SOME PRINCIPLES FOR FISHERIES REGULATION FROM AN ECOSYSTEM PERSPECTIVE

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Abstract

The paper discusses some principles to be considered in the formulation of a framework for the regulation of fisheries from an ecosystem perspective, under the Convention for the Conservation of Antarctic Marine Living Resources. An important task in this formulation is to derive subsidiary objectives for regulation which have a more rigorous scientific interpretation than the broad principles of conservation set out in the Convention. An important property required for subsidiary objectives is that they are framed in terms of quantities which can be robustly estimated, thus allowing the degree to which objectives are being met to be assessed. The advantages of using a feedback method of regulation are discussed. However, because of delays in detecting and correcting errors in rates of exploitation, it is important that initial levels of exploitation are potentially sustainable. This requires that estimates are required for the abundance of a stock in advance of the substantial development of a fishery. The design of a regulatory framework is a complex task involving systems analysis. The usefulness of simulation studies of potential management procedures is briefly discussed.

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QUELQUES PRINCIPES SUR LA REGLEMENTATION DE LA PECHE DU POINT DE VUE DE L'ECOSYSTEME

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Résumé

Le présent document examine quelques principes susceptibles d'être considérés pour l'élaboration d'un système de réglementation de la pêche du point de vue de l'écosystème, conformément à la Convention pour la Conservation de la Faune et la Flore Marines de l'Antarctique. En vue d'élaborer une réglementation, il est important de définir des objectifs subsidiaires offrant une interprétation scientifique plus stricte que les grands principes de conservation stipulés par la Convention. Un aspect important de ces objectifs subsidiaires est qu'ils soient posés en termes de quantités pouvant être estimées d'une manière fiable, permettant ainsi l'évaluation du niveau de la réalisation des objectifs. Les avantages d'une méthode de réglementation par retour d'information sont examinés. Cependant, du fait des délais dans la détection et la correction d'erreurs portant sur les taux d'exploitation, il est important que les niveaux initiaux d'exploitation soient potentiellement admissibles. Ceci exige que l'abondance d'un stock soit évaluée préalablement à l'expansion importante d'opérations de pêche. La conception d'un système de réglementation est une tâche complexe nécessitant une analyse fonctionnelle. L'utilité d'études par simulation des procédures possibles de gestion est brièvement examinée.

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ALGUNOS PRINCIPIOS PARA LA REGLAMENTACION DE LA PESCA DESDE UNA PERSPECTIVA DEL ECOSISTEMA

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Resumen

Este documento trata sobre algunos de los principios a ser considerados durante la elaboración de una estructura para la reglamentación de la pesca desde una perspectiva del ecosistema, de acuerdo con la Convención sobre la Conservación de los Recursos Vivos Marinos Antárticos. Una tarea importante en dicha elaboración es obtener objetivos secundarios para la reglamentación, que tengan una interpretación científica más exacta que los amplios principios de conservación establecidos en la Convención. Una condición importante que tales objetivos secundarios deberían tener es que se formulen a partir de cantidades que se puedan calcular sensatamente, permitiendo evaluar de este modo hasta qué grado se están logrando dichos objetivos. Se plantean las ventajas de utilizar un método en el que se aporten datos sobre la reglamentación. Sin embargo, debido a los retrasos en detectar y corregir los errores en los índices de explotación, es importante que los niveles iniciales de explotación sean eficazmente valederos. Esto precisa que se obtengan con anticipación los cálculos de abundancia de una reserva antes del desarrollo considerable de la pesca. La preparación de una estructura reguladora es una tarea compleja que implica el análisis de sistemas. Se debate brevemente sobre la utilidad de los estudios de simulacro de los posibles procedimientos de administración.

