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COMMENTS AND QUESTIONS ON ECOSYSTEM MANAGEMENT

Abstract

The objectives of the Commission as set out in Article II of the Convention are briefly discussed and the two approaches to ecosystem analysis reviewed. The top-down approach, following the flow of energy from primary production through to the animals of interest gives a broad understanding of how the system works, and rough estimates of the potential yield at various trophic levels. It is not very useful in formulating specific management advice, e.g., whether a catch of the same order of magnitude as the potential yield is too high or not. For providing advice the bottom-up approach is more useful, starting with examining the dynamics of the stocks of individual species, especially those currently being exploited.

"Ecosystem management" in the Antarctic will therefore depend on having a good understanding of the dynamics of each important species. The present knowledge of the behaviour of different stocks under exploitation, and of the basic parameters (growth, mortality, etc.) is reviewed. These range from fairly good for whales, through moderate for fish and krill, to poor or non-existent for squid. The most serious inadequacy is probably the lack of good methods of monitoring changes in krill abundance. Most catch per unit data for krill reflect local density rather than overall abundance.

The forms of interaction between species are discussed, and related to the work of modelling and data collection. It is suggested that of the various types of models, strategic simulation models which help address the right questions are, in the current state of knowledge, the most valuable.

COMMENTAIRES ET QUESTIONS SUR L'AMENAGEMENT DE L'ECOSYSTEME

Résumé

Les objectifs de la Commission exposés à l'Article II de la Convention sont revus brièvement et les deux approches d'analyse de l'écosystème sont examinées.

L'approche de haut-en-bas, en suivant le flux d'énergie à partir de la production primaire en passant par les animaux qui nous intéressent permet une compréhension globale du fonctionnement du système et fournit des prévisions approximatives du rendement possible à divers niveaux trophiques. Cette approche ne permet pas de formuler des recommandations particulières de gestion, comme, par exemple, si une prise du même ordre de grandeur que le rendement possible est trop élevée ou non. La méthode la plus utile pour donner des conseils est l'approche de bas-en-haut, en procédant à l'examen de la dynamique des stocks des espèces individuelles, en particulier des espèces exploitées actuellement.

"L'aménagement de l'écosystème" dans l'Antarctique sera par conséquent fonction d'une bonne compréhension de la dynamique de chaque espèce importante. Les connaissances acquises sur le comportement de stocks différents en cours d'exploitation et des paramètres fondamentaux (croissance, mortalité, etc.) sont examinés. Ces évaluations de paramètres sont classées de la manière suivante : assez bonnes pour les baleines, moyennement bonnes pour les poissons et le krill et peu satisfaisantes ou nulles en ce qui concerne les calmars. L'absence de méthodes adéquates de contrôle de changements dans l'abondance de krill est probablement le problème le plus grave. La plupart des données de prise par unité d'effort pour le krill traduisent une densité locale plutôt qu'une abondance globale.

Les formes d'interaction entre espèces font l'objet de discussions et sont examinées dans le contexte des études portant sur les modèles et la collecte des données. Il est suggéré que parmi les divers types de modèles, les modèles de simulation stratégiques permettant de poser des questions pertinentes sont les plus utiles compte tenu du niveau des connaissances actuelles.

ЗАМЕЧАНИЯ И ВОПРОСЫ ОТНОСИТЕЛЬНО УПРАВЛЕНИЯ ЭКОСИСТЕМОЙ

Резюме

В настоящем документе кратко рассматриваются цели Комиссии, установленные в Статье II Конвенции, и два подхода к анализу экосистемы. Нисходящий метод, следующий в направлении движения потока энергии от первичной стадии переработки к живым организмам, представляющим для нас интерес, дает широкое представление о том, как функционирует система и приблизительную оценку величины потенциальной продуктивности на различных трофических уровнях. Этот метод не представляет особой ценности при попытках выработки конкретных рекомендаций по управлению; например, является ли слишком высоким вылов такого же порядка величины, как потенциальная продуктивность. Для разработки рекомендаций более

полезен восходящий метод, исходным пунктом которого является изучение динамики запасов отдельных видов, особенно тех, промысел которых ведется в настоящее время.

Таким образом, "Управление экосистемой" в Антарктике будет зависеть от глубокого понимания динамики каждого имеющего значение вида. Сделан обзор имеющейся информации о поведении различных эксплуатируемых запасов и об основных параметрах (темпы роста, уровень смертности и т.д.). Глубина знаний варьируется от достаточно обширной информации о китах, через умеренное количество информации о рыбах и криле, до скудной или отсутствующей информации о кальмарах. Наиболее значительным недостатком, вероятно, является отсутствие точных методов мониторинга изменений количества криля. Большинство данных по улову на единицу промысловых усилий отражает локальную плотность, но не общее количество.

