in recruitment, that the level of MNR can be determined purely by the manipulation of data (principally of pairs of values of adult stock size and resulting recruitment) from that stock until there are some values for stock sizes less than MNR.

One approach to this problem is to recognize that there appear to be fairly consistent patterns in the stock-recruitment curves of different stocks within a taxonomic group. Thus for flatfish it is often difficult to detect any change in mean recruitment over a wide range of populations, and MNR occurs at a population that is a small proportion of the unfished stock. Small pelagic fish (herrings, anchovies etc) on the other hand seem prone to recruitment collapses. In individual cases it may be difficult to disentangle possible effects of overfishing from those of environmental changes to which these stocks also seem to be sensitive (Murphy 1977) but the records of collapses closely following periods of heavy fishing are too long to doubt the importance of fishing.

From these records it is possible to make rough estimates of the stock level at which recruitment starts to decline appreciably, expressed as a percentage of the unfished stock. A superficial examination of some of the available data, chiefly those presented at the 1983 FAO meeting in Costa Rica (Csirke and Sharpe 1984) suggests that MNR for clupeoid species occurs at stock sizes some 30-50% of the unexploited level. If further analyses confirm this suggestion, these values and similar values for other groups of species could be used for determining management measures.

Another approach is that being developed in the north Atlantic in terms of a replacement fishing mortality or fishing pattern (Anon 1985, Sissenwine and Shepherd 1987). This is based on a plot of observed values of adult stock, S, and subsequent recruitment, R, but no attempt is made to fit an explicit stock-recruit function. Instead it is noted that any fishing pattern (i.e. vector of fishing mortality at age) will correspond to a straight line in this diagram giving the adult stock that would arise from a given steady recruitment under that fishing pattern. Any points that lie above the line correspond to year-classes that would, under that pattern, do more than replace themselves. The proportion of points that lie above the line for any given pattern therefore gives an indication of the probability that the stock will increase under that pattern, i.e. that the yield is sustainable or better.

Using this approach, several possible target values of fishing pattern (or of F, if possible changes in age at first capture are not of concern) can be determined. Sissenwine and Shepherd propose the use of the median line, i.e. that with equal number of points above and below it, designated by F_{rep}, as likely to be best in practice. This could, if the mean value of R/S changes appreciably with stock size, be somewhat conservative. They point out that, (using the terms of this paper), MNR would probably be better estimated by putting greater weight on the observations at low stock sizes, and Shepherd (1982) suggested the line that had only 10% of the points above it. With this value of F, or with F_{high} in ICES terms (Anon 1986), it is known that the stock can sometimes replace itself, but these occasions may be so rare that over a period, replacement is not possible. Thus a value of F that will certainly avoid overfishing, but is not too restrictive cannot be determined without better knowledge of the underlying relationship. Nevertheless the various values noted here do give some guidance, with F_{rep} probably being the best if it is preferred to make any error on the safe side.

II. TOWARDS A POLICY FOR CCAMLR

The Problems of Providing Advice

One aim in preparing this note was to find some objectively definable quantities that the Scientific Committee of CCAMLR could use in advising the Commission in order that it could fulfil the objectives set out in the Convention. This was not entirely successful, and defining policies that will achieve GNAI (or MSY), even for single species, remains difficult for fish, and even more for krill so long as the true stock-recruit relation is cloudy. Some guidance can be given in terms of either fishing mortality or stock size, the presumption being that action is called for if either measure falls into the danger zone.

For krill, the problem is made more difficult by the need to take into account "associated and dependent" species. It is probably too early to hope to establish a policy for krill that can be put into quantitative terms, and the main consideration here will be given to the fish stocks.

The Fish Stocks

Limits on fishing mortality might be proposed in order to prevent either recruitment or growth overfishing. For the latter, F_{max}, the value giving maximum yield per recruit, is the extreme upper limit, but for most purposes, including that of improved economic performance, $F_{0.1}$ will be the more satisfactory. Similarly, F_{rep} is probably the better limit to use for avoiding recruitment overfishing. If these can be accepted as strategic objectives, then tactical advice can be framed in terms of preventing the actual value of F exceeding the lower of these two values. Consideration of limits on stock size, however, are likely to arise only through concern about recruitment overfishing.