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НЕКОТОРЫЕ ПРИНЦИПЫ РЕГУЛИРОВАНИЯ ПРОМЫСЛА С ЭКОСИСТЕМНОЙ ТОЧКИ ЗРЕНИЯ

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Резюме

В документе обсуждаются некоторые принципы, которые следует принимать во внимание при разработке основ регулирования промысла с экосистемной точки зрения, в соответствии с Конвенцией о сохранении морских живых ресурсов Антарктики. Важной задачей такой разработки является выявление дополнительных целей регулирования, у которых будет более жесткая научная интерпретация, чем упоминающиеся в Конвенции широкие принципы сохранения. Важным качеством, которым должны обладать дополнительные цели, является то, что они выражаются количественными факторами, которые могут быть четко определены, позволяя таким образом определить степень приближения к этим целям. Обсуждаются преимущества регулирования, построенного на методе обратного потока данных. Однако вследствие задержек в обнаружении и исправлении погрешностей при определении интенсивности эксплуатации важно, чтобы исходные уровни эксплуатации были потенциально устойчивыми. Это потребует получения оценок численности запаса до начала существенного развития промысла. Разработка основ регулирования - сложная задача, требующая использования системного анализа. Кратко обсуждается польза изучения моделей возможной методики управления.

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SOME PRINCIPLES FOR FISHERIES REGULATION FROM AN ECOSYSTEM PERSPECTIVE

INTRODUCTION

The main instrument for the regulation of fisheries in the Southern Ocean is the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), whose relevant articles are as follows :

1. The objective of this Convention is the conservation of Antarctic marine living resources

2. For the purposes of this Convention, the term 'conservation' includes rational use

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 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.

The CCAMLR Convention has been widely hailed as an important advance in the international regulation of fisheries because it does not concentrate solely on the objects of fisheries but also seeks to limit the impact of fisheries on 'dependent and related species', that is, the animals with which man enters into competition for their food supply (it is well established that fisheries can affect other species [Schaefer, 1971; Cushing, 1980; Rigler, 1982]).

The international regulation of fisheries takes place in an environment such that, even at a scientific level, considerations arise which would not arise in the pursuit of a purely scientific research activity. The Scientific Committee of CCAMLR has already attempted to formulate advice for the Commission working from incomplete knowledge and uncertain data which does not admit to an unambiguous interpretation. The Scientific Committee and the Commission have to take decisions by consensus (Rule 3 of the Scientific Committee rules of procedure, and Article XII of the Convention). Under these circumstances it is important to consider what kind of regulatory framework will help towards consensus within the Scientific Committee and the Commission. In this paper, fishery regulation is taken to be the scientific basis on which decisions are taken to formulate conservation measures designed to achieve the objectives of the Convention.

INTERPRETATION OF THE OBJECTIVES OF THE CONVENTION

The establishment of a clearly defined objective, or set of objectives, is an essential starting point of fishery regulation (ACMRR, 1980). It is a common situation that the objectives of international Conventions for the regulation of fisheries embody important principles, yet do not in themselves have precise scientific interpretation. In such cases, subsidiary objectives need to be developed which are scientifically meaningful (that is, measurable) such that progress towards them can be assessed.

Odum (1971) defines an ecosystem as :

> ... any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diveristy, and material cycles (i.e. exchange of materials between living and non-living parts) within the system ...

Clearly, regulating ecosystems is a task for which currently we possess neither the knowledge nor the tools. In this paper it is assumed that the system to be regulated is a complex of species (not necessarily all species) within an arbitrarily defined geographic region (management area), and will be referred to as the exploited system.

As discussed in Beddington and de la Mare (1986), there are a number of problems in interpreting the precise scientific meaning of certain portions of the text of the Convention. In particular, there is difficulty of interpreting article II paragraphs 3b and 3c unless, following Edwards and Heap (1981), distinction is made between :

(a) species in the low-trophic levels which form the food base for species in higher trophic levels (e.g. zooplankton, particularly krill)

(b) species at intermediate-trophic levels which prey on the species of the low-trophic level but are themselves subject to significant predation by the top-trophic level (e.g. squid and fish)

(c) species at the top trophic levels which prey on levels (a) and (b) but may not themselves subject to significant natural predation (e.g. whales, seals and birds).

