ALTERNATIVE METHODS FOR DETERMINING SUBAREA OR LOCAL AREA CATCH LIMITS FOR KRILL IN STATISTICAL AREA 48

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Abstract

CCAMLR Conservation Measure 32/X sets a 1.5 million tonne precautionary catch limit on krill (*Euphausia superba*) in Statistical Area 48. The measure also implies an application in future of precautionary limits to subareas or local areas of this area. Nine alternative methods of determining subarea or local area krill catch limits are evaluated relative to six criteria: (i) the degree to which information on biological relationships is considered; (ii) the cost of data collection; (iii) the reliability of required information; (iv) the ease of enforcement; (v) the effects on current fishing patterns; and (vi) the potential for delay in implementing the alternative. An alternative is less likely to adversely impact dependent species (e.g., penguins and seals) if the ecological relationships between krill and their predators are explicitly considered and the potential for delayed implementation is low. Therefore, we consider the following tradeoff to be important: choosing a biologically explicit alternative and delaying implementation, or choosing a biologically unrealistic alternative and implementing a management scheme immediately. We recognise that other tradeoffs may be equally important. Alternatives that allocate the 1.5 million tonne limit by evenly dividing the catch among subareas or by using historical catches to set limits can be categorised as having a low potential for delaying implementation, but they ignore information on biological relationships. Alternatives based on protective zones, critical periods, predator censuses, and predator-prey models include large amounts of biological information, but may not be practical in the near future. Alternatives based on continental shelf area, simple pulse fishing, and krill surveys are not biologically explicit and result in delayed implementation. None of the alternatives are categorised as being both biologically explicit and immediately available for implementation. However, two of the alternatives (i.e., protective zones and critical periods) are unsatisfactory only because they would alter current fishing patterns. These two alternatives could be implemented immediately if the CCAMLR Member nations are willing to tolerate changes in current fishing patterns.

Résumé

La mesure de conservation 32/X de la CCAMLR fixe la limite préventive de capture de krill (*Euphausia superba*) de la zone statistique 48 à 1,5 million de tonnes. Cette mesure implique également l'application prochaine de limites préventives aux sous-zones et aires localisées de cette zone. Neuf nouvelles méthodes de détermination des limites de capture de krill dans les sous-zones ou aires localisées sont évaluées, relativement à six critères: i) jusqu'à quel point sont prises en compte les informations sur les relations biologiques; ii) le coût de la collecte

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des données; iii) la fiabilité des informations requises; iv) la facilité de la mise en application; v) les effets sur les tendances de pêche actuelles; et vi) le risque d'un délai dans la mise en place d'une nouvelle méthode. Une nouvelle méthode risque de ne pas avoir autant d'effets néfastes sur les espèces dépendantes (telles que les manchots ou les phoques) si les relations écologiques entre le krill et ses prédateurs sont prises en considération et si sa mise en place est peu susceptible d'être retardée. Ainsi nous reconnaissons l'importance du compromis suivant: soit choisir une méthode explicite sur le plan biologique et retarder sa mise en place, soit choisir une méthode peu réaliste sur le plan biologique et mettre en place immédiatement un système de gestion. Nous reconnaissons que d'autres compromis peuvent être tout aussi importants. Les méthodes allouant la limite de 1,5 tonne soit à parts égales entre les sous-zones soit en basant les limites sur les captures anciennes peuvent être classées dans une catégorie à risques réduits de mise en place tardive, mais elles ne tiennent pas compte des informations sur les relations biologiques. Les méthodes fondées sur les zones de protection, les périodes critiques, les recensements des prédateurs, et les modèles prédateurs-proies comportent un grand nombre d'informations biologiques, mais risquent de ne pas être pratiques dans un proche avenir. Les méthodes reposant sur la zone du plateau continental, la pêche par à-coups ordinaire et les campagnes d'évaluation du krill ne sont pas explicites sur le plan biologique et se soldent par un retard dans la mise en place. Aucune de ces méthodes n'est à la fois explicite sur le plan biologique et prête à être mise en place dans l'immédiat. Toutefois, deux des méthodes (à savoir zones de protection et périodes critiques) sont peu satisfaisantes uniquement du fait qu'elles modifieraient les tendances de pêche actuelles. Ces deux méthodes pourraient être applicables dans l'immédiat si les pays membres de la CCAMLR acceptaient de tolérer des changements dans les tendances de pêche actuelles.

