REFINEMENTS TO THE STRATEGY FOR MANAGING DEPLETED FISH STOCKS BASED ON CCAMLR OBJECTIVES

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Abstract

A method of calculating fishing mortalities which will allow depleted fish stocks to recover to levels near those giving greatest net annual increment within two to three decades is illustrated. These fishing mortalities are based on probabilistic descriptions of the future states of a depleted stock, and take into account uncertainty in assessments. Sample calculations show that applying a policy of $\mathbf{F}_{0.1}$ will not always lead to stock recovery in two to three decades, and hence that additional management policies are required for depleted stocks. The implications of these studies for defining the terms 'depleted' and 'target levels for recovery' are briefly discussed.

Résumé

Une méthode de calcul des mortalités par pêche est illustrée, selon laquelle les stocks de poissons surexploités pourront récupérer à des niveaux proches de ceux permettant un accroissement maximum net annuel dans les 20 ou 30 années à venir. Ces mortalités par pêche sont fondées sur des descriptions probabilistes de l'état futur d'un stock surexploité, et tiennent compte de l'incertitude dans les évaluations. Des calculs effectués à titre d'exemples démontrent que l'application systématique de $\mathbf{F}_{0.1}$ ne conduit pas forcément à un repeuplement du stock en 20 ou 30 ans, et que, par conséquent, les stocks surexploités devraient faire l'objet de nouvelles mesures de gestion. Les implications de ces études pour la définition des termes "surexploité" et "seuil à atteindre pour le repeuplement" sont examinées brièvement.

Резюме

Демонстрируется метод вычисления уровней промысловой смертности, позволяющих восстановление истощенных рыбных запасов на протяжении двух-трех десятилетий до уровней, близких к тем, которые обеспечивают максимальный чистый годовой прирост. При расчете этих уровней промысловой смертности, основанных на вероятностных прогнозах состояния истощенного запаса, учитывалась имеющаяся в оценках неопределенность. Пробные расчеты показывают, что применение стратегии, основанной на $\mathbf{F}_{0.1}$, не всегда приводит к восстановлению запаса через два-три

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десятилетия, и, следовательно, необходимы дополнительные меры управления истощенными запасами. В общих чертах рассматривается значение данных исследований для уточнения значения терминов "истощенный" и "целевые уровни восстановления".

Resumen

En este documento se presenta un método para calcular la mortalidad por pesca que permitirá la recuperación de las poblaciones mermadas de peces a niveles cercanos a aquellos que producirán el mayor aumento anual neto dentro de dos a tres décadas. Estas mortalidades por pesca se basan en descripciones probabilísticas de la futura condición de una población mermada y toman en consideración las ambigüedades en las evaluaciones. Los cálculos experimentales indican que al aplicar una norma de $\mathbf{F_{0.1}}$ no siempre conducirá a una recuperación de la población dentro de de dos o tres décadas y, por lo tanto, se necesitan normas de administración adicionales para las poblaciones mermadas. Se trata brevemente como los resultados de estos estudios podrán ayudar con la definición de los términos "mermado" y "niveles objetivo para recuperación".

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1. INTRODUCTION

In 1988 the Working Group for the Development of Approaches to Conservation (WG-DAC) suggested that the interpretation of Article II of the CCAMLR Convention would be assisted by the development of operational definitions for "depletion" and for "target levels for recovery of depleted populations" (CCAMLR-VII, paragraph 140). In 1987 the Commission adopted the yield-per-recruit fishing mortality $\mathbf{F_{0.1}}$ as the appropriate management strategy for fish stocks (CCAMLR-VI, paragraph 61). The studies in this paper explore an approach to calculating values of fishing mortality (F) which are more appropriate than $\mathbf{F_{0.1}}$ in terms of the requirements of Article II of the Convention, for fish stocks which have been reduced to low levels. This approach represents a starting point for extending the management strategy to the case of depleted fish stocks, and points to factors to be considered in formulating operational definitions of depleted and target levels for recovery.