This distinction suggests that top predators may only be adequately treated by the Articles if levels of 'greatest net annual increment' are interpreted as those occurring when some specific amount of krill is harvested. In simple terms, in the absence of exploitation of their food supply, top predators will have some population level at which their net annual increment is at a maximum. If their food supply is exploited (and assuming that food is limiting at some point), there will be a new and lower population level at which their net annual increment will be maximised. Hence, there is a range of possible protection levels for top predators and the precise level will be determined by the level of krill harvesting : the higher the level of krill harvest the lower the protection level. This would appear to be against the spirit of the convention and some interpretation which avoids this difficulty is necessary. An obvious choice of protection level for the predator population is that derived from its population abundance pertaining to the absence of krill harvesting. However, it has proved to be very difficult in the case of marine mammals to determine where the relative levels of greatest net increment might be, and the time scale to determine the answer by experiment could be of the order of hundreds of years (de la Mare, 1986a). In practice, it is likely that an arbitrary percentage of pristine abundance will have to be used. Moreover, it is unlikely that all species will be of equal concern, a population decline in salps might not be regarded in the same light as the decline of a commercially valuable fishstock; or a depleted species of whales.

However, these are not the only difficulties of interpretation, ecosystems are complex and stochastic; to the extent that it is not possible to make reliable quantitative predictions about their future states or the consequences of perturbations (ACMRR, 1980; Pielou, 1981; Rigler, 1982; Bender, Case and Gilpin, 1984). Species interact in ways which make it difficult to decide exactly where the level of 'greatest net annual increment' might lie for a harvested species; nor, because of interactions, does such a level necessarily exist as a time invariant quantity. Once again, the solution in the short term would seem to be the adoption of some arbitrary levels below which harvested species should not be driven by exploitation. For the case of prey species, choosing this level as a relatively high proportion of unexploited abundance may ease the difficulties inherent in achieving conservation of dependent species in the interim.

It may be fruitful at this stage to attempt to formulate the objectives to be achieved by the regulatory framework for a set of dependent species which are representative of important groups of dependent species; along with species which are of direct concern, such as depleted whale populations; subject to the condition that they are practicable to monitor in some way. Such an approach would be related to the work which is already under development by the Ecosystem Monitoring Group (CCAMLR, 1986).

APPROACHES TO THE REGULATION OF FISHERIES

Following Walters and Hilborn (1978), there are three basic approaches to the regulation of fisheries, namely, (1) set point or open loop regulation; (2) passive adaptive regulation; and (3) active adaptaive regulation. Set point regulation can be defined as identifying the control strategy which will need the conservation objectives from a priori consideration of a model which is assumed to be consonant with the dynamics of the exploited system. Approach (2) incorporates the additional idea that, as exploitation continues, more will be learned about the dynamics of the system, and hence improved predictions can be made about the consequences of conservation measures. Approach (3) actively seeks to learn more about the dynamics of the system by deliberately manipulating catch levels and other parameters of the fishery; in essence, an analogue of a typical scientific experiment. Approach (3) is often cast in terms of what is known as the 'dual control' problem (reviewed in Goodwin and Sin, 1984), which considers how to combine the objectives of regulating the controlled system with actions which will lead to better information on its dynamics.

The classic approach to fisheries regulation relies on approaches (1) and (2). The aim of analytic fishery models such as that of Beverton and Holt (1956) is to predict optimum levels of fishing mortality and age at first fishing from estimates of growth curves and age-structure of an exploited fish stock. This method falls within the scope of approach (1). However, the parameter estimates required for the models are usually difficult to obtain with any precision, and hence the set point may not be particularly reliable. An example of approach (2) is the fitting of a production model, such as a Schaefer (1954) model, to time series of catch and effort data. In principle, such methods attempt to estimate production directly from the catch history of the fishery, and if continually revised, catch levels can be identified which will lead to some form of optimum catch level. However, in practice, production models have not been very successful in identifying optimal catch levels (Larkin, 1977; Gulland, 1978; Sissenwine, 1978; Hilborn, 1979; Uhler, 1980); although time will tell if more recent variants on the theme such as 'passive optimal control' (Walter, 1978) are more successful.

It is not the intent of this paper to examine in detail the strengths and weaknesses of various models used in fishery management; the important point is that, for a spectrum of reasons, we will make errors in predicting the level of catch which can be sustained or which will meet the other objectives of the Convention. The errors may lead to either underexploitation or overexploitation, although the consequences of such errors are not necessarily equal. An error on the conservative side does not cause disruption to fishing activities, but an error leading to overexploitation will have led to overinvestment in the fishery and all the attendant strains which result from having to reduce catches. Therefore, a key property that a regulatory framework should possess is the power to detect and correct such errors before the consequences are serious for either the fish stocks, the fishing industry, or both. A corollory of this property is that it allows adjustments to be made to the level of fishing with the least possible disruption to the fishing industry.