Резюме

Мера по сохранению 32/X устанавливает предохранительное ограничение на вылов криля (*Euphausia superba*) в Статистическом районе 48 размером 1,5 миллиона тонн. Данная мера также предусматривает распространение в будущем предохранительных ограничений на подрайоны или локальные районы этого района. Оцениваются девять альтернативных методов установления ограничений на объем вылова криля по подрайонам или локальным районам относительно шести критериев: (i) степень учета информации о биологических взаимосвязях; (ii) стоимость сбора данных; (iii) достоверность требуемой информации; (iv) степень осуществимости контроля за промыслом; (v) последствия для промысловых режимов, применяемых в настоящее время; и (vi) возможность задержок в применении того или иного метода. Та альтернатива окажет меньшие отрицательные воздействия на зависящие от криля популяции (например, пингвины и тюлени), которая учитывает экологические взаимосвязи между хищниками и потребляемыми видами и которая имеет низкую вероятность задержки в применении. В связи с этим мы считаем важным следующий компромисс: либо выбрать биологически очевидную альтернативу и отложить

осуществление, либо выбрать биологически нереальную альтернативу и сразу же внедрить систему управления. Мы признаем, что и другие компромиссы могут быть одинаково важными. Хотя альтернативы, которые равномерно распределяют вылов в 1,5 млн. тонн между подрайонами или используют промысловые данные за предыдущие сезоны с целью установления ограничений на вылов, можно охарактеризовать как имеющие низкий потенциал задержки в применении, они все-таки не принимают во внимание информацию о биологических связях. Альтернативы, основанные на закрытых районах, критических периодах, учетах хищников и моделях "хищник/потребляемый вид", предусматривают наличие большего количества биологической информации, однако они могут оказаться непрактичными в ближайшем будущем. Альтернативы, основанные на площади континентального шельфа, обыкновенном пульсирующем промысле и учетах криля, биологически не обоснованы и влекут за собой задержки в их применении. Ни одна из альтернатив не может быть охарактеризована как биологически обоснованную и готовую к применению. Тем не менее, две альтернативы (т.е. закрытые районы и критические периоды) являются неудовлетворительными лишь потому, что их применение изменило бы настоящий промысловый режим. Эти две альтернативы могли бы быть применены, если бы страны-Члены АНТКОМа согласились с изменением в существующих промысловых режимах.

Resumen

La Medida de conservación 32/X establece un límite de captura precautorio para el kril (*Euphausia superba*) de 1.5 millones de toneladas en el Area estadístisca 48. Esta medida también supone una futura aplicación de límites de captura precautorios a subáreas o zonas específicas en este área en el futuro. Se evalúan nueve métodos alternativos para determinar los límites de captura de kril por subárea o zona específica en conexión a seis principios: (i) la medida en que se considera la información sobre las relaciones biológicas; (ii) el coste de recopilación de datos; (iii) la fiabilidad de la información requerida; (iv) la facilidad de ejecución; (v) los efectos en los regímenes de pesca actuales; y (vi) la posibilidad de retrasar la puesta en marcha del método alternativo. Un método alternativo tiene menos probabilidades de dañar a las especies dependientes (p.ej. pingüinos y focas) si se toman en cuenta explícitamente las relaciones ecológicas entre el kril y sus depredadores y si la probabilidad de retrasar su aplicación es baja. Por lo tanto, consideramos relevantes las siguientes compensaciones: elegir una alternativa biológicamente detallada con un retraso en su aplicación, o elegir una alternativa biológicamente poco realista poniendo en marcha un sistema de gestión inmediato. Reconocemos que otras compensaciones podrían ser igualmente válidas. Aquellas alternativas que desglosan el límite de 1.5 millones de toneladas en partes iguales entre las subáreas o las que emplean los historiales de captura para fijar límites se pueden considerar con pocas posibilidades de retrasar la puesta en marcha, aunque se desconozca la información sobre las relaciones biológicas. Aquellas alternativas basadas en las zonas protegidas, en períodos críticos, en censos de depredadores, y en los