The part of Article II directly applicable to harvesting objectives states:

"3. Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:

(a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;

(b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above; and

(c) prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources."

From these general objectives several key concepts relevant to the management of depleted stocks stand out.

(1) Depleted populations are below levels near to the population level giving greatest net annual increment (GNAI).

(2) The minimum population level posited to ensure stable recruitment is equated with GNAI.

(3) The effects of exploitation should be compatible with potential reversibility in two or three decades, taking into account the state of available knowledge of, *inter alia,* the direct and indirect impact of harvesting.

The general objectives need to be supplemented to render their meaning more precise for the purposes of formulating advice in the Scientific Committee. It is very unlikely that in the near term that levels of GNAI for various stocks will be able to be estimated directly. Thus, levels will probably be chosen on the basis of conventional fisheries models. Similarly, identifying stock-recruitment (S-R) relationships will also be extremely difficult, and some form of model will have to be selected which is compatible with the concepts (1), (2) and (3) above.

A further factor to be taken into consideration in some practical way is the state of available knowledge about the stocks. Inevitably assessments of the state of a stock will include uncertainty, for example due to sampling variability. This uncertainty needs to be taken into account when formulating management advice.

A framework which integrates the elementary concepts above can be formulated as follows. An assessment is made of a fish stock, using whatever methods and data are available, to estimate the current stock level and the mean stock level which would exist without fishing. If the 'best' estimate of current stock level is substantially below GNAI (expressed as a fraction of the unfished mean stock level) then it is deemed to be depleted and hence fishing mortality must be set at levels which should not preclude stock recovery to GNAI (or other target level) within two or three decades. A 'best' estimate would be the mean or median of a probability density function which incorporates the uncertainty in the quantities estimated. Using this information the following fishing mortalities are calculated using a stock projection computer program:

(i) the fishing mortality which results in a specified subjective probability that the stock will be above the current level in 20 years;

(ii) the fishing mortality which results in a subjective probability of 0.5 that the stock is at or above GNAI (or other target level) in 20 years;

(iii) the fishing mortality which results in a specified subjective probability that the stock is above GNAI (or other target level) in 30 years; and

(iv) the fishing mortality corresponding to $\mathbf{F_{0.1}}$.

A TAC (which might be a by-catch limit in practice) would be set using whichever of these fishing mortalities was lowest. The assessments would be revised as new data became available. Once the procedure has been put into effect the target years for recovery become fixed at 20 and 30 years after the procedure is first put into effect. Thus, the fishing mortalities specified above have to be calculated using shorter projections as time progresses. The fishing mortalities would also be revised as more information accrues about the status of the stock.

2. METHODS AND RESULTS

The underlying process in calculating the probabilities is illustrated in Figure 1. In year 0 an estimate is available of the biomass relative to the average unexploited biomass. Around this point estimate will lie some distribution expressing degrees of belief in alternative values for the estimate. Calculating the subjective probability of the state of the stock at a given time in the future could be done with population projections. Each interval, such as A, B, or C in the probability distribution in the current assessment of the stock, can be projected forward with given values of **F**. However, because recruitment is stochastic, (and also because of uncertainty in the population dynamics) there will be a distribution of final population sizes for each current population size projected forward, shown as A', B' and C'. The probability distribution at year 20 is the sum of the projected distributions, for the set of current stock states in the distribution associated with the current assessment, weighted by their subjective probabilities.

These calculations will most likely have to be carried out numerically, using multiple simulation projections with some parametric or empirical model for generating variability in recruitment. In addition, some form of stock-recruitment model will be required. The starting point for the projections would be the centres of a range of intervals in the distribution of the current stock status. The weight to be applied to the distribution of the projections is the area of the respective starting interval.