Рассматриваются формы взаимодействия между видами и соотносятся с деятельностью по моделированию и сбору данных. Предполагается, что из всех существующих видов моделей модели симулирования стратегий, которые способствуют выявлению важных проблем, являются наиболее полезными при настоящем состоянии уровня знаний.

COMENTARIOS E INTERROGANTES SOBRE LA ADMINISTRACION DEL ECOSISTEMA

Resumen

Se comenta brevemente sobre los objetivos de la Comisión tal como se presentan en el Artículo II de la Convención y se revisan los dos enfoques del análisis del ecosistema. El enfoque de arriba hacia abajo, que sigue el flujo de energía desde la producción primaria hasta los animales de interés proporciona una idea general de cómo funciona el sistema, así como estimaciones aproximadas del posible rendimiento a varios niveles tróficos. No es muy útil para proporcionar recomendaciones específicas con respecto a la administración, por ejemplo si una captura de la misma magnitud que el posible rendimiento es demasiado alta o no. Parece proporcionar recomendaciones, el enfoque de abajo hacia arriba resulta más útil, al comenzar por examinar la dinámica de las reservas de cada especie

especialmente las que están siendo explotadas actualmente.

"La administración del ecosistema" en el Antártico dependerá por lo tanto de una buena comprensión de la dinámica de cada una de las especies importantes. Se está revisando el actual conocimiento sobre la conducta de las diferentes reservas bajo explotación, y sobre los parámetros básicos (crecimiento, mortandad, etc.). Estos varían desde bastante buenos para las ballenas, pasando por moderados para los peces y el krill, hasta pobres o inexistentes para los calamares. La insuficiencia más grave es probablemente la carencia de buenos métodos para controlar los cambios de la abundancia de krill. La mayoría de los datos sobre captura por unidad con respecto al krill reflejan la densidad local en lugar de la abundancia general.

Se comenta sobre las formas de interacción entre las especies, y se las relaciona con la labor de modelado y recopilación de datos. Se sugiere que de los diversos tipos de modelos existentes, los modelos de simulación estratégica que ayudan a formular los interrogantes adecuados, son los más valiosos de acuerdo al estado de los conocimientos actuales.

Introduction

At its second meeting the Scientific Committee of CCAMLR requested (para. 67 of its report) that members should send papers to the Committee commenting and raising questions on the matter of ecosystem management. It was also agreed that contributions from observer organizations would be welcomed. This note has been prepared by the Department of Fisheries of FAO in response to that request.

The objectives of the Commission and 'ecosystem management'

CCAMLR has been referred to as one of the first 'ecosystem' Commissions, in distinction from the more narrowly based 'fishery' Commissions, and the Antarctic marine ecosystem is mentioned explicitly in the preamble, and in several articles of the Convention. These do not, however, call on the Commission to 'manage the ecosystem', which if broadly interpreted would clearly be impracticable. The actual objectives, relative to managing the ecosystem are the three detailed sub-sections under Article II, and in particular 3(b) and 3(c), which call respectively for maintaining ecological relationships, and preventing (or minimizing the risk of) changes in the marine ecosystem that are not potentially reversible over two or three decades.

The direct implementation of these objectives may meet difficulties when matched against the growing - but still extremely incomplete - knowledge of the actual behaviour of the Antarctic ecosystem. For example, paragraph 3(a) - which does not involve the difficult ecological question of relation between species - calls for the "prevention of decrease in the size of any harvested populations to levels below those which ensure its stable recruitment". As more is known about populations of fish it becomes clearer that stable recruitment is unusual in nature and may be little more than the optimistic simplification of the mathematical modeller. Observed observations in recruitment range from the apparently random (or at least with little discernible patterns) year to year fluctuations over some three orders of magnitude in the North Sea haddock, to the longterm (over many decades) changes between periods of high and low abundance in many clupeoid stocks (Scandinavian herring, Californian sardine). Much of this instability is unrelated to exploitation, and has occurred even in the absence of any harvesting. The history of some of the clupeoid stocks also show that changes can occur, sometimes possibly triggered by over-exploitation, but sometimes due solely to natural events, which are not reversible in "two or three decades".

It would be surprising if some elements at least of the Antarctic marine ecosystem did not exhibit similar instability and changes that are, in the short term, irreversible. That is, the objectives of the Commission, if narrowly interpreted, could prove difficult or impossible to achieve. This is not too surprising. The objectives, as expressed in the Convention, are not intended to be an exposition of the scientific realities and complexities of the Antarctic marine ecosystem, but are largely the result of difficult negotiations when there were very different views regarding the approaches to managing and conserving the Antarctic ecosystem, both between and within countries.