The limits proposed here, whether to F or biomass, provide useful criteria for management only if it is possible to determine, with reasonable reliability, when the limits are being approached. The experience of the IWC has shown how doubts about the values of population parameters can be used, by different groups at different times, to achieve particular objectives. The general uncertainties surrounding the other Antarctic stocks are certainly no less than those surrounding whales. However by focussing on those parameters that are relatively well known, and by addressing explicitly the implications of uncertainty, it may be possible to determine procedures that will enable the Commission to reach definite conclusions on what to do.

For most fish stocks there are fairly good estimates of the biological parameters (growth, natural mortality, age at maturity etc) needed to construct yield per recruit curves and similar functions of fishing pattern, in fact, because age-composition data are available for several stocks from the time that exploitation began, the estimates of natural mortality for these stocks is probably better than for most other stocks. It is therefore possible to calculate for most stocks values of $F_{0.1}$ and also of the value of F that would prevent the spawning biomass per recruit falling below any desired percentage (say 30%) of that in the unexploited stock. Further, the nature of the uncertainties in the parameter estimates are such that it would not be unreasonable to ask the

Scientific Committee for lower limits to these F values, i.e. the lower limit to the possible values of $F_{0.1}$, taking into account uncertainties in growth, natural mortality etc.

The Commission could then set strategic policy objectives in terms of target Fs (based on the information on $F_{0.1}$, spawning biomass per recruit, etc. and the central and lower bounds of these figures). It might also determine a safety net in terms of lower bound to the absolute level of the spawning stock i.e. the level below which the fishery should be closed for a time to allow rebuilding, regardless of the value of F. This would give the following decision tree.

1. Is the spawning stock below the safety level?
   Yes; close the fishery.
   No; go to 2.
2. Is the value of F in the next season likely to reach the target F if no measures are applied?
   Yes; apply measures to keep F to the target level.
   No; allow unrestricted fishing for the next season.

For the purposes of taking decisions, an uncertain answer to either question should be treated as a Yes (i.e. the fishery should be closed unless it is clear that the spawning stock is not dangerously low, and measures should be introduced unless it is clear that F will not reach the target level).

A problem still remains, if measures are called for, in determining what measures, in an understandable and enforceable form, will ensure that the target F is not exceeded. Assuming that mesh regulations and similar measures have been taken as far as is practicable and have been taken into account in calculating yield per recruit and the target F, and that closed areas and closed seasons will not provide a sufficiently sensitive control, two types of controls remain - on catches and on fishing effort.

Catch quotas have been the standard method in the traditional fishery commissions, principally because they used a measure (tons of fish) which was immediately comparable between countries. Experience has shown that they can raise difficulties in enforcement and lead to uncertainties in the reported catch statistics, and, for some stocks, very serious problems in estimation. If next year's quota is to ensure a predetermined level of fishing mortality, i.e. have the hoped for effect on the stock, it must take account of the size of next year's stock. For long-lived stocks which are not subject to much natural variation e.g. whales, this is no problem. For most fish, including most North Atlantic fish subject to quotas, the work of calculating next year's quota is considerable. It involves two parts, determining (usually from catch records) the size of this year's stock, and how much of it will be present next year, and how many young recruits will enter the fishery next year (either from pre-recruit surveys or by assuming that recruitment will be average). Neither process is very accurate.

For Antarctic stocks it might be reasonable to hope that meaningful quotas be calculated for Notothenia rossii (once the stocks are rebuilt to the point at which fishing would be possible). For Champsocephalus however, the carry over of old fish is small, and the recruitment is so variable that controls by quota seems impracticable. If recruitment is strong, the opportunity for good catches may be lost, while if it is weak the stock may be severely over-fished.

Control by effort limitation may be easier. A serious objection, if no regular adjustments are made, is that improvements in fishing efficiency can mean that a control (e.g. that no more than 20 trawlers can fish) that may be satisfactory in 1987 can allow the actual value of F in say 1990 or 1995 to greatly exceed the target F. The worst of such dangers could be avoided by setting fresh limits on nominal effort each year, based on the values of F and fishing effort in the most recent years.

Since some fish stocks cannot, on the arguments presented here, be managed by catch quotas, but could be managed by effort control, the question arises whether effort controls should be applied to all stocks. This should be possible. The chief problem would seem to be that of determining when effort is directed at a species, and the question of incidental catches. This might be dealt with by counting activities (operations of a vessel for a season or a day) towards the effort limit for a species unless the catches of that species are below some acceptably low level.

