

K.A. Green-Hammond, D.G. Ainley, D.B. Siniff,
and N. Scott Urquhart
(United States of America)

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SELECTION CRITERIA AND MONITORING REQUIREMENTS FOR INDIRECT INDICATORS OF
CHANGES IN THE AVAILABILITY OF ANTARCTIC KRILL APPLIED TO SOME PINNIPED
AND SEABIRD INFORMATION

Summary

Antarctic krill, Euphausia superba, is the dominant herbivore in the Antarctic marine food web and a principal component in the diets of: fin, blue, hump-back and minke whales; crabeater seals and Antarctic fur seals; Adelie, chinstrap, macaroni and rock-hopper penguins; several other species of seabirds; and several species of fishes and squid. Some of these species are eaten in turn by sperm whales, killer whales, leopard seals, and other higher order predators. Thus, if it is not developed and managed properly, the fishery for E. superba could affect many dependent species and the basic structure and dynamics of the Antarctic marine food web, as well as the distribution, abundance or productivity of krill itself.

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) requires that harvesting of marine living resources in the Southern Ocean be conducted so as to maintain the ecological relationships between harvested, dependent and related populations of marine living resources, as well as to prevent the depletion of harvested species. It would be prohibitively costly, if not impossible, however, to assess and monitor each species and population that might be indirectly affected by krill harvesting. It follows, therefore, that one of the tasks of the Scientific Committee, established by the CCAMLR, will be to determine and design programs for monitoring those species, populations, or population characteristics that most likely will be affected, in detectable ways, by exploitation of E. superba.

The objectives of this project were to: (a) develop criteria for selecting species, populations, and population characteristics that likely would provide useful indicators of harvest-related changes in the availability of Antarctic krill; (b) to assemble and evaluate readily available information on the ecology, demography, and dynamics of Antarctic pinnipeds and seabirds to determine whether and what species and population variables might serve as useful indicators of harvest-related changes in krill availability; and (c) as possible, suggest aspects of programs that could or should be initiated to select and monitor potential indirect indicators of harvest-related changes in the availability of Antarctic krill.

Limitations

There are a number of species groups in addition to seabirds and pinnipeds that should be considered as possible indicators of harvest-caused changes in the distribution, density, or behaviour of krill. Several species of cetaceans, for example, eat Antarctic krill and possibly could be useful indicators. Similarly, one or more herbivore species may be krill competitors which might respond to and serve as sensitive indicators of changes in krill abundance. This paper considers only seabirds and pinnipeds since these are the species groups most familiar to the authors.

Criteria for Evaluating Potential Indicators

To function as an effective indicator of harvest-caused changes in krill availability, the indicator species or population must be a predator, prey or competitor of Antarctic krill, occur in or near areas where krill is being harvested, and be sensitive to changes in krill availability but relatively unresponsive, or predictably responsive, to natural environmental fluctuations. In addition, the responses should be relatively rapid (i.e., not subject to time lags of several years), detection of responses should be simple, inexpensive and allow large sample sizes, and adequate baseline information should already exist or should be relatively simple to collect. Data collection ideally could be accomplished during or in conjunction with fishing operations and/or from shore stations or vessels engaged in other activities - i.e., there ideally would be little or no need for dedicated vessels to carry out assessment and monitoring of selected indicators.

Sample Sizes

The ability to detect possible responses to harvest-caused changes in krill availability will depend upon the nature and magnitude of the response, the reliability of baseline information, the variability of the characteristic (parameter) being monitored, and the precision with which the variable can be measured. Much larger sample sizes than have been customary in pinniped and seabird research, as well as repeated sampling, may well be required to detect changes with adequate sensitivity.

Potential Seabird Indicators

Because of their large numbers, wide distribution, dependence upon krill, and accessibility during the breeding season, Adelie and chinstrap penguins may be potentially good indicators of localized or regional changes in krill availability. Parameters

that presumably could or would change in response to krill availability include colony size, clutch size, time that parents spend away from the chicks searching for food, relative quantity of krill and other species in the diet, fledgling success, weight of chicks at fledgling, and survival to breeding age. Changes in survival at age at first reproduction and colony size would take a number of years to be manifested and would be difficult to detect unless the changes and/or sample sizes were very large. Changes in time spent feeding, fledgling weight, and other similar variables would be less subject to time lags and easier to measure, making them better choices of potential indicators.

No matter what variables are selected for monitoring, the studies likely will be labor intensive and limited in scope unless some system of more or less automatic data collection can be established. A team of two to four investigators would be required, for example, at each selected indicator colony if traditional study techniques were used. Therefore, at an early stage, it will be necessary to investigate and, as possible, adapt and use remote sensing and automatic data recorders to collect data.

Potential Pinniped Indicators

Of the six pinniped species that occur in the Convention area, three depend upon Antarctic krill to some extent. The crabeater seal feeds more or less exclusively on krill. The leopard seal eats krill, at least in some areas, and preys on crabeater seals and Adelie penguins, both of which are dependent primarily upon Antarctic krill. Fur seals on South Georgia and elsewhere in the vicinity of the Antarctic peninsula also eat krill.

Parameters that could change in response to changes in krill availability include: population size; pup, juvenile and/or adult survival; age at first reproduction; size at birth and growth rate; pupping interval and/or age-specific reproductive rates; blubber thickness; time spent feeding; and proportion of species other than krill that are eaten.

Most of the potential indicator variables, other than population size, could be assessed and monitored by periodically collecting representative samples of animals from selected areas. Sample sizes necessarily would be large (30 to 50 individuals per age class) and sample intervals would have to be selected so as to assure that any observed changes in the selected indicator variables were not caused by the sampling.

Conclusions

Several species and population characteristics of penguins and pinnipeds appear to meet the described criteria and possibly could function as useful

indicators of the indirect effects of krill harvesting on krill-dependent species. As a general rule, it seems that population characteristics, reproductive variables, and/or vital rates will be better indicators than population counts. It also seems, as a general rule, that large sample sizes will be required and that, to the extent possible, automatic data recording systems should be developed and used to collect data. Finally, presently available information generally is inadequate to provide a basis for detecting harvest-related changes in selected indicators and development of baselines should be undertaken as a matter of priority. To provide a basis for assessing possible cause-effect relationships, collection of reliable information on the nature, location, and extent of krill harvesting also must be undertaken as a matter of priority.

CRITERES DE SELECTION ET CONDITIONS DE CONTROLE POUR LES INDICES INDIRECTS DE CHANGEMENTS DANS LA PRESENCE DE KRILL ANTARCTIQUE APPLIQUES A CERTAINES INFORMATIONS SUR LES PINNIPEDES ET OISEAUX DE MER.

Résumé

Le krill antarctique, *Euphausia superba*, est l'herbivore dominant de la chaîne trophique marine et un composant principal des régimes alimentaires des rorquals communs, des baleines bleues, des baleines à bosse (megaptera), des petits rorquals; des phoques crabiers et des phoques à fourrure antarctiques; des manchots Adélie et des espèces *Pygoscelis antarctica*, Gorfou Macaroni et Gorfou Sauter; plusieurs autres espèces d'oiseaux de mer; et plusieurs espèces de poissons et de calmars. Certaines de ces espèces sont, à leur tour, dévorées par les cachalots, orques, léopards de mer et autres grands prédateurs. Ainsi, si la pêche d'*E. superba* n'est ni développée ni réglementée de manière adéquate, elle pourrait être détrimentale à de nombreuses espèces dépendantes ainsi qu'à la structure fondamentale et à la dynamique de la chaîne trophique marine de l'Antarctique et également à la répartition, l'abondance ou la productivité du krill lui-même.