It has been recognised that the conservation of living resources is an area which can benefit from the application of control theory (for example, Watt, 1968; Walters and Hilborn, 1976). The importance of basing a fisheries regulatory framework on feedback principles is now also being recognised (Tanaka, 1984; de la Mare, 1986a and 1986b). Di Stefano, Stubberbud and Williams (1967) define feedback as :

> ... that property of a closed loop system which permits the output (or some other controlled variable of the system) to be compared with the input to the system (or an input to some other internally situated component or subsystem of the system) so that the appropriate control action may be formed as some function of the output and input.

Properly designed feedback systems have a number of important advantages over non-feedback systems. These include improved accuracy and stability in attaining objectives and reduced sensitivity to error in the model assumed to apply to the controlled system.

The implication of applying control systems theory and feedback to living resource conservation is that it directs attention to the specific examination of system input and output. For a convention such as CCAMLR, the system under discussion is the exploited system in combination with a regulatory framework. Thus, the system to be controlled (at least along some partial dimension) is the exploited system, and the regulatory framework forms a control system. The system input is formed from the objectives of the Convention, and hence, the system output is some attribute of the exploited system. In system terms, the catches are not necessarily considered as part of the output of the system, but they are the principal control action which can be applied to drive the ecosystem towards a specified set of objectives. A simplified example may make this more concrete in the context of the possible form of objectives for CCAMLR discussed earlier.

Suppose that it was decided that an exploited fish stock should not fall to below say X_{min} (to ensure recruitment) and that the optimal level of the stock was somewhat higher at X_{opt}. Similarly, suppose that some predator is to be maintained at a level above Y_{min} and to have a desirable level of Y_{opt}. Thus the input to the system is X_{opt} and Y_{opt}, and its output is the observed values of X and Y. Feedback control would lead to catches being increased, if the observed values of X and Y were above their target levels, but some reduction in catches would follow some form of rule, which could be rather complex, but which would include some element or proportionality in that small differences between the observed and target values for X and Y lead to smaller adjustments in catches than do large discrepancies between the observed values and their targets. If the observed values of X or Y were to be found below the minimum levels, then catching would cease until the stocks had recovered towards the target level. Simulation studies of such a regulatory system, in a single species context, have shown that the probabilities of erroneously curtailing exploitation on a stock or inadvertently reducing it to below the minimum level can both be controlled (de la Mare, 1986a and 1986b). However, it has also been shown that the time to detect and correct errors can be relatively long because of the effects of variability in estimates of absolute or relative abundance (de la Mare, 1984, 1986a).

The example outlined above is not intended to be definitive, but to illustrate how feedback regulation might work, and in particular to highlight three important principles. The first principle is that the initial rate of exploitation should be basically feasible in terms of a likely level of sustainable yield. This requires that an estimate of abundance is available for each exploited stock in advance of the substantial development of its fishery. This is important for two reasons : (1) that it helps to avoid over-capacity in the fishery; and (2) it helps to ensure that the reduction in the biomass of the stock occurs over a sufficiently long time span to allow sufficient data to accumulate so that errors in the predicted yield can be identified and corrected, before the consequences become serious for the fishery. The second principle requires that the objectives for the regulatory system should be framed in terms of aspects of the status of the controlled system which can be robustly estimated. The third principle is that the regulatory framework specifies what actions are required given the observed values of status of the controlled system. These principles are also an important factor in creating an environment in which scientific consensus is more readily obtained.