KRILL

For krill much the same considerations apply, so far as constructing a yield per recruit curve or similar relations is concerned. The population parameters are not quite so well known (doubts surround the exact growth pattern, and it may be necessary to use a relatively wide range of parameter values). On the other hand F is clearly negligible at the moment, and any estimate of total mortality will also be an estimate of natural mortality. The difference comes in selecting a target, or limiting value of F. Clearly the value of $F_{0.1}$, or other target based on single-species considerations will correspond to very high levels of catch, (at least if applied to the Antarctic as a whole), and concern will almost certainly arise over the possible impact on other species before such target Fs are approached.

Knowledge of the interactions between krill and other species is still far from enabling a target F to be set that would, for example, offer no threat to penguins. On the other hand information is being obtained on the degree of natural variation in local krill abundance that can occur, and its impact on associated species. From this it may be possible to determine boundaries to the extent of change in mean krill abundance that could be accepted without risk to other stocks - perhaps a decline of 10%. From calculations similar to those of yield per recruit it would be possible to determine what level of F on krill would be associated with such declines in krill abundance (assuming constant recruitment), thus giving a preliminary target for the maximum allowable F for krill (for the Antarctic as a whole, or for smaller areas) based on multi-species considerations.

Translating these target Fs, which might be adopted as medium term Commission strategic objectives, into specific measures will be more difficult than in the case of fish. At the time that such measures are first considered it is likely that no direct estimates of F on krill will be available. However estimates of krill biomass have been made from acoustic surveys, appeals to consumption rates by predators etc. These are highly variable, but they do allow lower bounds to be set to the biomass, in the whole Antarctic, or for particular regions. The fact that such bounds may differ substantially from the true biomass (perhaps by an order of magnitude) is not important. The point is that the use of the relation Catch = F x mean biomass, will allow catch limits to be set that will ensure that the krill fishery does not harm other species. It will only be when these conservative limits become substantive obstacles to further development to the krill fishery that better estimates of biomass, or of current F, will become important.

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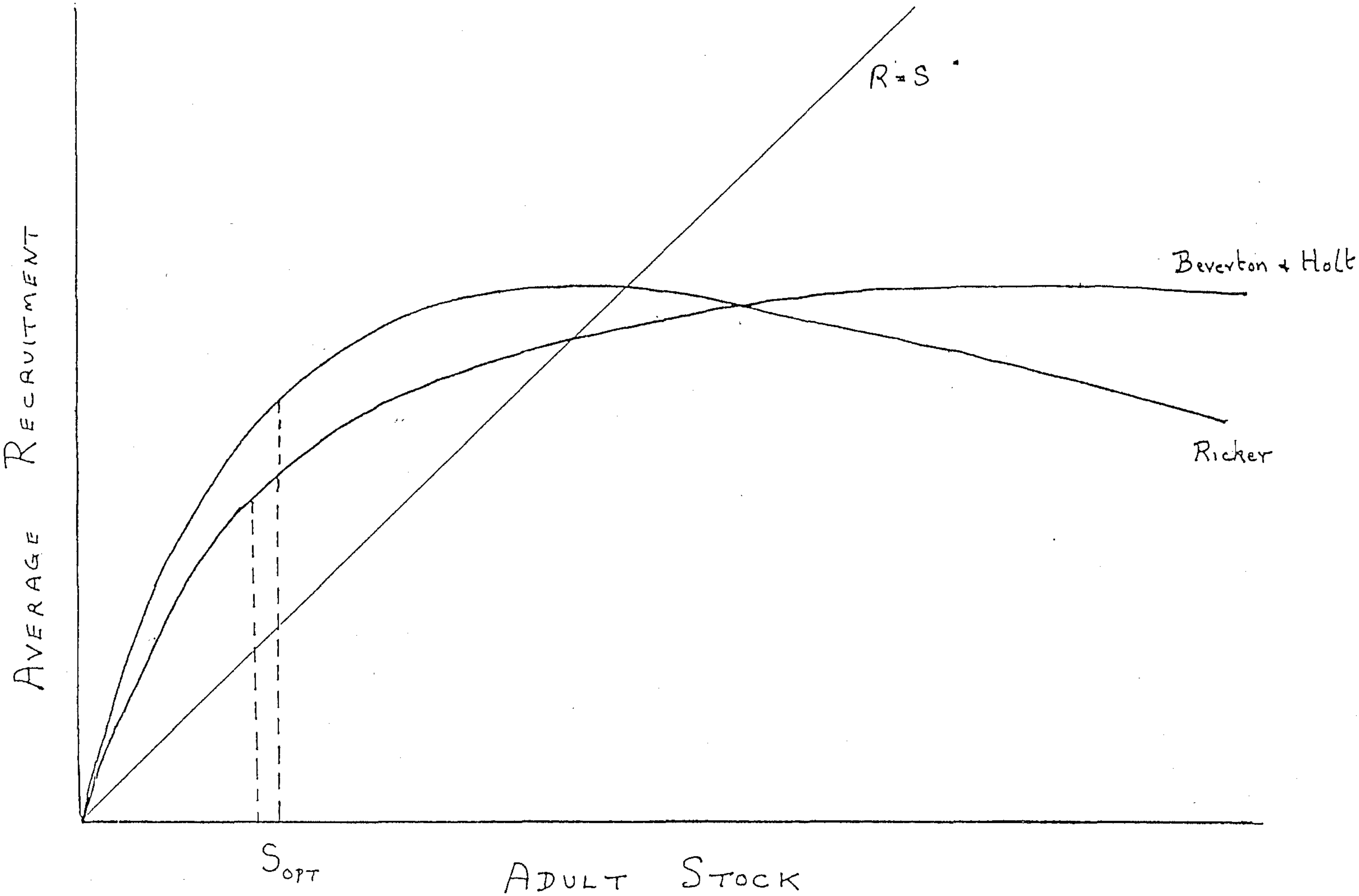