The Scientific Committee should therefore be prepared to consider wide interpretation of the Commission's objectives, always bearing in mind that its functions are, as spelt out in Article XV, themselves mostly general ("to assess the trends and status of populations ..... analyse data concerning the direct and indirect effects of harvesting ... assess the effects of proposed changes in the methods or levels of harvesting, etc."). Only in respect of Article XV 2(e) ("transmit ... recommendations ... regarding measures and research to implement the objectives of this Convention") may it be essential for the Committee to look carefully and in detail at the objectives, e.g., on what is meant by "stable recruitment" or "maintenance of ecological relations". For most of the Committee's work, and for the purposes of this note, the Commission's objectives are important as general guides on the nature of the Committee's advice, and hence (and probably most important in the short term) on the kinds of analyses that should be made and the data that should be collected.

Approaches to ecosystem analysis

In making quantitative ecosystem analyses two approaches can be used. The top-down approach looks at the whole picture at once, and in particular follows the flow of energy from sunlight through phyto- and zoo-plankton to whatever sizes and species of animals find favour in the world's market place. This approach is logically satisfying, and can give satisfactory order-of-magnitude estimates of the yields that can probably be sustained at different stages in the food web. For the Antarctic this approach has indicated similar conclusions to those obtained from other approaches Figures for the sustainable yield of krill that lie in the high tens or even low hundreds of millions of tons annually are not unreasonable. For the manager the approach is less satisfactory, in that small changes in the estimated figures of total primary production, the transfer efficiency between ecological stages, or in the proportion of krill in the total zooplankton can make a very big difference to a conclusion on whether or not, say a catch of 45 million tons is too high.

The bottom up approach starts with the individual species. By studying its population dynamics, and its links with other species, it is hoped that enough pieces of the jig-saw can be put together to obtain a reasonable picture of the ecosystem. Undoubtedly in the early stages of this process any picture obtained is likely to be greatly distorted. However, this distortion will be least for those species which are best known, which are probably those currently harvested, and of major interest to the manager. That is, the distorted picture can still, in most cases, be used to give useful advice. For example, the model used by the Committee of Four to advise the IWC on the state of Antarctic whale stocks in 1964 was an over-simplification of the population dynamics of whale stocks. However, it gave the IWC for the first time a quantitative scientific basis for its quota discussions, and shifted those from whether or not the current quota was too high to arguments on how quickly the quota could be reduced to the estimated sustainable level. It is likely that if this quantitative advice had been available earlier, when the reduction in the quota might have needed to have been, say, 25%, rather than the 75% needed in 1964/65, the history of the IWC and of Antarctic whaling might have been very different. The lesson for CCAMLR may be that good, but not perfect, advice that comes early is much more useful than perfect analyses that come too late.

The Convention implicitly leans towards the bottom-up approach in starting its listing of objectives with one (Article II 3(a)) that deals only with a single species. This calls on the Commission to prevent stocks falling below the level close to that which ensures the greatest net annual recruitment. 'Net Recruitment' is not explicitly defined, but it seems not unreasonable to interpret it broadly to include the additions to the biomass of the stock (or the exploitable part of the stock) from births and growth of the individual animals. For whales and seals the distinction between this and the narrower (and commoner) interpretation of recruitment in terms of births, or the entry of young animals into the exploitable part of the stock, is small, and is zero if the stock is reckoned in terms of number rather than weight. For fish the distinction may be vital. Fishery scientists often distinguish between 'growth over-fishing' - causing too high a fishing mortality from too early an age, so that the fish are caught before they get to a good size - and 'recruitment over-fishing' - reducing the adult stock to a level at which the number of young fish (recruits) entering the fishery is reduced. Recruitment over-fishing may be much more serious, but it is difficult to demonstrate, and is probably rarer. Fish stocks can be reduced to a very low level without obvious effect on reproductive success. For example, the spawning stock of the southern bluefin tuna (which has been recorded as being caught in the Convention area) has been reduced to a tenth or less of its unfished abundance without any detectable effect, at least so far, on the number of young fish entering the fishery. In common fishery terms this would mean that the Commission's objectives would be obtained by holding the fishing mortality at F_{max}, i.e., that giving the maximum sustained yield, with the stock abundance being determined by this mortality.