A computer program implementing this algorithm has been used to generate some approximate results to illustrate some of the properties of the fishing mortalities defined above. A modified version of the CCAMLR stochastic population projection program (PROJ) was used to set a deterministic initial age-structure for hypothetical fish stocks. The same model was then used with stochastic recruitment for the projections using catches by weight, however, rather than applying fishing mortality. The catches by weight were calculated using the biomass from a deterministic projection (i.e., no recruitment fluctuation) of the median of the current stock assessment. This series of catches was applied for each interval selected from the distribution about the current stock estimate. 100 projections with recruitment fluctuation were made from 20 intervals. Other sources of uncertainty, for example, in the population dynamics parameters such as natural mortality (**M**) and growth rates, could also in principle be taken into account in the assessment and in the stock projections, but this has not been attempted here.

Calculations were made for two hypothetical fish stocks with different levels of production, one relatively high, the other relatively low. The population dynamics parameters for the two stocks are given in Table 1. Two current stock states are examined, one with the population at 30% of average pre-exploitation biomass, and the other at 5%. GNAI is taken to be 50% of the average pre-exploitation biomass. Two stock-recruitment relationships are used, one with the recruitment constant (independent of stock size, denoted C in the table) and the other with recruitment declining linearly to zero for stock sizes less than 50% of the unexploited level (denoted L). These particular forms were chosen because they represent the bounds of the plausible S-R relationships which might apply below GNAI. Stochastic variation in recruitment is drawn from a lognormal distribution with median determined by the S-R relationship and a coefficient of variation of 0.4. The subjective probability distribution of the estimate of the current status of the stock is taken to be normal, with median equal to the true value of the stock assessment. CV's of 0.1 and 0.3 are used for this distribution. This leads to a total of 16 cases, with results shown in Table 2.

The fishing mortalities given in the table are those which would result in

(1) $F_{0.1}$;

(2) 95% confidence in the stock being above the current level in year 20 (denoted $P_{L,20} > 0.95$ in the table);

(3) 50% confidence in the stock being above GNAI in year 20 (denoted $P_{GNAI,20} = 0.5$ in the table); and

(4) 95% confidence in the stock being above GNAI in year 30 (denoted $P_{GNAI,30} \geq 0.95$ in the table).

There are several points worth noting about the results. In most cases, the fishing mortalities required to meet all of the three criteria relating to projected outcomes in two to three decades are less than $F_{0.1}$. This has clear significance for applying $F_{0.1}$ for stocks below GNAI, in that it will not necessarily lead to fulfilment of the basic objective of reversibility in two to three decades. This suggests that an operational definition of depletion for fish stocks would involve the concept that the stock state is such that the application of the normal policy of applying $F_{0.1}$ will not lead to the stock being restored to at or near GNAI within two to three decades.

In all these cases, the fishing mortality which gives 95% probability of exceeding GNAI is the limiting value. The value is lower for the more uncertain estimate of current stock status. A population recovery level different from GNAI might be selected for this particular criterion in light of the language of Article II 3. (a) which is couched in terms of levels "close to that which ensures" GNAI; the definitions and calculations given here are illustrative. However, the calculations point to the selection of the level to be used in such a criterion as having a significant effect on the level of fishing allowed on recovering stocks.

As might be expected, the S-R relationship plays a major role in determining the critical value of the fishing mortality. A constant S-R relationship is an implausible choice for stocks depleted substantially below GNAI. Where a more suitable form of S-R is unknown it may be appropriate to use the linear model given here, in order to determine fishing mortalities at a likely lower bound with regard to uncertainty in the S-R relationship.

Interestingly, the degree of uncertainty in the estimate of current stock status does not have a great effect on the levels of fishing mortality which would prevent further decline over 20 years or lead to median recovery to GNAI by year 20. However, the 95% probability of being above GNAI by year 30 is sensitive to the degree of uncertainty in the current stock status estimate. This uncertainty would be reduced as further data accrued, and consequent recalculation of the various fishing mortalities could lead to increased TACs at least in cases where the fishing mortality for 95% recovery by year 30 is binding.

The final column in the table shows the median value to which the stocks would be expected to recover under the lowest of the fishing mortalities calculated (i.e., 95% probability of being above GNAI in three decades). In many cases it can be seen that these levels are not greatly above GNAI, and the form of calculation suggests a procedure for selecting target levels for exploited stocks which takes into account uncertainty in estimates of stock status. This would entail managing the stocks by choosing a stock target level so that there is a given level of confidence that the stock will be maintained above GNAI (or other nearby selected value).