Figure 1 Typical curves relating average recruitment to the abundance of the adult stock for the Ricker and Beverton and Holt equations. S_{OPT} denotes the value of adult stock that results in the maximum difference between parent stock and subsequent recruitment.

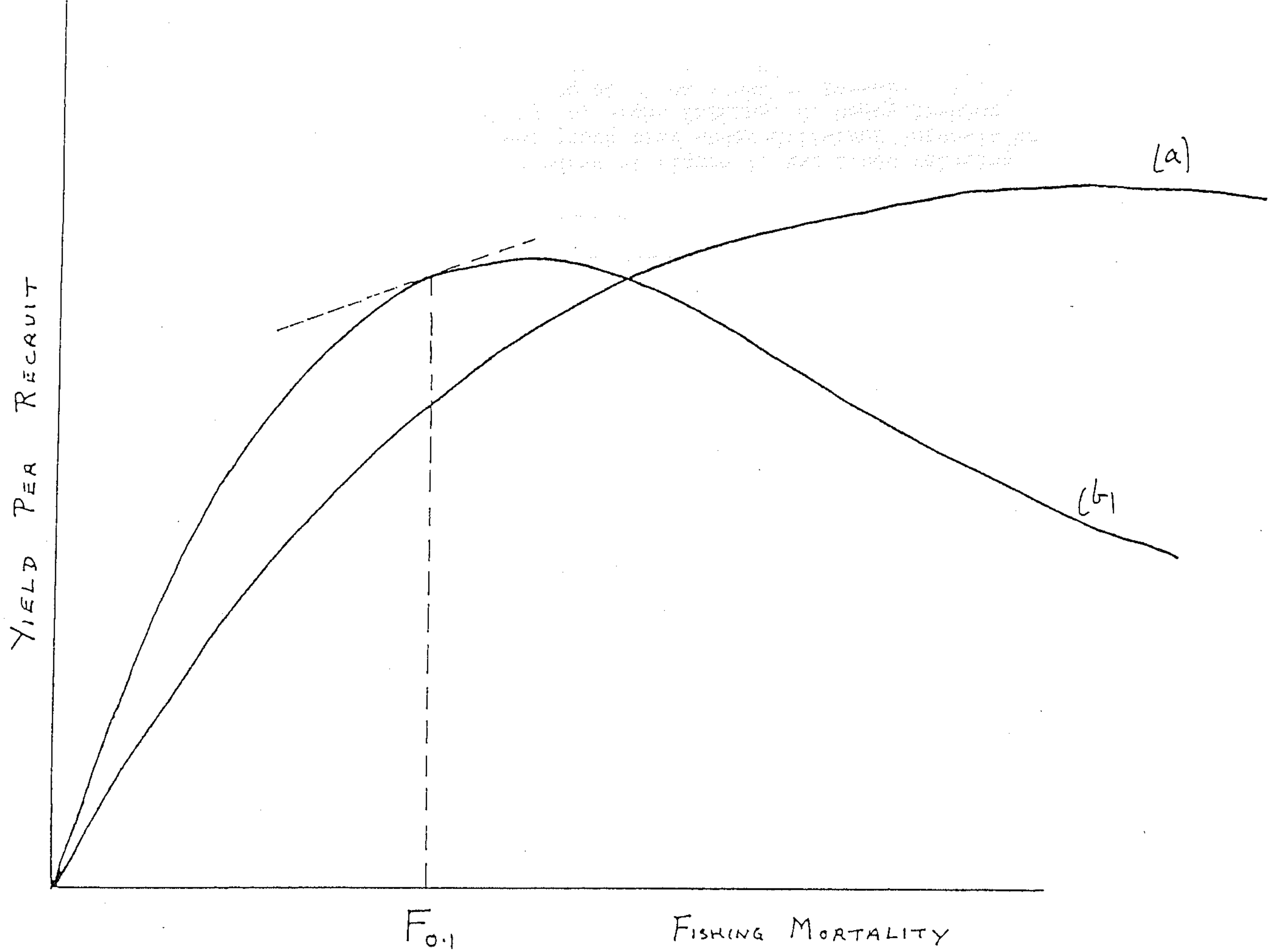

Figure 2 Typical yield per recruit curves for high and low sizes at first capture (curves (a) and (b) respectively). $F_{0.1}$ denotes, for curve (b), the value of F at which the slope of the curve is one-tenth of that at the origin.