Single-species analysis :

Fish

It would probably be very hard to demonstrate to the satisfaction of the Commission as a whole (and particularly to those countries who might believe that it would be to their disadvantage to impose restrictions on catches unless these are absolutely necessary) that many fish stocks, for example, those round South Georgia, even if reduced very greatly, had been reduced to the level at which they were exposed to 'recruitment over-fishing'. The existence of 'growth over-fishing' would be much easier to demonstrate. Probably enough is now known about the likely values of the growth and natural mortality of these fish, and of the fishing mortality (e.g., from the ratio of catches to biomass) to construct yield-per-recruit curves (or better a family of yield-per-recruit curves, covering the likely range of parameter values), and to locate the likely current position (e.g., as determined by the average catches of fishing effort over the last few fishing seasons). It might then be possible to demonstrate that in terms of yield-per-recruit the stocks are fully exploited (no increase, or at most a very insignificant increase, in Y/R would be achieved by increasing fishing effort) or even over-exploited (in the sense that Y/R would be <u>increased</u> by reducing the amount of fishing.)

Despite our ignorance about the stock-recruit relationship (i.e., the degree to which the average recruitment changes with changes in adult stock), there is no reason to suppose that the recruitment will increase if the stocks are further reduced below their current levels. Therefore the conclusions above about the yield-recruit would apply also to the total yield, and the conclusions from the Y/R analysis would be enough to advise the Commission that the amount of fishing should, according to the earlier interpretation of Article II 3(a) not be allowed to increase and might need to be decreased.

Bearing in mind the conditions of fishing in the Antarctic and the fact that the fish are moderately long-lived, this advice might be better presented in terms of the average amount of fishing over a period, rather than the specific amount in any one season. It is probable that it is operationally more attractive to mount a moderately large expedition with several fishing vessels and support craft in one season, and then not fish at all for one or more seaons, than to fish at a low level of perhaps no more than half a dozen fishing vessels each year. In fact it has been shown that if the recruitment to a long-lived fish stock is variable, and the pulses of high fishing effort can be matched to the years when the good year-classes are at the optimum size, such a pattern of fishing will actually increase the gross yield that can be taken. Of course a policy of pulse-fishing should not be used to allow a highly excessive fishing effort in one year on the argument that it will be made up by zero fishing in later years; the concept should be one of regular harvesting of a well-grown crop down to some acceptable level, rather than periodic recoveries from depletion.

The pattern for advice within the mandate of the Commission, but looking in the first instance at the single-species situation, on the management of the fish stocks can therefore be very similar to that for fish stocks in many other regions, with the immediate emphasis on the collection of catch and effort statistics, estimation of growth and mortality rates, and the calculation of yield-per-recruit curves.

Mammals

The pattern for whale stocks, to the extent that the Commission should be directly concerned with these resources, rather than leaving the immediate responsibility to the IWC, seems equally clear. Because of the differences in the population dynamics, with net annual increment being determined almost wholly by recruitment - which is very closely related to the size of the adult stock - the Commission is likely to follow the pattern of the IWC, in setting its targets in terms of some minimum population level (e.g., at or above the level giving MSY), and its controls in terms of catch at or less than some replacement number. The situation in respect of seals is similar except that in the absence of commercial hunting of seals little is being done within the context of the relevant Convention.

While the simple population model implicit in this approach has served the IWC well, especially for baleen whales, and probably fits the dynamics of these species much better than it fits the dynamics of most fish species, there are a number of points that CCAMLR needs to consider. Some of these - the uncertainties in the estimation procedures, the fact that although it is generally agreed that the MSY occurs at a percentage of the initial population greater than the 50% occurring in the simplest model, there is little data that will support any particular value in the range from 50% up to 80% or possibly more - are of obvious concern to the IWC, and are being discussed, in varying detail, in that forum. Of more specific concern to CCAMLR is the fact that the 'carrying capacity' of the Antarctic for, say fin whales (and hence the maximum abundance, and the abundance, in actual numbers, at which the MSY, or maximum next increment, occurs) is not fixed, but may vary for natural reasons (e.g., the position of the antarctic convergence, or the extent of ice-cover during the feeding season) and due to changes brought about by exploitation of other species (e.g., increasing with decreasing abundance of other baleen whales, and decreasing with decreasing abundance of krill).