3. CONCLUSION AND DISCUSSION

There are important details to sort out regarding methods of estimating the status of the stock with respect to the average pre-exploitation biomass, and in particular, concerning the means of formulating a subjective probability distribution about such estimates. Consideration needs to be given to procedures to be applied in cases where the available data are too sketchy to calculate subjective probability distributions for the current assessment, or to assess variability in recruitment. The routine application of the calculations presented in this paper will require the development of a more sophisticated computer program than that used to make the illustrative calculations here.

The calculation of fishing mortalities which lead to assessments of the subjective probability of a depleted stock being in a state which conforms to the basic objectives of the Convention seems to be a promising line of enquiry for further refinement of the Commission's management policy for finfish stocks. It is shown that the current strategy of applying $\mathbf{F_{0.1}}$ would not always be sufficient to restore depleted populations to the levels envisaged in the Convention. The approach outlined here gives an objective basis for basing scientific advice on fishing mortalities which will be expected to achieve management goals with selected levels of probability. The selection of the probability level to apply is not a purely scientific question, and hence guidance from the Commission will be required. However, this will be most easily obtained if further analyses can be carried out of the merits of these or other suggestions for definitions and procedures, so that the Commission has an objective and quantitative basis for selecting management policy parameters.

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Table 1: Population parameters used for the two hypothetical fish stocks.

Lower yielding stock		
Natural Mortality	=	0.15 $year^{-1}$
Von Bertalanffy **K**	=	0.12 $year^{-1}$
Von Bertalanffy $\mathbf{W_\infty}$	=	2 500 grams
Age at first fishing	=	5 years (knife-edge)
Age at first spawning	=	5 years (knife-edge)
Pooled age-class	=	20 years
Higher yielding stock		
Natural Mortality	=	0.40 $year^{-1}$
Von Bertalanffy **K**	=	0.20 $year^{-1}$
Von Bertalanffy $\mathbf{W_\infty}$	=	1 000 grams
Age at first fishing	=	3 years (knife-edge)
Age at first spawning	=	3 years (knife-edge)
Pooled age-class	=	10 years

Table 2: Fishing mortality rates consistent with each of the three criteria for managing stocks below the putative level giving greatest net annual increment. (See text for explanation of terms).

S/R	CV	Current Stock	$P_{L,20} > 0.95$	$P_{GNAI,20} = 0.5$	$P_{GNAI,30} \geq 0.95$	Stock at 30 years
			Lower Yielding Stock ($F_{0.1}$ = 0.123)			
C	0.1	0.30	0.210	0.139	0.130	0.63
L	0.1	0.30	0.044	0.041	0.029	0.75
C	0.3	0.30	0.103	0.112	0.074	0.63
L	0.3	0.30	0.012	0.041	0.008	0.92
C	0.1	0.05	0.318	0.106	0.071	0.62
L	0.1	0.05	0.044	0.	0.	0.23
C	0.3	0.05	0.197	0.104	0.067	0.65
L	0.3	0.05	0.011	0.	0.	0.23
			Higher Yielding Stock ($F_{0.1}$ = 0.336)			
C	0.1	0.30	0.304	0.340	0.150	0.69
L	0.1	0.30	0.073	0.117	0.057	0.88
C	0.3	0.30	0.302	0.340	0.150	0.69
L	0.3	0.30	0.032	0.120	0.031	0.94
C	0.1	0.05	>1.0*	0.367	0.150	0.75
L	0.1	0.05	0.087	0.	0.	0.83
C	0.3	0.05	>1.0*	0.355	0.149	0.70
L	0.3	0.05	0.011	0.	0.	0.83

* Approximate values: current version of computer program failed to converge on more accurate solution.