La Convention pour la Conservation de la Faune et la Flore Marines de l'Antarctique (CCAMLR) exige que la capture des ressources marines vivantes de l'Océan Austral soit effectuée de manière à maintenir les liens écologiques entre les populations capturées, dépendantes et voisines, et à empêcher la décimation des espèces exploitées. Toutefois, il serait beaucoup trop coûteux, voire impossible, d'évaluer et de contrôler chaque espèce et population susceptible d'être indirectement touchée par la capture de krill. Par conséquent, l'une des tâches du Comité Scientifique établi par la CCAMLR consistera à déterminer et à mettre au point des programmes de contrôle des espèces, populations ou caractéristiques des populations les plus susceptibles d'être touchées, d'une manière discernable, par l'exploitation d'*E. superba*.

Ce projet avait pour but: (a) développer des critères de sélection de espèces, de populations et de caractéristiques de populations susceptibles de fournir des indices utiles des changements liés à la capture dans la présence de krill antarctique; (b) rassembler et évaluer les données disponibles sur l'écologie, la démographie et la dynamique des pinnipèdes et oiseaux de mer antarctiques en vue de déterminer les variables de population et d'espèces et si ces variables pourraient servir d'indices utiles des changements liés à la capture dans la présence de krill; et (c) dans la mesure du possible, signaler les points importants de ces programmes qui pourraient ou devraient être mis en application pour sélectionner et contrôler les indices indirects potentiels des changements liés à la capture dans la présence de krill antarctique.

Limitations

En plus des oiseaux marins et des pinnipèdes, un nombre de groupes d'espèces devrait être considérés comme pouvant servir d'indices possibles des changements causés par la capture dans la répartition, la densité ou le comportement du krill. Plusieurs espèces de cétacés, par exemple, se nourrissent de krill antarctique et pourraient éventuellement servir d'espèces indicatrices. De même, une ou plusieurs espèces d'herbivores pourraient entrer en compétition avec le krill, autre facteur pouvant servir d'indice sensible des changements se produisant dans l'abondance de krill. Seuls les oiseaux de mer et les pinnipèdes sont examinés ici, ces groupes d'espèces étant les mieux connus des auteurs.

Critères d'évaluation d'espèces indicatrices potentielles.

Pour fonctionner en tant qu'indice efficace des changements causés par la capture dans la présence de krill, il est important que l'espèce ou la population sélectionnée soit prédatrice, proie ou concurrente du krill antarctique, qu'elle se déplace sur les lieux d'exploitation du krill ou à proximité et soit sensible aux changements survenant dans la présence de krill mais qu'elle soit relativement insensible ou qu'elle réagisse d'une manière prévisible aux fluctuations naturelles du milieu. De plus, les réactions devraient être relativement rapides (c'est-à-dire non soumises à des périodes de plusieurs années), la détection des réactions devrait être simple, peu coûteuse et permettre d'obtenir de grandes tailles d'échantillons, et des informations de base adéquates devraient déjà être disponibles ou être relativement simples à rassembler.

L'idéal serait de réaliser la collecte de données au cours de, ou conjointement aux opérations de pêche et/ou à partir de stations côtières ou de navires engagés dans d'autres activités, c'est-à-dire que la présence de navires consacrant leurs activités à l'évaluation et au contrôle des espèces sélectionnées serait peu ou ne serait pas nécessaire.

Tailles des échantillons

La faculté de détecter les réactions éventuelles aux changements causés par la capture dans la présence de krill sera fonction de la nature et de l'importance de la réaction, de la précision des informations de base, de la variabilité de la caractéristique (paramètre) contrôlée, et de la précision avec laquelle la variable peut être mesurée. De plus grandes tailles d'échantillons qu'il est coutume de relever dans les travaux de recherche sur les pinnipèdes et les oiseaux de mer, ainsi qu'un échantillonnage régulier, pourraient bien être nécessaires pour détecter les changements d'une manière suffisamment sensible.

Espèces d'oiseaux de mer susceptibles de servir d'indices

Vu le grand nombre de manchots des espèces Adélie et *Pygoscelis antarctica*, leur répartition, leur dépendance du krill et la possibilité de s'approcher d'eux durant la période de reproduction, ceux-ci pourraient éventuellement servir d'indices précis des changements localisés ou régionaux dans la présence de krill. Les paramètres qui pourraient changer ou changeraient en réaction à la présence de krill comprennent la taille de la colonie, la taille des couvées, le temps consacré par les parents à la recherche de nourriture pour les jeunes oiseaux, la quantité relative de krill et des autres espèces dans le régime alimentaire, le nombre d'oiseaux atteignant l'âge d'achèvement du plumage, le poids des jeunes émancipés et la survie jusqu'à l'âge de reproduction. Les changements concernant la survie jusqu'à l'âge de la première reproduction et la taille de la colonie mettraient plusieurs années à se manifester et seraient difficiles à déceler sauf si les changements et/ou les tailles d'échantillons étaient très importantes. Les changements dans le temps consacré à la nourriture des oisillons, le poids à l'achèvement du plumage, et autres variables semblables seraient beaucoup moins fonction des décalages dans le temps et plus faciles à mesurer et représenteraient ainsi de meilleurs choix d'indices potentiels.

Quelles que soient les variables sélectionnées pour le contrôle, les études seront probablement fondées sur un travail intensif et d'envergure limitée, à moins qu'un système de collecte de données plus ou moins automatique puisse être établi. Une équipe de deux à quatre chercheurs serait nécessaire, par exemple, dans chaque colonie d'espèce sélectionnée si des méthodes traditionnelles d'études étaient utilisées. Par conséquent, il sera nécessaire, dès le départ, de considérer et, autant que possible, d'adapter et d'utiliser des appareils de mesure à distance et des enregistreurs automatiques de données pour la collecte de données.

Espèces de pinnipèdes susceptibles de servir d'indices

Parmi les six espèces de pinnipèdes évoluant dans la zone de la Convention, trois espèces dépendent jusqu'à un certain point du krill antarctique. Le phoque crabier se nourrit plus ou moins exclusivement de krill. Le léopard de mer se nourrit de krill, du moins dans certaines zones, et a pour proie les phoques crabiers et les manchots Adélie, deux espèces se nourrissant presque exclusivement de krill. Les phoques à fourrure de la Géorgie du Sud et d'ailleurs autour de la péninsule antarctique se nourrissent également de krill.

Les paramètres pouvant refléter les changements se produisant dans la présence de krill comprennent: l'ampleur de la population, la survie des nouveaux-nés, des juvéniles et/ou des adultes; l'âge à l'époque de la première reproduction; la taille à la naissance et le taux de croissance; l'intervalle entre les périodes de reproduction, et/ou les taux spécifiques de reproduction par âge; l'épaisseur de la couche graisseuse; le temps consacré à l'alimentation; et la proportion des espèces autres que le krill servant de proies à ces espèces.

La plupart des variables pouvant éventuellement servir d'indices, autres que l'ampleur de la population, pourraient être évaluées et contrôlées périodiquement en relevant des échantillons représentatifs d'animaux dans des zones sélectionnées. Les tailles d'échantillons seraient nécessairement importantes (30 à 50 individus par catégorie d'âge) et les périodes entre les échantillonnages devront être sélectionnées de manière à faire en sorte que tout changement observé dans la variable indicatrice sélectionnée ne soit pas causé par l'échantillonnage.