Krill

The form of analysis and possible advice in respect of krill is less clear. The dynamics of reproduction, expressed either in fishery jargon as recruitment (absolute numbers of animals reaching an exploitable size) or as a stock-recruitment relation, or in mammal jargon as reproductive success (numbers of surviving young produced per adult female) is likely to depend greatly on fecundity. The fecundity of krill is much higher than whales, and lies towards the bottom range of fishes, between salmon (2,000 - 4,000 per female) and below herring and sardine (20,000 - 80,000) (Cushing, 1971) but well below gadoids and flatfish (up to a million or more). We might therefore expect that so far as possible 'recruitment over-fishing' is concerned, krill will not behave like whales, but like those relatively low-fecundity fish, such as salmon and herring, which seem susceptible to 'recruitment over-fishing' but which do not have a clear on-to-one relation between stock and subsequent recruitment. In particular there is no reason to expect krill stocks to have a neat quasi-proportional relation between spawning stock and the recruits, i.e., the number of young surviving to an exploitable size. It is more likely that over a considerable range of adult stocks krill dynamics will be similar to most fish, with a great deal of variation in recruitment from year to year, and no clear relation observable between recruitment and adult stock. A more precise statement is that the probability distributions of recruitment for different adult stock sizes will be difficult to distinguish over quite a wide range. At present little is known about the variability of recruitment in krill. There seem to be quite large year-to-year changes in abundance in specific areas; these may reflect differences in distribution, with the actual abundance being much the same. If they reflect real changes in abundance it may be due to differences in growth or in post-recruit mortality, but if the analogy with fish stocks is correct, the more likely proximate cause is recruitment variations.

Calculation of a yield-per-recruit function for krill presents fewer problems, though until the doubts about the growth and longevity of krill are resolved, there will be some uncertainties in the precise form of the relation of yield-per-recruit to the intensity and pattern of exploitation. The exact form of the yield-per-recruit curve will depend on the size (or age) at which the young krill first become liable to harvest, and this, like the parameters of growth and natural mortality, is not yet well-defined, but probable values of all these parameters will produce a rather flat yield-per-recruit curve, i.e., one with no pronounced maximum, or with one that occurs at a fairly high exploitation rate.

From the preceding paragraphs one may conclude - always bearing in mind that the discussion was somewhat hypothetical - that the net annual increment, as indicated by either the recruitment or the yield-per-recruit may not be reduced until the exploitation rate is quite high, or if it is reduced, this reduction may be very difficult to demonstrate. While this would seem to imply that it is unlikely that considering the krill fishery in isolation the Scientific Committee will be able to advise the Commission that action is necessary according to Article II 3(a), it is possible that it could be in a position to advise that action might be desirable on other grounds.

The only explicit reference to economic factors in the Convention is the remark (Article II 2) that "conservation includes rational use". This may well be a reaction to the manner in which the references to economics in the text of the International Whaling Commission have been used to oppose the introduction of management measures until the eleventh hour or later. It would, though, be a mistake to believe that economic or social interests are always opposed to conservation interest (in the narrow sense). Indeed it is commonplace in fishery literature that the optimum pattern of exploitation, in most economic or social senses, is one with a lower exploitation rate and a higher population size than that giving the MSY, or a greatest net annual increment. Clark (1973) has pointed out an exception, in that if the growth rate of a population is less than the discount rate, and if costs of applying fishing effort are ignored, it would pay to deplete a stock. This would not apply to krill. In other words the fisherman's interest to maintain a high catch rate (and hence low costs and high profits) points virtually always in the same direction as conservation interests. The interests of the two groups can, but need not, diverge, when the main interests of the fishermen and the fishing industry is in maintaining some level of existing activity e.g., a certain whale quota. If management is not considered until the need for controls on biological grounds is urgent, these controls will almost certainly cause undesirable disruption of the fishing operations, and will therefore be opposed on economic grounds. On the other hand management can be considered early in the development of a fishery before there is any biological need for controls. This consideration can lead to a planned growth of the fishery in such a manner that at such a time as there appears to be a biological need for controls (e.g., on total catch) these controls can be applied with a minimum disruption to the fishery. On this argument economic interests would seem to call for early discussion of possible approaches to management, and consideration of the types of policy which would to the extent possible ensure both the conservation objectives of the Commission, and the order of economic development of the industry.

Single species analysis : Summary of current data

It may seem strange that, in a paper discussing ecosystem management, so much space has been taken up in the previous section in discussing single species. There is a good reason for this; if the bottom-up approach is to be followed, it is essential to know how much can be understood about each single species, and the impact of fishing on it, before going on to try to understand, and to make management proposals concerning the impact that fishing of that species has on the dynamics of other species. Apart from noting what is likely, or unlikely, to be deduced about the status of exploitation of single species relative to the objectives of the Commission, we should also note what can reasonably be expected to be known about the dynamics and population parameters of the various species. This may be summarized roughly as follows - though this summary, which is put forward here as a first attempt at a classification rather than as a authoritative statement, will need revision and updating.

Whales

Abundance: Good estimate of past abundance, fair estimates of current levels; little chance of estimating trends except over very long periods.