modelos depredador-presa, incluyen muchos datos biológicos pero pueden ser inútiles a corto plazo. Por otra parte, las alternativas centradas en la zona de la plataforma continental, en la pesca por pulso simple, y en las prospecciones de kril no contienen información biológica detallada y resultan en una ejecución tardía. Ninguna de las alternativas se clasifican a la vez como biológicamente detalladas y disponibles para ser aplicadas inmediatamente. Sin embargo, dos de las alternativas (p.ej. zonas protegidas y períodos críticos) son inapropiadas por el solo hecho de que pueden alterar los regímenes de pesca actuales. Estas dos alternativas podrían ser aplicadas de inmediato si los Estados miembros de la CCRVMA estan dispuestos a aceptar cambios en los regímenes de pesca existentes.

1. INTRODUCTION

In November, 1991, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) adopted Conservation Measure 32/X. This conservation measure sets a 1.5 million tonne precautionary catch limit on krill, *Euphausia superba*, in Statistical Area 48 (CCAMLR, 1991a). Conservation Measure 32/X also requires CCAMLR's Scientific Committee to provide the Commission with advice on how the 1.5 million tonne limit could be allocated between subareas or local areas if the total catch in Subareas 48.1 (Antarctic Peninsula), 48.2 (South Orkney Islands), and 48.3 (South Georgia) exceeds 620 000 tonnes in any fishing season.

It is important to consider alternative methods for estimating subarea or local area catch limits before the total krill catch in Statistical Area 48 totals 620 000 tonnes. Reactive management is not an acceptable, long-term strategy for managing the krill fishery (SC-CAMLR, 1991). Considering alternative catch allocation strategies before 620 000 tonnes of krill are caught in Statistical Area 48 helps prevent reactive krill management.

The primary goal of any catch allocation scheme should be to minimise the probability of adversely impacting species that depend on krill as a primary food source (e.g., penguins and seals); this is mandated by Article II of the CCAMLR Convention. The probability of adverse impact is affected by our understanding of the relationships between krill, their predators, and their environment, and the degree to which this understanding can be incorporated into specific management terms. The probability of adverse impact is also affected by practical considerations, such as the reliability of information used by the alternative, the complexity of the management rules, the disruption of current fishing strategies, and, ultimately, the delay in implementing an effective allocation scheme.

We used the following criteria to evaluate nine alternative schemes for allocating krill catches among subareas or local areas:

(1) Amount of information on biological interactions explicitly considered in the alternative: Presumably, as more information is incorporated into an allocation scheme, the probability of adversely impacting dependent species will decrease. This may not be the case, particularly if functional relationships are incorrectly specified or if there is high variability in the data, but, as a first approximation, we will ignore these concerns.

(2) Longterm costs of collecting the data required to implement the alternative: Cost will increase if frequent surveys are required or if sampling effort must be increased to achieve a desired level of precision. Short-term costs associated with initial implementation of an alternative are not considered.

(3) Reliability of the information used in the alternative: Both precision and accuracy are important. Reliability is high if the required quantities/parameters can be estimated precisely and without bias.

(4) Ease of enforcing the alternative: Enforcement is difficult when the allocation scheme is complex and when catch allocations are frequently changed (these make it harder to maintain consensus in the Commission).

(5) Change to current fishing patterns: Allocation schemes differ in the degree to which they would change the historical distribution of fishing effort and in the amount of discretion given to the fishing vessels. Schemes that alter current fishing patterns usually lead to management delays (see below).

(6) Delay in implementing the alternative: Delays may be caused by political resistance towards altering current fishing patterns or by data unavailability. We assume that delay in implementing the alternative increases the probability of adverse impact on dependent species.