Conclusions

Plusieurs espèces et caractéristiques de populations de manchots et de pinnipèdes semblent répondre aux critères spécifiés et pourraient peut-être servir

d'indices utiles des effets indirects de la capture de krill sur les espèces dépendant du krill. En principe, il semble que les caractéristiques de population, les variables de reproduction et/ou les taux de vie seront de meilleurs indices que les recensements de population. Il semble aussi, en principe, que de grandes tailles d'échantillons seront nécessaires et que, dans la mesure du possible, des systèmes automatiques de collecte de données devraient être mis au point et utilisés pour relever les données. Enfin, l'information à présent disponible n'est pas, en général, suffisante pour servir de base à la détection de changements liés à l'exploitation dans les espèces sélectionnées et le développement de bases de recherches devrait être entrepris en priorité. Pour fournir une base d'évaluation des relations possibles de cause à effet, la collecte d'informations sûres concernant le caractère, la position et l'étendue de l'exploitation du krill devra également être entreprise en priorité.

КРИТЕРИИ ОТБОРА И ТРЕБОВАНИЯ МОНИТОРИНГА В ОТНОШЕНИИ НЕКОТОРЫХ ЛАСТОНОГИХ И МОРСКИХ ПТИЦ ПРИ ИХ ИСПОЛЬЗОВАНИИ В КАЧЕСТВЕ КОСВЕННЫХ ИНДИКАТОРОВ ИЗМЕНЕНИЙ В ДОСТУПНОСТИ АНТАРКТИЧЕСКОГО КРИЛЯ

Резюме

Антарктический криль, *Euphausia superba*, является доминирующим травоядным морской трофической цепи Антарктики и основным элементом пищевого режима финвалов, синих китов, китов-горбачей и остромордых полосатиков; тюленей-крабоедов и антарктических котиков; пингвинов Адели, чинстрапов, золотоволосых и хохлатых пингвинов; некоторых других видов морских птиц; а также некоторых видов рыб и кальмаров. Некоторые из этих видов, в свою очередь, поедаются кашалотами, касатками, морскими леопардами и прочими хищниками более высокого порядка. Таким образом, при неправильном развитии и управлении промысел *E. superba* может оказать воздействие на многие зависящие виды, на основную структуру и динамику трофической цепи Антарктики, а также и на распространение и количество и продуктивность самого криля.

Конвенция о сохранении морских живых ресурсов Антарктики требует проведения промысла морских живых ресурсов Южного океана таким образом, чтобы поддерживались экологические взаимоотношения между эксплуатируемыми, зависящими и связанными популяциями морских живых ресурсов; а также предотвращалось истощение эксплуатируемых видов. Тем не менее, было бы непомерно дорого, если не сказать - невозможно

но, проводить оценку и мониторинг каждого вида или популяции, которые могут быть подвержены косвенному воздействию промысла криля. Таким образом, отсюда следует, что одной из задач, стоящих перед Научным комитетом, который был организован АНТКОМ'ом, является определение и разработка программ мониторинга тех видов и популяций, или их характеристик, на которые скорее всего окажет поддающееся обнаружению влияние эксплуатации *E. superba*.

Задачами этой программы были: (a) разработать критерии отбора видов, популяций и характеристик популяций, которые, вероятно, предоставят полезные индикаторы связанных с промыслом криля изменений в доступности антарктического криля; (b) собрать и оценить имеющуюся информацию по экологии, демографии и динамике антарктических ластоногих и морских птиц для того, чтобы определить какие изменяющиеся характеристики видов и популяций смогут явиться полезными индикаторами связанных с промыслом изменений в доступности криля; и (c) по возможности, предложить те аспекты программ, которые могут быть или должны быть введены в целях отбора и мониторинга потенциальных косвенных изменений в доступности антарктического криля.

Ограничения

Помимо морских птиц и ластоногих существует ряд групп видов, которые следует рассматривать как возможные индикаторы связанных с промыслом изменений в распределении, плотности и поведении криля. Например, несколько видов китов, которые питаются крилем, возможно, являются полезными индикаторами. Тем же образом, один или более видов травоядных могут являться конкурентами криля, которые могут отреагировать на изменения в количестве криля и послужат их чувствительными индикаторами. В данном документе рассматриваются только морские птицы и ластоногие, поскольку авторы наиболее хорошо знакомы с этими группами видов.

Критерии оценки потенциальных индикаторов

Для того, чтобы вид или популяция могли служить эффективными индикаторами вызванных промыслом изменений в доступности криля, они должны быть хищниками, питающимися крилем, входить в пищевой режим криля или являться его конкурентом; обитать в тех районах, где ведется промысел криля, или вблизи таких районов и быть чувствительными в отношении изме-

нений в доступности криля, но относительно невосприимчивыми или восприимчивыми в предсказуемой степени к естественным изменениям окружающей среды. Помимо того, они должны реагировать относительно быстро (то есть не должно быть отставания в несколько лет), процедура обнаружения реакций должна быть относительно простой, недорогой и допускать использование крупноразмерных проб, а также должна иметься адекватная исходная информация или возможность ее относительно простого сбора. В идеале сбор данных должен проводиться во время или в связи с промысловыми операциями и/или береговыми станциями и судами, ведущими другую деятельность, то есть должна отсутствовать или иметься минимальная необходимость использования специально снаряженных для этого судов для оценки и мониторинга выбранных для изучения индикаторов.

Размер проб

Возможность выявления вероятных реакций на связанные с промыслом изменения в доступности криля будет зависеть от природы и интенсивности реакции, достоверности исходной информации, степени изменчивости той характеристики (параметра), мониторинг которой проводится, а также от той степени точности, с которой эта переменная может быть измерена. Вполне вероятно, что для выявления изменений с адекватной точностью, может понадобиться взятие проб более крупного размера, чем это обычно принимается при изучении ластоногих и морских птиц, а также повторное их взятие.

Потенциальные индикаторы из морских птиц

Вследствие их большой численности, широкого распространения, зависимости от криля и достижимости во время сезона размножения, пингвины Адели и чинстрапы могут явиться хорошими индикаторами локализованных или региональных изменений в доступности криля. Размер колонии, количество птенцов в выводке, продолжительность времени, которое родители проводят в поисках пищи, оставляя птенцов, относительное количество криля и других видов в пищевом режиме, быстрота оперения, вес птенцов при оперении и выживаемость до возраста размножения являются параметрами, которые, предположительно, могут измениться или изменяться как реакция на изменения в доступности криля. Изменения в выживаемости до времени первого размножения и размере колонии станут очевидными лишь по прошествии нескольких лет; и их выявление окажется затруднительным, если только эти изменения и размеры проб не будут очень велики. Изменения во

времени кормления, вес при оперении и прочие подобные изменяющиеся величины, будут менее подвержены отставанию во времени, и их легче измерить, что делает их более подходящими потенциальными индикаторами.

Независимо от выбора переменных для мониторинга, исследования, вероятно, потребуют больших затрат труда, и их размах будет ограничен, если только не будет выработана более или менее автоматизированная система сбора данных. Например, потребовалась бы группа, состоящая из двух-четырех исследователей, при каждой отобранной колонии-индикаторе, если использовать традиционные методы исследований. Таким образом, на ранних стадиях будет необходимо изучить и, если возможно, адаптировать и использовать приборы дистанционного обнаружения и автоматической регистрации для сбора данных.

Потенциальные индикаторы из ластоногих

Среди шести видов ластоногих, которые встречаются в зоне действия Конвенции, три в какой-то степени зависят от антарктического криля. Тюлени-крабоеды питаются в основном крилем. Морские леопарды, по крайней мере в некоторых районах, питаются крилем и являются хищниками, питающимися тюленями-крабоедами и пингвинами Адели, которые в основном зависят от антарктического криля. Морские котики, обитающие на Южной Георгии и в остальных районах вблизи Антарктического полуострова, также питаются крилем.