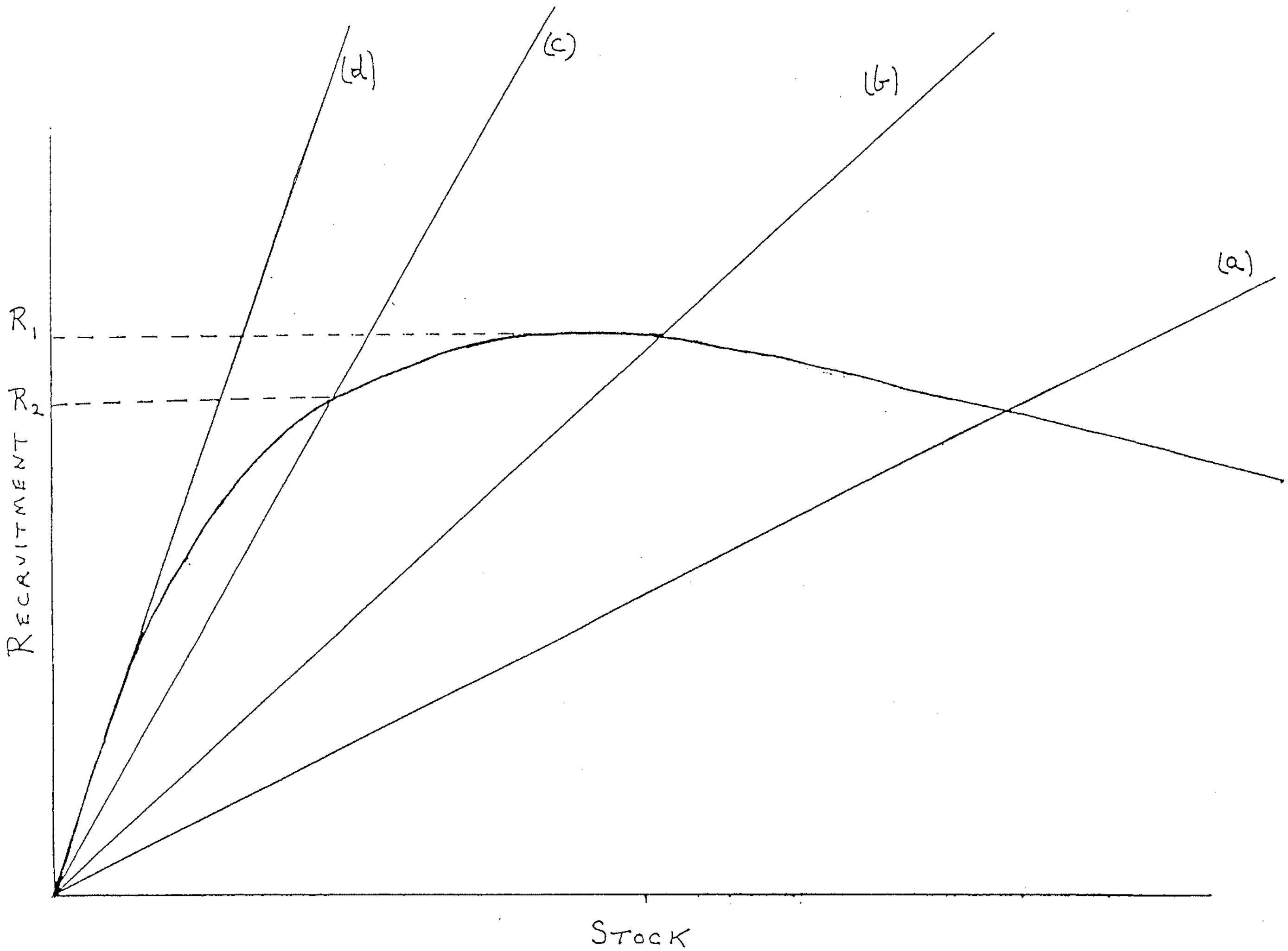

Figure 3 The Ricker stock-recruit curve of Figure 1, and lines relating recruitment to subsequent stock size under different intensities of fishing (a, no fishing, b, light fishing, c, heavy fishing, d, limiting value of fishing at which stock collapses). R_1, R_2 denotes equilibrium recruitments under light and heavy fishing.

Légendes des figures

Figure 1 Courbes typiques mettant en relation le recrutement moyen et l'abondance du stock adulte pour les équations de Ricker et de Beverton et Holt. S_{OPT} indique la valeur du stock adulte qui mène à la différence maximale entre le stock parental et le recrutement subséquent.

Figure 2 Courbes typiques de rendement par recrue pour les tailles élevées et basses à la première capture (courbes (a) et (b) respectivement). $F_{0.1}$ indique, pour la courbe (b), la valeur de F à laquelle la pente de la courbe est égale au dixième de la pente à l'origine.

Figure 3 Courbe de Ricker stock-recrue de la Figure 1, et lignes mettant en relation le recrutement et la biomasse subséquente en fonction de différentes intensités de pêche (a, aucune pêche, b, pêche d'intensité légère, c, de forte intensité, d, valeur limite de la pêche à laquelle le stock s'effondre). R_1, R_2 indiquent des recrutements d'équilibre dans les cas de pêche légère et intense.

Leyendas de las Figuras

Figura 1 Curvas típicas que correlacionan el restablecimiento promedio con la abundancia de la población adulta para las ecuaciones de Ricker y de Beverton y Holt. S_{OPT} indica el valor de la población adulta que resulta en la diferencia máxima entre la población progenitora y el restablecimiento subsiguiente.