The nine alternatives for allocating krill catches among subareas are:

(1) Historical catches,
(2) Even division among subareas,
(3) Shelf area,
(4) Simple pulse fishing,
(5) Protective zones,
(6) Critical periods,
(7) Predator censuses,
(8) Krill surveys, and
(9) Models of predator-prey interactions.

This paper is intended to initiate a discussion about alternative methods of allocating the 1.5 million tonne precautionary catch limit in Statistical Area 48 between subareas or local areas. Since krill catches are usually concentrated near predator breeding colonies (Agnew 1991; Everson and Goss 1991), an allocation scheme is necessary to protect vulnerable predator populations and maintain CCAMLR's ecosystem perspective. The list of alternative allocation strategies presented in this paper is not exhaustive. The examples discussed in this paper focus on methods that limit krill catches directly; we do not consider methods to limit the catch by controlling fishing effort or fishing efficiency.

2. COMPARISON OF ALTERNATIVE ALLOCATION STRATEGIES

2.1 The Historical Catch Alternative

One of the initial proposals for setting a precautionary catch limit on krill in Statistical Area 48 was to base this limit on historical catches (SC-CAMLR, 1991). This type of strategy could also be used to allocate the catch between subareas or local areas. Between 1981 and 1991, about 18%, 48%, and 34% of the total krill catch in Statistical Area 48 was taken from Subareas 48.1, 48.2, and 48.3, respectively (CCAMLR, 1991b). Estimating precautionary catch limits according to historical catches gives a limit of 270 000 tonnes for Subarea 48.1 (1 500 000 tonnes x 0.18 = 270 000 tonnes), 720 000 tonnes for Subarea 48.2, and 510 000 tonnes for Subarea 48.3.

The historical catch alternative does not consider interactions between krill and dependent predators. The data used to calculate the historical catch distribution are probably reliable. There are no costs associated with data collection. The management scheme is not complex and is easy to enforce. Fishing patterns can be maintained because past behavior is used to set current catch limits. Finally, this management scheme could be implemented immediately. These points are summarised in Table 1.

2.2 The Even Division Alternative

The precautionary limit of 1.5 million tonnes can be evenly divided between subareas or local areas. For example, the catch limits for Subareas 48.1, 48.2, and 48.3 could be set at 500 000 tonnes each (1 500 000 tonnes/3 = 500 000 tonnes). The catch can be further divided between local areas. For example, if the catch limit for Subarea 48.1 was 500 000 tonnes, then localised catch limits for Smith Island, Livingston Island, King George Island, and Elephant Island areas could be set at 125 000 tonnes each (500 000 tonnes/4 = 125 000 tonnes).

Evenly dividing the total catch between subareas or local areas does not consider interactions between krill and dependent predators. This alternative does not require data collection, so data reliability and collection costs are not important concerns. The simplicity of the even division alternative makes it easy to enforce. This alternative might not affect current fishing patterns because the largest catch ever taken from a single subarea is just over 250 000 tonnes (CCAMLR, 1991b). However, if fishing effort continues to be distributed according to historical proportions some of the catch will have to be redistributed from Subarea 48.2 to Subarea 48.1 (compare 500 000 tonnes per subarea to the limits prescribed by the historical catch alternative). Thus, for the even division alternative, it is difficult to evaluate the effects on current fishing patterns. The even division method can be implemented immediately. These points are summarised in Table 1.

2.3 The Shelf Area Alternative

Krill catch limits can be based on the area of continental shelf (say depth 250 m) within each subarea or local area. The basis of such an allocation scheme is to evenly distribute the catch throughout the areas where land-based predators and fisheries are most likely to interact. The total area of seabed in Subareas 48.1, 48.2, and 48.3 less than or equal to 250 m in depth is about 208 861 km^2 (Everson, 1987; Everson and Campbell, 1990). Approximately 52% of the total is from Subarea 48.1, 32% from Subarea 48.2, and 16% from Subarea 48.3. Using these proportions, catch limits for Subareas 48.1, 48.2, and 48.3 would be 780 000 tonnes (1 500 000 tonnes x 0.52), 480 000 tonnes, and 240 000 tonnes, respectively.