В число параметров, которые могут измениться в ответ на изменения в доступности криля, входят: величина популяции, выживаемость детенышей, неполовозрелых и/или взрослых особей, возраст во время первого размножения, размер новорожденных особей и скорость роста, интервалы между размножениями и/или отношение между возрастом и специфическими темпами размножения, толщина подкожного сала, время, занятое кормлением, и относительное количество отличных от криля видов в пищевом режиме.

Оценка и мониторинг большинства потенциальных переменных-индикаторов, помимо размера популяции, могут быть проведены путем периодического сбора репрезентативных выборок из отобранных районов. Размеры выборки должны быть крупными (30-50 особей от возрастной группы), и интервалы между выборками должны быть установлены так, чтобы была уверенность в том,

что отмеченные изменения у отобранных переменных-индикаторов не были вызваны самими выборками.

Выводы

Некоторые характеристики видов и популяций пингвинов и ластоногих, по всей вероятности, отвечают упомянутым критериям и могут служить полезными индикаторами косвенного воздействия промысла криля на виды, зависящие от него. Как правило представляется, что характеристики популяций, переменные воспроизводства и/или показатели естественного развития были бы лучшими индикаторами, чем определение величины популяции. Помимо этого, представляется вероятным, что, как правило, будут необходимы крупные выборки и, по мере возможности, следует разработать и внедрить автоматическую систему сбора данных. И, наконец, имеющаяся в настоящее время информация в основном недостаточна, чтобы предоставить основу для выявления связанных с промыслом изменений у отобранных индикаторов, и разработка базы исходной информации должна быть предпринята в срочном порядке. Обеспечение основы для оценки возможных причинно-следственных связей, сбор достоверной информации о природе, районах и величине промысла криля должны быть сделаны срочно.

CRITERIOS DE SELECCION Y REQUISITOS DE CONTROL PARA LOS INDICADORES INDIRECTOS DE CAMBIOS EN LA DISPONIBILIDAD DE KRILL ANTARTICO APLICADOS A LA INFORMACION DE ALGUNOS PINNIPEDOS Y AVES MARINAS

Resumen

El krill antártico, *Euphausia superba*, es el herbívoro dominante en la cadena trófica marina antártica y un componente principal de las dietas de los rorcuales comunes, ballenas azules, jorobadas y enanas; focas cangrejeras y focas peleteras antárticas; pingüinos Adélie, *Pygoscelis antarctica*, macaroni y rockhopper; varias otras especies de aves marinas; y varias especies de peces y calamares. Algunas de estas especies son a su vez consumidas por cachalotes, orcas, *Hydrurga leptonyx* y otros depredadores mayores. Por lo tanto, si no se desarrolla y administra en forma adecuada, la pesca de *E. superba* podría afectar a muchas especies dependientes y a la estructura básica y a la dinámica de la cadena trófica marina antártica, como así también a la distribución, abundancia o productividad del mismo krill.

La Convención sobre la Conservación de los Recursos Vivos Marinos Antárticos (CCAMLR) requiere que la recolección de recursos vivos marinos en el Océano Austral se efectúe en forma tal que se mantengan las relaciones ecológicas entre los recursos vivos marinos recolectados dependientes, y las poblaciones correspondientes, como así también que se evite el agotamiento de las especies recolectadas. Sin embargo, sería de un costo prohibitivo, si no imposible, evaluar y controlar cada especie y población que indirectamente pudiera verse afectada por la pesca de krill. Por consiguiente, esto significa que una de las tareas del Comité Científico establecido por CCAMLR, será determinar y diseñar programas para controlar aquellas especies, poblaciones, o características de poblaciones que con mayor probabilidad se verán afectadas, en formas detectables, por la explotación de E. superba.

Los objetivos de este proyecto eran: (a) desarrollar criterios para seleccionar especies, poblaciones y características de poblaciones que posiblemente proporcionasen indicadores útiles de cambios relacionados con la recolección en la disponibilidad de krill antártico; (b) recopilar y evaluar información de fácil disponibilidad con respecto a la ecología, demografía y dinámica de los pinnípedos y aves marinas antárticos, a fin de poder determinar si algunas especies y variables de la población pudiesen servir como indicadores útiles de cambios relacionados con la recolección en la disponibilidad del krill y cuáles serían estas especies; y (c) en lo posible, sugerir aspectos de programas que podrían o deberían ser iniciados a fin de seleccionar y controlar los posibles indicadores indirectos de cambios relacionados con la recolección en la disponibilidad del krill antártico.

Limitaciones

Hay una serie de grupos de especies, además de las aves marinas y los pinnípedos, que deberían ser considerados como posibles indicadores de cambios ocasionados por la recolección en la distribución, densidad o comportamiento del krill. Varias especies de cetáceos, por ejemplo, se alimentan de krill antártico y posiblemente podrían ser indicadores útiles. En forma similar, es posible que una o más especies herbívoras compitan con el krill, y podrían responder a, y servir de indicadores susceptibles a los cambios en la abundancia del krill. Este documento considera solamente las aves marinas y los pinnípedos, ya que éstos son los grupos de especies con los cuales los autores están más familiarizados.

Criterios para la Evaluación de Posibles Indicadores

Para poder actuar como indicadores efectivos de cambios causados por la recolección en la disponibilidad del krill, las especies o poblaciones indicadoras deben ser depredadores, presa o competidores del krill antártico; deben encontrarse en, o cerca de, las áreas en las cuales se está pescando krill; y deberán ser susceptibles a los cambios en la disponibilidad del krill, pero relativamente indiferentes o responder de manera previsible a las fluctuaciones ambientales naturales. Adicionalmente, las respuestas deberían ser relativamente rápidas (es decir, no estar sujetas a retrasos de varios años); la detección de respuestas debería ser simple, de bajo costo, y permitir muestras de gran tamaño; y debería ya existir una información básica adecuada o debería ser relativamente simple de recopilar. Idealmente, la recopilación de datos debería efectuarse durante, o en conjunto con las operaciones de pesca y/o desde las estaciones costeras o desde embarcaciones dedicadas a otras actividades - es decir, idealmente habría poca o ninguna necesidad de embarcaciones especializadas para efectuar evaluaciones y control de indicadores seleccionados.

Tamaños de las muestras

La capacidad de detectar posibles respuestas a los cambios causados por la recolección en la disponibilidad del krill dependerá de la naturaleza y la magnitud de la respuesta, la fiabilidad de la información básica, la variabilidad de las características (parámetros) que se están controlando, y la precisión con la cual se puede medir la variable. Es muy posible que durante las investigaciones de pinnípedos y aves marinas sea necesario obtener muestras de mucho mayor tamaño que lo acostumbrado, así como también realizar muestreos repetidamente, a fin de poder detectar cambios con adecuada susceptibilidad.

Posibles Indicadores de Aves Marinas

Debido a su gran número, amplia distribución, dependencia del krill, y accesibilidad durante la época de reproducción, los pingüinos Adélie y Pygoscelis antarctica pueden ser potencialmente, buenos indicadores de los cambios localizados o regionales en la disponibilidad del krill. Los parámetros que probablemente podrían cambiar o cambiarían en respuesta a la disponibilidad del krill incluyen: el tamaño de la colonia, tamaño de la nidada, tiempo que los padres pasan alejados de sus polluelos en busca de alimentos, cantidad relativa de krill y otras especies en la dieta, éxito de la cría, peso

de los polluelos durante la muda y supervivencia hasta la edad de reproducción. Los cambios en la supervivencia a la edad de la primera reproducción y en el tamaño de la colonia tomarían varios años en manifestarse y serían difíciles de detectar a menos que los cambios y/o los tamaños de las muestras fuesen muy grandes. Los cambios en el tiempo empleado en la alimentación, peso de los polluelos y otras variables similares estarían menos sujetas a retrasos y serían más fáciles de medir, convirtiéndolas en mejores opciones de posibles indicadores.