Population parameters: Good estimates of past age, growth, mortality, age at maturity, reproductive rate, and fair estimates of natural mortality and of how these other parameters have changed with changes of whale density. Little chance of getting future estimates in the absence of whaling.

Seals

Abundance: Fair to good estimates (good locally), and possibility of good estimates of local trends in abundance.

Population parameters: Fair to good estimates of age, growth, reproductive rate, etc. Good chances of reliable monitoring of these parameters in some locations.

Birds

Much as seals.

Fish (commercially exploited)

Abundance: Moderate estimates of absolute abundance from surveys, and of relative abundance and of trends from catch-per-unit-effort of commercial trawlers. Moderate to poor estimates of annual recruitment.

Population parameters: Moderate to good estimates of growth and total mortality. Probably sufficiently good estimates of division of total mortality between fishing and natural causes (e.g., by analogy with other species) to construct reasonable yield-per-recruit curves.

Fish (Others)

Very little information.

Squid

Virtually no information other than deductions from consumption by other animals.

Krill

Abundance: Poor estimates of total abundance; moderate to good estimates of current abundance in some areas, at least of that part of the population that is in swarms. Moderate to poor chance of studying trends in abundance from commercial catch and effort data (c.f., problems with pelagic fish). Estimation from special surveys possible, but likely to be expensive, and with high variance.

Population parameters: Fair estimates of most parameters, though with some doubts about ageing. Good chances of monitoring future changes except to the extent that commercial fisheries or scientific nets are selective.

Species interaction

While the CCAMLR Convention, and the discussions about the Convention, talk about the Antarctic marine ecosystem as a whole, the specific aspect in the thoughts of most people is the case of whales, and the possible threat to the recovery of the depleted whale stocks by a large krill fishery. In terms of the Convention the key question arises from the second part of Article II 3 (b), as to whether the rate of recovery of depleted whale stocks, or the level to which the recovery tends, will be affected by a krill harvest.

Here there is a problem of definition. The level of the abundance of, say, blue whales, which gives, in the wording of Article II 3(a), the greatest net annual increment, is not a fixed quantity, but will vary with any natural changes in the carrying capacity of the Antarctic marine ecosystem, and with man-induced changes in the abundance of food and competitors of blue whales. Strictly therefore the target level below which a stock should not be allowed to be reduced, and at or above which it should be restored if already depleted, is not defined until the external conditions (state of the environment, abundance of other species) have previously been defined. In the IWC the general practice is to take as the reference level for the depleted whale stocks the state around 1900, before Antarctic whaling started. This implicitly ignores the possible effect of the earlier depletion of the seal stocks, and of natural changes in the environment. In the present state of knowledge this is reasonable. For minke whales there has been some tendency to use a reference level a value rather above the population size in 1900, taking account of a strong belief, at least around 1980, that minke whales were increasing. The particular piece of evidence that seemed to prove the existence of that increase (change in age at maturity, as deduced from the pattern of the ear-plugs), has now been shown to be an artifact. This is however not proof that the minke whale stocks are failing to increase as a result of the great reduction in other baleen whales, especially blue whales which has caused some, unspecified, change in parameters. If indeed one or other of the parameters (growth, reproduction, mortality) of the minke whale stocks has not been changed, as a result of the dramatic declines in the other baleen whale stocks, in a way that will lead to an increase in abundance, it would be surprising, and would cast doubt on the great concern about species interaction that lies at the heart of the ecosystem approach of the CCAMLR Convention.

Some changes in parameters of a depleted stock must occur related to the density of the stock itself, if the imposition of even the smallest additional mortality due to exploitation is not, if maintained to drive the stock to extinction. This theoretical statement is confirmed for whales by the very few cases of regular monitoring of the abundance of a depleted whale stock over a period of years (e.g., grey whales), where the stocks have shown a steady increase of a few per cent per year. It is less clear which parameters have changed (as noted above doubts have been cast on some of the changes, e.g., in age at maturity, that had seemed to be clearly established), still less how these changes are quantitatively related to the abundance of the stock itself or of associated species. The first aspect is important in determining the form of the relation of sustainable yield (or net recruitment) to adult stock, which in the simplest theories has a maximum when the population abundance is half its unexploited level. More realistic models of the dynamics of large mammals (Fowler and Smith, 1981) demonstrate that even if some of the individual parameters are linearly related to density (or abundance), the resultant relation between sustainable yield and abundance is not symmetrical, but has a maximum at a population level higher than 50% of the unexploited level.