The shelf area alternative does not explicitly consider the relationships between krill and dependent predators. The seabed area data presented in Everson (1987) and Everson and Campbell (1990) are reliable. There are no data collection costs for this alternative, and enforcement would be easy. The shelf area method would significantly alter current fishing patterns. Historically, the krill fishery has taken the bulk of its catch from Subareas 48.2 and 48.3 (CCAMLR, 1991b), but the greatest proportion of shelf area is in Subarea 48.1 (Everson, 1987; Everson and Campbell, 1990). Therefore, allocating catches according to shelf area will concentrate krill catches on the southern edge of the historical fishing grounds. This redistribution of catch could have adverse impacts on the fishery (e.g., shorter fishing seasons during years with increased ice cover). The shelf area alternative could be effected immediately, but, since current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.4 The Simple Pulse Fishing Alternative

A simple pulse fishing strategy could be used to temporally cycle the krill catch between subareas by allowing all 1.5 million tonnes to be taken from a single subarea in a single year. Then, for the following two years, that subarea would be closed to fishing. For example, if

1.5 million tonnes of krill were taken from Subarea 48.1 this year, it would be closed to fishing during the two following years while Subareas 48.2 and 48.3 were subsequently opened and closed. We do not know if 1.5 million tonnes of krill can be taken from a single subarea, every three years, without adversely impacting dependent predator populations.

The simple pulse fishing alternative does not make an explicit consideration of krill-predator interactions, so data collection costs and problems with data reliability are not significant. This type of allocation scheme would be relatively difficult to enforce because fishing regulations would have to be changed annually (this would require international consensus at each meeting of the Commission). Pulse fishing would alter current fishing patterns. Fishing vessels would have limited flexibility areas when Subareas 48.2 and 48.3 are closed and ice is abundant. A pulse fishing strategy could be effected immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.5 The Protective Zone Alternative

This alternative creates protective zones around specific predator breeding colonies. For example, krill fishing could be prohibited within a 100 nautical mile radius of any island where fur seals (*Arctocephalus gazella*) are known to breed. Protective zones provide a spatial refuge for breeding predators and their prey. Under this alternative, no allocation would be made among subareas.

The protective zone alternative accounts for interactions between krill and predators by considering the foraging range of the farthest ranging predator. Foraging range data is usually collected with radio tracking equipment (see Amos *et al.*, 1990; AMLR, 1991 for examples), and this makes initial data collection costs high. However, since foraging ranges only need to be measured once, there would be no recurring, long-term data collection costs. The data are also highly variable (some animals swim farther than others), so reliability is a concern. Enforcing protective zones would be easy, although current fishing patterns would be drastically altered. Agnew (1991) and Everson and Goss (1991) have clearly shown that krill catches are concentrated near islands where predators breed. Closing island zones to fishing will force the fishing vessels farther offshore where krill will be more difficult to find. Vessels would probably spend considerably more time searching for fishable concentrations of krill. On the other hand, fishing vessels would not be restricted by subarea catch limits and could freely pursue operations in those subareas that are most economical. Protective zones could be prosecuted immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.6 The Critical Period Alternative

The krill fishery can be closed during "critical periods" corresponding to certain portions of the predators' reproductive cycles. This alternative is similar to the protected zone approach, but the catch limitation is based on temporal rather than spatial considerations. This method provides a temporal refuge for predators and their prey.

The critical period alternative accounts for interactions between krill and land-breeding predators during the predators' reproductive phases. Data are already available to describe the duration of this period for most predator species, so data collection costs will not be significant. The available data are also reliable. Enforcement of critical periods would be easy because the management scheme is relatively simple. However, management according to critical periods would significantly alter current patterns of fishing. Historically, some of the largest catches in Subareas 48.2 and 48.1 were taken when land-breeding predators were rearing their young (Everson and Goss, 1991), but these important fishing times would be closed according to the critical period alternative. The critical period alternative could be effected immediately, but, because current fishing patterns would be altered, delays in implementation would be likely. These points are summarised in Table 1.