Cualquiera que sean las variables seleccionadas para el control, los estudios requerirán probablemente una ardua labor y estarán limitados en su alcance, a menos que pueda establecerse algún sistema de recopilación de datos más o menos automático. Se necesitaría un equipo de dos a cuatro investigadores, por ejemplo, en cada colonia indicadora seleccionada, si se fueran a usar técnicas tradicionales de estudio. Por lo tanto, durante la etapa inicial, será necesario investigar y, en lo posible, adaptar y usar control a distancia y registros automáticos para la recopilación de datos.

Posibles Indicadores Pinnípedos

De las seis especies de pinnípedos que se encuentran en el área de la Convención, tres dependen, hasta cierto punto, del krill antártico. La foca cangrejera se alimenta más o menos exclusivamente de krill. *Hydrurga leptonyx* come krill, por lo menos en algunas áreas, y depreda focas cangrejeras y pingüinos Adélie, los cuales a su vez dependen primordialmente del krill antártico. Las focas peleteras de Georgia del Sur y otros lugares en las vecindades de la Península Antártica también se alimentan de krill.

Los parámetros que podrían variar en respuesta a los cambios en la disponibilidad del krill incluyen: tamaño de la población, supervivencia de cachorros, jóvenes y/o adultos; edad al momento de la primera reproducción; tamaño al nacer y tasa de crecimiento; intervalo entre pariciones y/o tasas de reproducción según edad y especie; grosor de grasa; tiempo empleado en alimentarse; y proporción de especies además del krill, que sirven de alimento.

La mayoría de las variables del posible indicador, aparte del tamaño de la población, podrían evaluarse y controlarse recopilando periódicamente muestras representativas de animales de áreas seleccionadas. Los tamaños de las muestras serían necesariamente grandes (30 a 50 individuos por clase de edad) y los intervalos de muestras tendrían que ser seleccionados

de manera que aseguren que cualquier cambio observado en las variables del indicador seleccionado no fuera causado por el muestreo.

Conclusiones

Varias especies y características de las poblaciones de pingüinos y pinnípedos parecen cumplir con los criterios descritos y posiblemente podrían servir como indicadores útiles de los efectos indirectos de la pesca de krill en las especies dependientes del krill. Como regla general, parece que las características de la población, las variables de reproducción, y/o las tasas vitales serán mejores indicadores que el recuento de poblaciones. Parece también, por regla general, que se requerirán muestras de gran tamaño y que, en lo posible, se deberían desarrollar y usar sistemas de registro automático para la recopilación de datos. Finalmente, la información actualmente disponible es en general inadecuada para proporcionar una base para la detección de cambios relacionados con la recolección en indicadores seleccionados y se debería emprender el desarrollo de pautas básicas como una cuestión de prioridad. Asimismo debería darse prioridad a la recopilación de información fidedigna con respecto a la naturaleza, ubicación y extensión de la recolección de krill, para que sirva de base en la evaluación de las posibles relaciones de causa y efecto.

1. INTRODUCTION

BACKGROUND

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) requires that harvesting of living resources in the Convention area be conducted so as to prevent harvested populations from being reduced below their level of maximum net productivity and to maintain the ecological relationships between harvested, dependent, and related populations of Antarctic marine living resources. Thus changes in any populations, and the acceptability of such changes in terms of the conservation standard, are pertinent concerns under the CCAMLR.

Obtaining information on every species and population that might be affected directly or indirectly by harvesting and related activities would be prohibitively expensive, if not impossible. It follows, therefore, that one of the tasks of the CCAMLR Scientific Committee will be to identify those species and populations, in addition to those being harvested, that should be monitored to determine the possible indirect effects of harvesting and related activities. The Scientific Committee will also need to devise sampling strategies (monitoring schemes) that will facilitate rapid and sensitive detection of changes in selected indicator variables.

This paper addresses conceptual and practical aspects of the selection of indicators and monitoring strategies through examination of potential indicators of the indirect impacts of krill harvesting on seabird and pinniped populations. Krill harvesting may affect the availability or vulnerability of krill to predators by changing the abundance, density, distribution, or swarming behaviour of krill. This paper refers to harvest-related changes in "krill availability", rather than only "krill abundance", to indicate that predators could be affected by changes in krill distribution or behaviour as well as by changes in krill abundance or density.

OBJECTIVES

The project objectives were to :

- a. develop criteria for selecting species, populations, and population characteristics that likely would provide useful indirect indicators of harvest-related changes in the availability of Antarctic krill ;
- b. assemble and evaluate readily available information on the ecology, demography, and dynamics of Antarctic pinnipeds and seabirds to determine whether and what species and population variables of pinnipeds and seabirds might serve as useful indicators of harvest-related changes in krill availability ; and
- c. recommend a process and, as possible, suggest programs, for selecting indicators and devising monitoring regimes for indirect indicators of harvest-related changes in the availability of Antarctic krill.

METHODS

A tentative list of criteria for evaluating potential indicators was developed, and readily available information on the ecology, demography, and dynamics of selected Antarctic seabirds and pinnipeds was compiled and organised to facilitate evaluation of indicators. The authors then met to evaluate both the data and the tentative criteria for assessing the utility of possible indicators of indirect impacts of harvest related changes in krill availability. The authors also evaluated the potential utility of available data sets as baselines for detecting future changes, and considered the design characteristics of monitoring regimes necessary and feasible for enabling detection of indirect impacts of krill harvesting.

LIMITATIONS

There are species groups in addition to pinnipeds and seabirds that might be useful indicators of harvest-related changes in the availability of Antarctic krill. Several species of baleen whales and some possible krill competitors, for example, might be sensitive to changes in krill

availability. This project was intended to provide general guidelines for selecting possible indicators and devising monitoring strategies. Seals and seabirds were used as examples for applying the criteria and evaluating the possible utility of species and population variables as indicators. The criteria for useful indicators could and should be applied to other species groups and to other population variables as well. Neither the literature search nor the evaluation were exhaustive. An absence of discussion of any particular species, variable, or data set does not necessarily imply less potential importance as an indicator than those which are discussed.

2. CONSIDERATIONS FOR DETECTING CHANGES

Since we cannot accurately predict the responses of krill predator populations to varying levels of krill harvest, we need to design and implement baseline/monitoring programs to detect any changes associated with harvesting at an early time, when the magnitude of such changes is still small.

SOURCES OF VARIATION

In order to detect change in a variable, it is necessary to take at least two separate observations, and then compare them to see if they are different. The comparison of observations is made difficult in practice because of the variation inherent in data sets. First, some variation arises from sampling techniques. The same observer taking the same measurement twice will not get exactly the same results. Second, although the variable of interest is probably a population characteristic, observations must be made on individuals within a population, and individuals vary. The results from different subsamples of individuals within a population will be different. Because of these sources of variation, there is some uncertainty associated with any observation, and the greater the sampling or individual variation, the greater the uncertainty. The uncertainty then complicates the comparison of observations.