The essential problem is that the Antarctic marine ecosystem is too complex to frame objectives to cover all species, but the intent of the Convention seems to require an approach which is broader than the classic single species approach for each possible fishery. However, it may be possible to regulate the real exploited system as if it were a much simpler system; the true level of complexity of a system of interacting species may be abstracted into a subset of species of interest (the single species model being the extreme example). The degree to which the abstracted system model can describe the corresponding elements of the true systems depends, amongst other things, upon the dynamics of the elements left out of the model (Schaffer, 1981; Bender, Case and Gilpin, 1984). However, potential lack of predictive power from the abstracted model may be considerably reduced in importance when it is part of an adaptive feedback system, it may transpire that fitting the abstracted system model to data from the real system can lead to estimates of the parameters of the abstracted system model such that appropriate control actions are taken. This can occur even though the abstracted model is not an accurate representation of the real system. Such a scheme would not necessarily lead to accurate control for those species left out of the model. However, if the species included are those of greatest concern, or are those which are representative of key sections of the exploited system, then it seems reasonable to assume that the overall objectives of the convention are being met as far as is possible.

The use of feedback control could be described as an empirical or observational approach to the regulation of fishing activities, but there are many factors to be taken into consideration in designing such a regulatory framework which might meet the objectives of the Convention. It is not the intention to discuss these factors at length here, however, it is pertinent to indicate the nature of a few of them.

One such factor is the selection and calibration of variables which describe some aspect of the status of the system, and, as shown by the work of the Ecosystem Monitoring Working Group (CCAMLR, 1986), it is far from a trivial question. For example, data from catches or other samples may not be representative of a population as a whole because of tendencies for animals to segregate by size, age, or reproductive condition. For another example, catch per unit effort (CPUE) is, in general, not linearly related to the abundance of an exploited fish stock (Ulltang, 1977; Peterman and Steer, 1981; Cooke, 1985; Winters and Wheeler, 1985). Moreover, fishery regulation based purely on CPUE data has the weakness of not separating information from control; that is, the control action (catches) is also the source of information about the status of the exploited fish stock.

Another factor to be considered in designing a feedback regulatory system is how to deal with observation uncertainty and the stochastic variations in the exploited system, and in particular, what level of risk is acceptable that exploited or dependent species may be inadvertently reduced to levels below those 'ensuring stable recruitment', and conversely, what level of risk is acceptable that fishing might be erroneously curtailed.

A further factor is the cost of monitoring. Data collection from the fisheries themselves can be obtained more economically than those from specially mounted scientific surveys. However, data from fishing operations generally have reduced scientific utility due to 'laisser faire experimental design'. Naturally, fishing operations continually strive to improve their efficiency and so introduce technical innovations, move fishing grounds and seasons as more is learned about the characteristics of the exploited species. This has the unfortunate effect of masking changes in the status of the system, or precluding unambiguous interpretation of the fisheries data, or both. Conversely, scientific surveys are very expensive and so there is a tradeoff between the level of harvest, the risks associated with types of error discussed earlier, and the amount of resources committed to monitoring. A potential scheme for obtaining data of enhanced scientific utility from commercial operations is for a small proportion of the fishing effort of the commercial fleet to be channeled into 'survey fishing' within a proper experimental design.

The empirical feedback approach need not be the only candidate for a regulatory framework that might be considered. The problem with the feedback approach is that it has a considerable overhead in terms of data collection, supplemental surveying, and stock assessment. The Convention allows considerable flexibility in the kinds of conservation measures that could be adopted. For pelagic fisheries such as krill in particular, it might be simpler and considerably less costly to attempt to guarantee a certain level of escapement by combinations of open and closed seasons and areas instead of trying to regulate the amount of catching or effort directly. For example, a management area could be divided into sub-area, in a (perhaps randomly selected) proportion of which fishing could be as intense as desired by the fishing industry; the unexploited proportion serving to maintain 'essential ecological relationships' as sought by the Convention. However, such an approach gives a low priority to learning about the ecosystem and optimising the level of catches. On the other hand its simplicity may make it a suitable candidate for an interim method of regulation.

CONCLUSION

Although the outline of principles and problems given in this paper is relatively brief, it should serve to illustrate that the design of a regulatory framework for marine living resources from an ecosystem perspective is a complex task which may take a number of years to complete. Such design work can be thought of as 'systems analysis' as suggested by Watt (1968). Examples of this type of analysis are to be found in Hilborn (1979) and de la Mare (1986). A valuable tool used in both examples is simulation modelling. Potential management procedures can be tested and refined by applying them to a whole range of artificially exploited systems of increasing complexity and variability. Only those procedures which pass such tests need to be considered as candidates for adoption by the Commission.

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