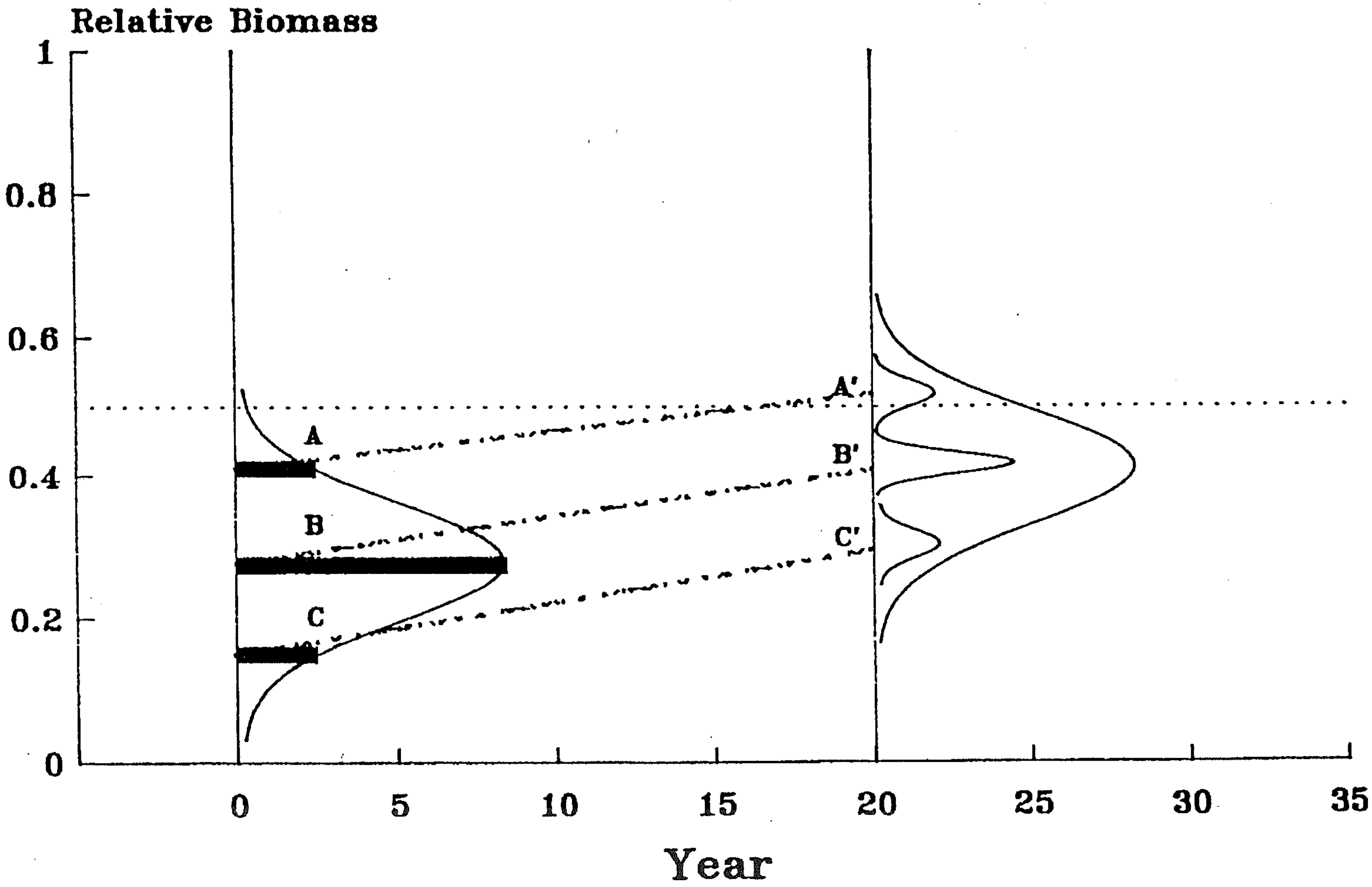

Figure 1: Schematic illustration of the method of calculating subjective probabilities of future states of a fish stock by stochastic forward projection of the subjective probability distribution associated with the current stock assessment.

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