To use two (or more) observations of a variable made at different times to detect changes associated with krill harvesting, one of those observations needs to come from a time before any harvesting has occurred, or, if that is impossible, from as early as possible once fishing has started. Then, if observations from different times are different, and a change has been detected, the ecological significance of that change must be evaluated. Here a third source of variation arises, namely natural variation or population responses to the physical, chemical, or biological environment. The range of variation in a variable in an undisturbed population over recent historical time is usually considered to be the natural variation for that variable. Natural variation increases the difficulty of detecting the changes of greatest interest, namely perturbations due to human activities such as harvesting, the fourth source of variation that needs to be considered.

SAMPLE SIZE

The several sources of variation contribute to uncertainty in any estimate of a variable at a particular place and time. Clearly one measurement is not enough basis for an estimate, but how many observations are necessary? The sample size required for any estimate depends on how bad the problem is (the extent of variation) and how badly you want an answer (the size of the response to be detected). The greater the variation, and the smaller the size of the change you want to be able to detect, the larger the sample size that will be required.

As an example of sample size requirements, Table 1 indicates sample sizes needed to detect differences between means for two populations under selected conditions. Table 1 indicates that only about 20 measurements from each population would be necessary to recognise a relatively large difference in means if variation among individuals were relatively small, but that several thousand measurements from each population would be needed to recognise a small difference between populations with relatively greater variation among individuals.

The values for variance and difference to be detected used in Table 1 were selected to represent a realistic problem for Antarctic monitoring. Consider for example fledging weights of Adelie penguin chicks as the variable of interest as a potential indicator (Table 2). Most of the reported means differ by up to 0.7 kg, so a need to detect differences of 0.1 to 0.5 kg between means clearly is reasonable. Although standard deviations were not reported along with means, apparent differences between heaviest and lightest chicks at fledging were about 1 to 1.5 kg, so that standard deviations of 0.1 to 0.5 kg again are reasonable. Thus a likely monitoring objective of detecting a 0.5 kg difference in average fledging weight in successive years from samples with standard deviation of around 0.5 kg would require sample sizes of around 500. In contrast, sample sizes from past studies have been on the order of 50 first and 50 second chicks. It is obvious, therefore, that field techniques allowing much larger sample sizes would be needed for early detection of changes.

SAMPLE PATTERN

Sample size is an important consideration for detecting changes, but not the only one. Our ability to draw inferences about differences between populations also depends on the pattern of observations in time and space.

Literature reports of Adelie penguin chick fledging weight lack multiple observations in the same place at different times (with useful sample sizes) and also lack observations in several locations during the same year. Although a number of studies of Adelie fledging weights have been made, the studies do not provide a basis for determining the mean or variance of fledging weight characteristic of any region and time period, and likewise do not provide an adequate basis for estimating the magnitude of natural variation. Consequently there is little basis for determining the ecological significance of any different estimates in the future.

IMPLICATIONS FOR MONITORING

National and international research programs conducted to date in Antarctic waters have not provided a data base sufficient for detecting changes in any aspect of the marine ecosystem on a time scale shorter than decades. Samples have not been reported at regular intervals and sample sizes generally have been too small to be useful. A baseline/monitoring strategy which facilitates the repeated, comparable sampling of carefully selected variables necessary for detecting changes would also make possible the evaluation of hypotheses concerning ecosystem level responses to perturbations, and improve capability for predicting changes.

Since Antarctic research programs traditionally have not produced the kind of data necessary for monitoring, it would be unwise to rely on such programs for monitoring in the future. Thus it seems likely that the main body of data for monitoring will need to be generated from within the Convention framework, and a monitoring strategy relying on fishing vessels as platforms for collection of data from non-target species (as well as information on target and by-catch species) should be carefully considered. Information from research programs external to the Convention will be useful, but most probably as supplementary rather than primary information for monitoring.

These general considerations of how to detect changes in a single variable point to some requirements for designing monitoring programs so as to obtain useful data. Adequate sample sizes will be needed for each indicator variable selected. Time series of observations, in several locations, also will be needed for each indicator variable. Careful reporting of results, and observations on several factors at the same place and time, are also necessary. Since such sampling regimes would not be possible for large numbers of variables, the variables to be examined must be selected carefully, in order to maximise the useful information derived from the effort invested in data collection. Variables selected should be those for which adequate sampling is feasible, and those which provide relevant information as well.

3. CRITERIA FOR SELECTING INDICATORS

RESPONSE TO KRILL CHANGES

Indicators for population responses to krill harvesting clearly must come from species that respond to changes in abundance, density, behavior, and/or distribution of krill. Selected species should have an appropriate ecological relationship with krill as predators, prey, or competitors. Predation is the best understood relationship, and is analogous to fishing. Thus krill predators are the most obvious candidates for indicators of the indirect effects of krill harvesting. Indicator species or populations should be sampled in locations where impacts from krill fisheries are likely. Since populations affected by krill harvesting may be affected by natural environmental variation as well, populations away from fishery zones should also be sampled to provide information for comparison. The location of areas sampled in terms of the distribution of the entire species (center, fringe) should be known to aid in interpreting observed changes.

Any variable selected for use as an indicator of krill availability may also respond to changes in the physical environment, for example, sea ice distribution. Therefore, the way a potential indicator responds to sea ice, and possibly to other physical or chemical variations in the environment, should be assessed so that such responses can be separated from responses to krill per se.

Those variables which respond most rapidly to krill changes are the ones most likely to be useful as indicators, so that trends or changes in populations can be detected as early as possible. Population characteristics which are manifested only after substantial time lags (years or decades) would likely not be suitable indicators.

ABILITY TO COMPARE OBSERVATIONS

The detection of change requires comparison of observations separated in time or in space. Thus for selected indicator variables to be useful, it must be possible to make comparable observations at different times and/or places. The kinds of variables capable of being compared include measurements, counts, and indices (all quantifiable) as well as the means, variances, and distribution patterns of the data sets.

Indicator variables will be population characteristics but must be estimated from observation of individuals within the population. Hence the ecology and life history of the indicator species must be known well enough to insure that different samples can be collected in such a way that comparison makes sense. In the Antarctic, both timing of sampling with respect to seasonal variation and subsampling of individuals within the population must be considered. Primary production is an example of a variable for which timing of sampling is critical, since production is highly seasonal. Breeding success of nesting seabirds provides an example of a variable for which responses of different subsets of individuals within a population differ, since breeding success depends, among other things, on the distance of the nest from the center of the colony, and samples from central nests might produce a different estimate of success than samples from edge nests in the same season.

FEASIBILITY OF COLLECTING DATA

The selection of indicator variables must take into account the necessity for large sample sizes to provide data that can be used to detect changes in their early stages. Ideally it should be possible to get large sample sizes for selected variables at several different geographic locations in a year, as well as to repeat sampling at regular and frequent intervals, in order to detect trends and evaluate their ecological significance. Collection of information on environmental variables, such as sea ice, for the same time and place, should also be possible.

ABILITY TO INTERPRET DATA

The detection of changes in population characteristics is necessary, but not necessarily sufficient for CCAMLR requirements. Once a change is detected, the causes of that change must be determined or hypothesized. Statistical analysis can indicate associations among factors, but cannot provide information on cause and effect relationships. The causes of observed changes will be a matter for interpretation and argument. The availability of information on environmental factors in addition to krill availability will help to determine probable cause and effect relationships.

Having data on indicator variables from two or more species, with somewhat different ecological and behavioral responses, will also be helpful.

The magnitude and pattern of undisturbed or natural variation in an indicator variable will also assist in assessing the significance of observed changes, so baseline or pre-fishing information should be already available or possible to collect for selected indicators.

Obviously, complete and accurate data on krill and by-catch harvests will be essential to evaluate the possible causes of any observed changes in indicator variables. Structuring the development of the krill fishery as a controlled experiment would facilitate evaluation of possible cause and effect relationships involving indicators and the fishery, and development of capability for predicting indirect impacts of anticipated fishing levels.