Figura 2 Curvas típicas de rendimiento por restablecimiento para tamaños altos y bajos en la primera captura (curvas (a) y (b) respectivamente). $F_{0.1}$ indica, para la curva (b), el valor de F donde la pendiente de la curva es una décima parte de la pendiente en el origen.

Figura 3 La curva de población-restablecimiento de Ricker de la Figura 1, y las líneas que correlacionan el restablecimiento con el tamaño de la población subsiguiente bajo diferentes intensidades de pesca (a, pesca nula, b, pesca ligera, c, pesca intensa, d, valor límite de pesca que provoca el colapso de la reserva). R_1, R_2 indican los restablecimientos de equilibrio bajo pesca ligera e intensa.

Подписи к рисункам

Рисунок 1 — Типичные кривые, связывающие величины среднего пополнения с размером запаса взрослых особей в уравнениях Риккера и Бевертона и Хольта. S_{OPT} - величина объема запаса взрослых особей, полученная как результат максимальной разницы между родительским запасом и последующим пополнением.

Рисунок 2 — Типичные кривые "вылова на особь пополнения" при больших и малых размерах при первом вылове /кривые (a) и (b) соответственно/. $F_{0,1}$ - для кривой (b) дает величину F, при которой наклон кривой равняется одной десятой такового у начала координат.

Рисунок 3 — Кривая "запас/особь пополнения" - Риккера, данная на Рисунке 1, и кривые, связывающие пополнение с последующим размером запаса при различных уровнях интенсивности промысла (a - отсутствие промысла, b - небольшой промысел, c - интенсивный промысел, d - предельная величина интенсивности промысла, при которой запас истощается). R_1, R_2 - величины пополнения при небольшом и интенсивном промысле, дающие равновесное состояние.