2.7 The Periodic Predator Census Alternative

Krill catch limits can be set for subareas or local areas by periodically censusing predator populations at important breeding sites and adjusting the catch according to some relationship between predator abundance (or predator condition) and harvestable krill biomass. This alternative considers predators as indicator species. The Working Group for the CCAMLR Ecosystem Monitoring Program (WG-CEMP) has made significant progress towards determining when predators are most vulnerable to competition from commercial fishing and how this vulnerability may be manifested (e.g., in lowered chick and pup survival rates). WG-CEMP is also making progress towards defining the prey requirements of many predators (Croll, 1990; Croxall, 1990; SC-CAMLR, 1991). Thus, it is apparent that much of the information necessary to implement this alternative is already being collected. However, more data needs to be collected in order to know how predators respond to temporal changes in prey availability (i.e., we need a time series of observations that covers a wide range of krill densities). It may take several years to arrive at a preliminary understanding of how predators respond to krill fishing.

Using predator censuses to estimate krill catch limits explicitly considers the interactions that occur between some of the major components of the Antarctic marine ecosystem. There will be an initial cost to collect the data necessary for defining the impacts to predators caused by changing prey availability, but, in the long term, we expect the most significant cost to be associated with conducting periodic predator censuses. Annual or semi-annual predator censuses should not be required because there will probably be a lag before population level responses to prey availability can be detected and because some predators are fairly long lived. The reliability of predator census data is probably good. This alternative would be relatively difficult to enforce because catch limits would have to be periodically changed in order to respond to changes in predator abundance or condition. There is potential for this alternative to change current fishing patterns, but this potential is difficult to evaluate. The periodic predator census alternative could be implemented immediately. These points are summarised in Table 1.

2.8 The Frequent Krill Survey Alternative

Krill catch limits can be set as some proportion of the krill biomass surveyed in a particular subarea or local area. It would be simple to determine a harvest rate based on some arbitrary notion. For instance, we might say that the harvest rate for krill in any subarea or local area could not be greater than the annual survival rate of krill in that area. Then, if the instantaneous rate of natural mortality for krill is 0.8 (the annual survival rate of krill is 0.45), and a survey determined that 200 000 tonnes of krill were present in a small, local area, the catch limit for krill in that area would be 90 000 tonnes (200 000 tonnes x 0.45 = 90 000 tonnes).

Using frequent krill surveys to determine catch limits does not explicitly consider predators; this is essentially a single-species alternative. Frequent estimates of krill biomass are necessary because patterns of krill abundance and distribution are highly variable in time and space (see Hewitt and Demer, 1992 for one example). This is in direct contrast to the frequency of surveys required by the periodic predator census alternative. Allocating catch limits according to estimates of krill biomass requires more frequent sampling because krill distributions are more dynamic in time and space than predator distributions. Thus, estimating catch limits from survey estimates of krill biomass will incur substantial long-term costs associated with data collection. It is also important to note that estimates of the instantaneous rate of natural mortality rate for krill are highly variable (Miller and Hampton, 1989). Thus, using this rate (or some derivative of it) may introduce uncertainty into estimates of catch limits. Enforcement will be difficult because the catch limits will be frequently changed. Current fishing patterns might be altered if fishermen have to wait until the krill surveys are completed before they can start fishing. CCAMLR's Working Group on Krill (WG-Krill) has made substantial progress towards refining survey design and estimating krill target strength (SC-CAMLR, 1991); therefore, the krill survey alternative could be implemented immediately. However, because current fishing patterns are likely to change, actual implementation would probably be delayed. These points are summarised in Table 1.

2.9 The Model Alternative

Simulation models can be used to estimate subarea or local area krill catch limits. Consider a simple model with the following form:

> local TAC = (local krill biomass) - (local number of predators • per capita predator demand) - "safety factor"

where the "safety factor" is some number that ensures future krill recruitment. This simple model has substantial information requirements. It requires both predator surveys and krill surveys to estimate predator numbers and krill biomass, respectively, and to provide periodic updates for these estimates. It requires information about krill recruitment, immigration, and emigration in order to calculate a reasonable "safety factor". Information about per capita predator demand for krill is also necessary. Also, since most of the data are likely to be spatially and/or temporally variable, it would be necessary to collect information from every subarea or local area of interest and to collect this information for a number of years.