Models can be used to assess possible alternative explanations of indicated changes, and to evaluate the implications of apparent trends over time. Development of models with predictive capabilities will require a substantial data base. Available information probably is sufficient, however, to develop models that can be used to identify critical data gaps and sensitive variables.

4. SOME VARIABLES THAT MEET THE INDICATOR CRITERIA

Theoretical and practical requirements for indicator species, populations, and variables were discussed in the previous section. Are there any variables that appear to meet that set of requirements? Yes, there are.

SEABIRDS

Of the Antarctic seabird groups, penguins seem most likely to provide useful indicators of local changes in krill abundance or distribution associated with krill harvesting because of their distribution both in and away from areas where krill fishing is occurring or expected, because of their accessibility in breeding colonies, and because of their ecology. Of the penguins, Adelies and chinstraps are the most promising indicator species because of their dominance of penguin biomass, and because of their habit of feeding predominantly on krill in the local area of breeding colonies. An additional advantage is the existence of some baseline information from studies which pre-date krill fishing in several locations. Of the suite of population variables that could be examined for the two penguin species, the reproductive variables such as clutch size, feeding interval, or fledging success or weight presumably will have the fastest response to changes in krill availability. Changes in certain reproductive variables can occur and be detected in a single season. In contrast, changes in population size or composition would take many years to occur and detect in such a long lived species.

The reproductive variables which seem most likely to be affected in detectable ways by krill availability include chick fledging weight, the time adults spend at sea between chick feedings, and meal size. For each of these variables, the mean, variance, or shape of the distribution of data on individuals could be the population variable used as an indicator.

The weight of single chicks or first chicks in a clutch tends to be slightly heavier than that of second chicks, so analysis of fledging weights would be enhanced by information on either the hatching order of

each chick weighed (for examining separate means for first and second chicks) or on the proportion of second chicks in a cohort (for examining a mean for the whole cohort). Alternatively, in the absence of such information, the population means of fledging weight for first and second chicks could be broken out of a sample of several thousand chick weights using appropriate statistical tools.

Adult Adelies and chinstraps spend between a day and a half and three days at sea feeding before returning to shore to regurgitate meals for their chicks. The average time spent at sea should respond to the availability of krill, since the faster an adult can fill its stomach, the sooner it presumably will return to feed its chick. There probably is a limit on maximum time spent at sea at which an adult will return with only a partial load.

Meal sizes, which are several kilograms, could be determined either by weighing individually recognizable adults as they leave and then re-enter the water, or by weighing chicks periodically to get weights before and after feedings. Then the differences are meal sizes, assuming negligible weight loss due to metabolic maintenance.

Where and when should reproductive variables be examined to provide indications of changes in krill availability? As one example, King George Island is a likely spot because of its proximity to areas where krill harvesting is occurring, and because penguin studies have occurred there. A string of several stations, beginning with Signy Is. in the South Orkneys, then Elephant Is. and stations on either side of it, King George Is. and Palmer on the peninsula, would provide good coverage of near shore areas in the Scotia Sea. All of the locations should be sampled in each year when indicator information is collected, and, initially, studies probably would be needed every year.

How can that much data collection be accomplished in one season? To date, studies of penguin breeding colonies usually have involved several investigators present at a colony from 2 to 4 weeks and have been very labor intensive. Several people working together could determine first and

second chicks, obtain fledging weights on 50 or so chicks, get some weights for meal size, and make some observations of time spent at sea by adults. Observations on time at sea probably would have large confidence intervals since relying on sightings is chancy. With the addition of some instrumentation, namely putting transmitters on adults, perhaps 100 adults at each location could be monitored for very accurate measurements of time at sea.

Additional and innovative uses of remote sensing and automated data recording should be considered. As an ad hoc example, consider setting up fences with gates which would force a large number, perhaps thousands, of chicks to go through the gates on their way into the water at fledging. If the gates were equipped with scales and automatic recording for the scales, the chicks could hop on and weigh themselves before going into the water. Then thousands of observations of chick weights would be feasible with a relatively small investment of time by investigators. With such a set up, investigators could instrument several locations in a season, and return at some later time to pick up the data records. Although this particular technique may not be workable, a little thought about it should generate other more promising ideas for automated data collection. The potential returns in usable data for time invested justify several years of research on innovative uses of technology for remote sensing and automated data recording in the Antarctic.

Suppose a change in fledging weight is detected. What does it mean? A number of environmental variables might be associated with observed changes, so additional information would be needed to sort out the impacts of fishing. For example, sea ice extent and density in the vicinity of breeding colonies may affect the ability of penguins to feed and so should be a factor considered along with krill fishing in trying to explain any observed changes in penguin reproductive variables. Therefore, good data on sea ice would be a useful complement to data on penguin reproductive variables. Sea ice data, now collected from remote sensing by satellites which provide good coverage on clear days, might be enhanced through use of additional sensors that can see through clouds. Also important, though, is providing easy access to the ice data for investigators.

Data on other krill predator species in the same area where penguin reproductive data are collected would also help in distinguishing the causes of any detected changes. Of course complete and accurate data on fishing activities would be essential in evaluating any observed changes in indicators.

PINNIPEDS

Studies of Antarctic seals are summarised in Table 3. The utility of seal species in the Convention area as indicators is in part a function of their ecology and distribution. The best time series data available on Weddell seals come from McMurdo in the Ross Sea, not an area where krill fishing is anticipated. Ross, elephant, Weddell, and leopard seals are unlikely candidates for indicators because of feeding habits that do not depend mainly on krill, and/or abundance that makes collection of adequate samples difficult. Conversely, crabeater seals, which are the most abundant Antarctic seal and which have a circumpolar distribution in the Antarctic ice pack, feed almost exclusively on krill. Their ecology, distribution, and abundance make them a likely candidate for a useful indicator species.

Large samples of crabeater seals can be collected, and observations on several variables, including blubber thickness, weight, length, teeth, and toenails, can be made from collected animals. Teeth can be analysed to yield information related to age, both age of maturity and population age structure. Since it is not known whether there is more than one breeding population of crabeaters, or the precise relationship between seal movements and pack ice distribution, it is possible that crabeaters should serve as indirect indicators of krill availability over broad rather than local areas.

There are some difficulties with using crabeater seal age data as indicators. First, the time required to detect changes is on the order of several years, possibly a decade or more. Second, one of the more useful kinds of analysis will be comparison of cohorts. In that case every time a

sample is taken, enough animals must be collected to provide perhaps 30 to 50 individuals in each age class of interest. Even without considerations of how behavior and distribution patterns may bias sampling for various age groups, that implies larger collections than have been taken in the past. Finally, some additional work will be needed on the interpretation of trends apparently indicated by the age data. Models can be used to examine alternative explanations of historical data as an initial basis for interpreting any future observations.

Some data on age at maturity for crabeater seals have been interpreted as indicating that the average age at sexual maturity has become younger over recent decades (Laws, 1977). In turn, the apparent decrease in average age at sexual maturity is thought to be associated with more krill available for food due to reduction in numbers of krill-eating whales. The crabeater seal collections were made from 1966 to 1973, and results were expressed as average age at maturity of year classes born from 1944 through 1968. For these data the more recent cohorts had an average age of maturity about one and a half years less than that of the older cohorts. An actual decrease in average age of sexual maturity for the more recent cohorts is one explanation for the results presented, but not the only one.