If the relation between the parameter values and population density are themselves non-linear, as is argued by Fowler and Smith, this would tend to shift the MSY level further from the 50% point towards the unexploited level. The evidence for non-linearity in marine mammals is scanty. In some cases it seems that the onset of the density-dependent effect is abrupt. For example, Figure 8 of Eberhardt (1981) suggests that the survival of young female fur seals is almost constant (around 0.38) over most stock sizes, as measured by the number of female births, but when this number increases much above 220,000 there is a rapid reduction of survival. Such a form of relation would be reasonable <u>inter alia</u> in large terrestrial herbivores, which at high densities can cause great damage to the ecosystem (e.g., elephants in Uganda); in these cases the density-dependent effects may not come into operation until the stock abundance is very close to the carrying capacity, and when it does operate may cause a substantial and sustained drop in carrying capacity (Laws, 1981).

The maximum productivity of these stocks could be very close to the maximum population level, and managing them so as to maintain the population at the level giving maximum productivity (i.e., within, say, 95-99% of the maximum) raises problems. Above the maximum level the net production must drop rapidly towards zero at the undisturbed population level. Given uncertainties in parameter estimation, and possible natural variation, it is unlikely that the population can be maintained exactly at the maximal level. Upward departures above this level will cause significant drops in net production, such that in practice a larger average net annual production might be achieved by targetting a little below the absolute maximum.

So far as the Antarctic is concerned, this is a somewhat academic issue, relevant if at all only to the minke whales. It is raised here to underline the fact that, in considering the possible impact of krill fishing on whales, it is not sufficient to determine that krill abundance affects the dynamics of whales, but there has to be some knowledge of the form of the relation. Does a given change in krill abundance have the same impact on the parameters (which parameters?) of the whale stocks at all levels of krill abundance, or are there critical levels of abundance? Is the total abundance the important factor, or is the abundance or density at particular times and places (e.g., the presence of dense swarms of krill at the time when the females are feeding young) the more critical factor?

This suggests that before the Scientific Committee can expect to give quantitative advice to the Commission on the impact of a krill fishery on the rate of recovery of whale stocks, two sets of questions need to be addressed.

First, whale scientists would like to know what parameters (age at maturity, juvenile mortality, etc.) of which whale stocks are affected by which changes in the krill stock (total abundance, density in particular times/areas, etc.), and whether the changes are simple (e.g., linear with krill density), or occur at critical levels. They should also consider whether these changes in whale parameters are the same as the changes caused by changes in whale abundance. It is often assumed, implicitly if not explicitly, that density dependent effect in whales is due to the chain of events fewer whales-less krill eaten-greater krill abundance-more krill eaten per whale-better whale growth/reproduction, etc. If this is so, it is a relatively simple modelling exercise to fit other factors (e.g., human harvest) into the link of the chain concerning krill abundance. However, there might be other factors at work, e.g., social dependent effects within whale stocks leading to their recovery from depletion is not, or only partly, associated with changes in krill.

Second, krill scientists would like to be able to measure changes in abundance and in any other characteristic of the krill stock that is believed to be important for the dynamics of whales, and to determine the extent to which these changes have been due to fishing for krill, and to predict the impact on these characteristics of future development or modifications in that fishery. To do all this is a very tall order.

Present techniques for estimating krill abundance (net hauls, acoustic surveys) are very expensive, even for a moderately small area, and have, because of the patchy distribution of krill, a high degree of sampling variance, and probably some bias (e.g., through escapement from nets). The catch per unit effort of the commercial fishing may have less variance, but may correctly reflect the changes in relative abundance only if very carefully adjusted. The catch per day will probably mainly reflect the processing capacity of the vessel, while the catch per hour trawling will reflect within-swarm density and detailed information on searching time, communications between ships, etc., will be needed to provide some information on the between-swarm distances, and the size of swarms. The immediate prospects of directly detecting small fishery-induced changes in krill abundance are therefore small.

Given an estimate of total abundance, it is possible to estimate, from volumes of the catches, the fishing mortality, and hence deduce, less directly, the impact of fishing on the krill stock. Another indirect approach, mentioned at the 1983 CCAMLR meeting, would be to monitor changes in the characteristics of stocks of other consumers of krill. Some of these changes, e.g., in the breeding success of penguins, may be much easier to monitor (at least in some colonies), though there is the chance that to the extent that they reflect events in the krill stocks, these may be only local, and be somewhat irrelevant to possible effects on whales.

The shopping list in the preceding paragraphs on what should, in the ideal world, be known about whales and krill in order to give advice to managers about the impact of a krill fishery on whale dynamics must not be taken as implying that in the messy and uncertain real world no advice can be offered until these questions have been answered. Managers will nearly always have to take decisions on the basis of uncertain and incomplete knowledge. A major task of the Scientific Committee will be to provide those taking decisions about managing the Antarctic ecosystem (i.e., the Commissioners) with as good advice as possible, which should include indications on the uncertainties in the various elements in the advice (e.g., the level of krill harvest that can be taken without significant impact on the rate of recovery of whale stocks) and the implications of these uncertainties.