Currently, CCAMLR does not have all of the information that a simple model like the one described above would require. It is important to note, however, that models can be formulated in the absence of information and gradually updated as more information is obtained. Preliminary models can be very useful for guiding research or making provisional management decisions. CCAMLR does have some information (although more information would be required) on subarea and local area predator abundance and krill density (Shuford and Spear, 1988; Bengtson *et al.*, 1990; Hewitt and Demer, 1992), and WG-Krill is currently working on problems associated with krill movement and recruitment (SC-CAMLR, 1991). WG-CEMP plans to develop some preliminary estimates of predator demand by the summer of 1993 (SC-CAMLR, 1991). In general, however, it will take a number of years for CCAMLR to collect all of the information necessary to successfully model interactions between predators, krill, and fishermen. During the first few years of data collection, some of the information that is obtained may not be very reliable (producing uncertainty in any model's estimation of a catch limit). Again, to account for this variability, data will need to be collected over a period of years and for a number of areas. The commitment to data collection may be further increased if we consider that some species are long lived; it may take several generations to detect how krill fishing impacts predator populations.

There are several advantages associated with using models to estimate subarea or local area krill catch limits. Models, when formulated successfully, allow large amounts of data to be incorporated into the management scheme. This is advantageous because including all of the relevant biological and physical information into a catch allocation strategy meets CCAMLR's goal of maintaining an ecosystem perspective. Incorporation of economic factors can also account for changes in fishing dynamics. Simulation techniques (e.g., bootstrapping) can be used to estimate parameter uncertainty and evaluate management costs (i.e., risk) before CCAMLR institutes a conservation measure. Thus, models can be used to avoid reactive management policies.

Estimating subarea or local area catch limits with models incorporates large amounts of biological information. Data collection will obviously be expensive, and we should expect uncertainty from model results. Enforceability and effects on current fishing patterns will be difficult to evaluate until a specific model is proposed. Implementation of the model alternative will be significantly delayed while CCAMLR Member nations collect data and debate model specification. These points are summarised in Table 1.

3. DISCUSSION

Choosing from the list of alternatives is difficult because the choice involves tradeoffs; none of the alternatives are perfect. Alternatives that require large amounts of information are good because they represent an ecosystem approach, but it takes time to collect and analyze this information. This results in delayed management, and predator populations can be adversely impacted during this time. Alternatives that do not require much information can be implemented more quickly to prevent uncontrolled expansion of the fishery, but these alternatives are not biologically realistic.

In choosing an allocation scheme that minimises the probability of adverse impact to dependent species, we believe that one of the principal tradeoffs is between the amount of biological information explicitly considered and the potential for delayed implementation. Essentially, we feel that the following questions are important: "Should CCAMLR select an alternative that considers interactions between krill and predators even though the delays caused by data collection and resistance to alter current fishing patterns, may have adverse impacts on dependent predator populations? Or, should CCAMLR select an alternative that controls expansion of the krill fishery without being biologically explicit?" The nine alternatives were arranged in a tradeoff matrix (Table 2). Alternatives based on even division among subareas and historical catches can be categorised as having a low potential for delaying implementation, but they ignore information on biological relationships. Alternatives based on protective zones, critical periods, predator censuses, and predator-prey models include a large amount of biological information, but may not be practical in the near future. The shelf area, simple pulse fishing, and krill survey alternatives are not biologically explicit and result in delayed implementation. None of the alternatives were categorised as being both biologically explicit and immediately available for implementation (this reiterates the point that none of the alternatives are perfect). However, two of the alternatives (i.e., protective zones and critical periods) are unsatisfactory only because they would alter current fishing patterns. These two alternatives could be implemented immediately if the member nations to CCAMLR are willing to tolerate changes in current fishing patterns.