An immediate task is therefore to explore the above questions to see what, if any, can be fully answered, and for the others to determine to what extent they can be answered, and how far these partial answers can help the Scientific Committee to formulate advice. One important aspect of this exploration would be the 'strategic simulation' models described by Beddington and de la Mare (MS). These models do not, like theoretical systems models, seek to provide a comprehensive (if often over-simplistic) picture of the whole system, or like estimation models, to provide quantitative estimates of important parameters, but to provide a feel of how parts of the system might operate, and thus inter alia help, in Beddington and de la Mare's words "evaluate strategies for the acquisition of information".

This data aquisition should be the other important aspect of exploration, and should not merely be concerned with those data that are the standard currency of stock assessment studies (catch and effort statistics, size composition, etc.), vital though they are, but can include a wide range of information that the 'strategic simulation' models show to be of possible value. For example, one such model might demonstrate that if one effect of a krill fishery were to break up the dense swarms of krill, and if whale growth depended on these swarms, then even a moderate krill fishery would have a serious effect on whales, even if the overall abundance of krill was changed little. Investigation of the feeding behaviour of whales could throw light on whether the second hypothesis was reasonable.

Stability and reversibility

The Commission objective (Article II 3(c)) "prevention of changes, or minimization of the risk of changes in the marine ecosystem that are not potentially reversible over two or three decades" can be approached in two ways.

The first is a special part of the analysis discussed above in which the dynamics of each species (taking account of the impacts of other species) are examined to see how long various changes would take to have their full effect, and whether the changes needed to reverse the impact of over fishing would take more or less than two or three decades. For example, yield-per-recruit changes in fisheries become fully effective within one generation; while stock/recruitment effects may take several generations to operate. For krill either effects would be fully operative within a decade or so, but even a moderate change in whales would take much longer. If, in the absence of exploitation a depleted whale stock would recover at 3% per year, a doubling of stock abundance, e.g., from 40% to 80% of initial stock would take over 20 years.

The weakness of this approach is that it assumes that there are no fundamental changes in the system, and that, given the appropriate time-scale, all changes are reversible. The second approach examines this assumption, and looks at the degree of stability and reversibility in the system. There is a large volume of recent literature on the stability of ecosystems, as a function inter alia of the number of species, and their interrelationships. From these it is clear that ecosystems are not necessarily stable, and that there can be more than one stable position. Thus, if exploitation (of krill, whales or whatever) displace the ecosystem across the boundary between the areas of attraction of two stable points, the system would not return to its original position even if all exploitation ceased.

Whether or not this is a real practical possibility calls again for modelling, in the first instance of the system-model type, taking account of what is known about the dynamics of the various species. On the face of it some fears about non-reversibility, and in particular of the less than full recovery of the larger whales, may be exaggerated. It may well be that when large whales are depleted, the smaller, 'r-selected' species will expand more rapidly, but one would expect that in the long-run (and the long-run may be very long indeead) the larger 'K-selected' species would have, by the nature of their strategy, the competitive advantage and recover to their initial level, provided that they have maintained a foothold in the system. This, however, is a matter for more study. A more comforting thought for those concerned about the recovery of whales is that they are more mobile than seals or penguins, and are therefore less potentially vulnerable to local depletion of krill close to breeding areas.

SUMMARY

The objectives of the Commission as set out in Article II of the Convention are briefly discussed and the two approaches to ecosystem analysis reviewed. The top-down approach, following the flow of energy from primary production through to the animals of interest gives a broad understanding of how the system works, and rough estimates of the potential yield at various trophic levels. It is not very useful in formulating specific management advice, e.g., whether a catch of the same order of magnitude as the potential yield is too high or not. For providing advice the bottom-up approach is more useful, starting with examining the dynamics of the stocks of individual species, especially those currently being exploited.

"Ecosystem management" in the Antarctic will therefore depend on having a good understanding of the dynamics of each important species. The present knowledge of the behaviour of different stocks under exploitation, and of the basic parameters (growth, mortality, etc.) is reviewed. These range from fairly good for whales, through moderate for fish and krill, to poor or non-existent for squid. The most serious inadequacy is probably the lack of good methods of monitoring changes in krill abundance. Most catch per unit data for krill reflect local denisty rather than overall abundance.

The forms of interaction between species are discussed, and related to the work of modelling and data collection. It is suggested that of the various types of models, strategic simulation models which help address the right questions are, in the current state of knowledge, the most valuable.

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