Perhaps CCAMLR should consider two time horizons as it allocates the total catch in Statistical Area 48 to subareas or local areas. In the short-term CCAMLR should be concerned with controlling the expansion of the krill fishery. Conservation Measure 32/X, combined with a provisional catch allocation scheme based on protective areas and/or critical periods, would be an important step in this direction. Data collection should continue, however, and, in time, sufficient data would be available to adjust krill management according to the biological goals outlined in Article II of the CCAMLR Convention.

Finally, we would like to reiterate this paper's intent. This paper is intended to provide a basis for discussion and a template for evaluating other alternative allocation schemes. We hope that people will feel free to add new alternatives (columns) and new criteria (rows) to Table 1, develop new tradeoff matrices like Table 2, and make their own evaluations of the various allocation schemes.

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Table 1: Characteristics of nine alternatives for allocating the 1.5 million tonne precautionary catch limit in Statistical Area 48 between subareas or local areas. See the text for a more detailed description of the evaluation criteria and the allocation alternatives.

	ALTERNATIVES								
CRITERIA	Historical Catch	Even Division	Shelf Area	Pulse Fishing	Protective Zones	Critical Periods	Predator Censuses	Krill Surveys	Models
Krill-Predator Interactions Considered?	NO	NO	NO	NO	YES	YES	YES	NO	YES
Data Reliability	HIGH	-	HIGH	-	LOW	HIGH	HIGH	HIGH	HIGH
Long-Term Data Collection Costs	LOW	LOW	LOW	LOW	LOW	LOW	HIGH	HIGH	HIGH
Easy to Enforce?	YES	YES	YES	NO	YES	YES	NO	NO	?
Alter Current Fishing Patterns?	NO	?	YES	YES	YES	YES	?	YES	?
Delay to Implement?	NO	NO	YES	YES	YES	YES	YES	YES	YES

Table 2: Tradeoff matrix characterising krill catch allocation schemes based on the amount of biological information explicitly considered and the potential for delay in implementation. The probability of adverse impact on dependent species is minimised when a high amount of biological information is considered and the potential for delay is low.

Potential Delay in Implementation	Biological Information Explicitly Considered	
	Low	High
Low	• even division • historical catches	
High	• shelf area • pulse fishing • krill surveys	• predator censuses • predator-prey models • protected zones • critical period closure

Légende des tableaux

Tableau 1: Caractéristiques de neuf méthodes d'allocation de la limite préventive de capture de 1,5 million de tonnes dans la zone statistique 48 aux sous-zones ou aux aires localisées. Se reporter au texte pour la description plus détaillée des critères d'évaluation et les méthodes d'allocation.

Tableau 2: Matrice des compromis caractérisant les systèmes d'allocation de la capture de krill basée sur le nombre d'informations biologiques examinées explicitement et le risque de retard dans la mise en place. La probabilité d'effets nuisibles sur les espèces dépendantes est réduite au minimum lorsque la quantité d'informations biologiques examinée est élevée et le risque de retard dans la mise en place est faible.

Список таблиц

Таблица 1: Характеристики девяти альтернативных вариантов распределения предохранительного ограничения на вылов (1,5 миллиона тонн) в Статистическом районе 48 между подрайонами или локальными районами. Более подробное описание критериев оценки и альтернатив распределения дается в тексте.

Таблица 2: Матрица расчета различных схем распределения вылова криля, основанная на объеме непосредственно учитываемой биологической информации и возможности отложения осуществления. Вероятность отрицательных последствий для зависимых видов минимальна если рассматривается большое количество биологической информации и возможность задержок низка.

Lista de las tablas

Tabla 1: Características de nueve alternativas para distribuir el límite de captura precautorio de 1.5 millones de toneladas en el Area estadística 48 por subáreas o zonas específicas. Refiérase al texto para obtener una descripción detallada del criterio de evaluación y las alternativas de distribución.

Tabla 2: Matriz de compensación que caracteriza los sistemas de distribución de capturas de kril basada en la cantidad de información biológica considerada en detalle y la posible demora de la puesta en marcha. La probabilidad de dañar a las especies dependientes se ve reducida cuando se considera gran cantidad de información biológica y la posibilidad de retraso es mínima.