Collections made in the early 1970's for animals born in the late 1960's would include some individuals who had not yet reached sexual maturity, but would be expected to mature at an older age. Since age at maturity would be unknown for immature animals, they would likely be omitted from analysis. Hence, for cohorts born shortly before collections were made, the estimate of average age of maturity may be biased downwards since only animals maturing early could contribute to the estimate. At the other end of the scale, collections made in the 1970's of cohorts born in the 1940's would include only older animals. A differential mortality related to age at maturity which favored late maturing animals only slightly would bias the sample of old animals toward those that matured late, since they would be more likely to still be alive than earlier maturing individuals. Hence the estimate of age at maturity for cohorts born long before the collections were made would be biased upward. Thus it

is possible that cohorts born long before collections were made would appear to have older average ages at maturity than cohorts born shortly before collections were made, even though no change in average age at maturity had actually occurred.

To test these two different possible interpretations of the crabeater age at maturity data, a second collection made perhaps 10 years later than the first should be examined in the same way. Then the cohorts born say in the 1960's would be seen in both collections, but at different ages when collected. Their apparent average age at sexual maturity and the possibility of differential mortality by age at maturity could be examined by comparing the two data sets.

Other crabeater seal population variables presumably would change in response to krill availability, but would not be suitable as indicators for various reasons. Population size would likely respond too slowly to be useful because of the long life span of crabeaters, and population estimates would also be very imprecise and subject to confounding by large scale movement patterns. Rates of recruitment to the breeding population would be very difficult to estimate because of distribution patterns of juveniles, and would only become apparent after long time lags in any case. However, any possible indicator variables, including, for example, blubber thickness, age-specific survival and reproductive weights, time spent feeding, age-weight relationships, or diet composition, could and should be evaluated carefully with respect to all of the criteria for indicators to determine their potential utility.

5. A VARIABLE THAT DOES NOT MEET INDICATOR CRITERIA

One purpose of making counts of either seal or seabird populations is to detect changes in the absolute or relative size of those populations. Overall population size is a variable that responds slowly in long lived species, and for that reason alone may be unsuitable as an indicator. However, there are other problems with counts as well.

It is very difficult to get comparable counts in successive years for most populations. The distribution patterns for birds and seals depend on highly seasonal behavior. To be comparable, successive counts would have to be made at exactly the same time in the seasonal cycle. The timing of seasonal cycles depends on annual ice patterns and other physical and biological factors, and not just on dates, so that considerable effort would be required to do replicate sampling and/or to identify the point in a seasonal cycle at which a count was made. Further, and perhaps most telling, the effort required for counts with small confidence intervals is prohibitive except where photographs of colonies from aircraft are feasible. If $\pm 20\%$ is the best that can be done on a count, and even that is probably too expensive, then it will take decades to detect gradual population trends on the order of a few percent per year. Therefore it seems unlikely that the results of counts will be useful as indicators of ecosystem responses to changes in krill availability.

6. CONCLUSIONS

We have identified several points that should be taken into consideration by the Scientific Committee in selecting and determining how to monitor possible indirect indicators of harvest-related changes in krill availability. The potential indicator variables mentioned are intended to serve as illustrations for applications of criteria for selecting indicators and requirements for developing methods for monitoring. This paper represents a starting point, not a solution, to the need for monitoring of indicators for effective CCAMLR operations.

1. Species, populations, and population variables should be selected to provide adequate, timely, and relevant information on indirect impacts of krill harvesting. Indicator species should include krill predators with population distributions overlapping krill harvesting areas. It should be possible to compare selected variables from populations at different times or places. Data on selected variables should be feasible to collect, with adequate sample sizes, larger than sample sizes customary in previous Antarctic research, and possible to

interpret. For seabirds, potential indicator variables include Adelie and chinstrap penguin reproductive variables. For pinnipeds, crabeater seal collections probably will provide the most useful indicator variables ; counts will not be suitable.

2. Possible indicator variables from other groups should be evaluated on the basis of ecology, comparability, and feasibility of collection and interpretation.
3. It is desirable to be able to detect population changes associated with krill harvesting as early as possible while the magnitude of such changes is still small. To do so requires baseline information on variables in an undisturbed condition, as well as repeated, comparable samples with adequate sample sizes to enable comparisons to be made. Data on each selected variable should be collected in several locations, at regular and frequent intervals at each location. Information should be reported in a way that makes comparisons between studies possible.
4. Data which allow early detection of changes in potential indicator variables have not been collected under research strategies customary in past Antarctic work. Repeated, comparable sampling with adequate sample sizes is essential for monitoring to make possible the detection of changes in any indicator variables, and would also contribute to developing a capability to predict indirect impacts of varying levels of krill harvest.
5. Available technology such as transmitters, remote sensing, and automatic data recording should be used to the greatest extent possible for monitoring. Several years of research on innovative use in the Antarctic of existing technology would be worthwhile.
6. Complete, accurate, and timely catch and effort data from krill harvesting in the Convention area are essential both for assessing the causes of observed changes in indicator variables and for developing an information base for predicting impacts of krill harvesting on

non-target species. An experimental approach to fishery development would enhance investigation of the relationships between harvesting and non-target population responses.

7. Once changes in indicator variables are detected, the problems of explaining them and evaluating the causes remain. Assessing causes for detected changes could be made easier by collection of data on several indicator variables in the same location.
8. Models should be used to help evaluate alternative explanations for observed changes in indicator variables.

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Table 1. Approximate sample sizes required to detect indicated differences in means given indicated variances, with a confidence level of 0.90 (calculations based on Steel and Torrie, 1980, equation 9.18, page 232).

How bad the problem is :		How badly you want an answer :	
Standard deviation based on n=100	Variance σ^2	Difference to be detected	
		0.1 units	0.5 units
0.1 units	1	500	20
0.5 units	25	12,500	500

Table 2. Adelie penguin chick fledging weights. Paired numbers indicate mean weights for the first, then the second, chick in a nest. Single values lump all chicks. Sample sizes in parentheses.

<u>Geographic Area</u>	<u>Time</u>			
	early 1950's	1959/60	1969/70	1977/78
South Orkneys, Signy Island	3.6 kg (?) (Sladen, 1958)	-	-	-
South Shetlands, King George Is.	-	-	-	3.9 kg (47) (Volkman & Trivel- piece, 1980)
Ross Sea, Ross Is., Cap Crozier	-	-	3.3 kg, 3.1 kg (87) (Ainley & Schlatter, 1972)	-
Cape Royds	-	4 kg, 3.7 kg (113) (Taylor & Roberts, 1962)	-	-
Adelie Land	2.3 kg (2) (Sapin-Jaloustre, 1955)	-	-	-

Table 3.

Locations, dates and data collected for studies of Antarctic Pinnipeds.

1. Weddell Seal (Leptonychotes weddelli)

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
60°43'S 45°36'W Signy Island	1952-1953 1970's-1981	A. Mansfield, (1952-53) J. Croxall, (1970-1980)	Collections for age and reproduction, tagging data, some estimates reproduction rates, from Croxall. (in press).
66°40'S 140°01'E Pointe Geologie at Dumont d'Urville Station	1976,77 Some effort 78-81	A. Cornet and P. Jouventin	Some tagging. Social organisation, behavior. Estimates of vital rates not given.
McMurdo Sound 77°50'S 166°40'E	1964-1983	C. Ray, I. Stirling, D. Siniff, R. Hofman, D. DeMaster J. Thomas & W. Testa	Long term tagging estimates of vital rates generally available except for survival of immatures.

2. Crabeater seal (Lobodon carcinophagus)

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Bay of Whales 78°S 164°W	1934	A. Lindsey	Collection immatures, adult males and females (n=61)(American Museum of Natural History).
Marguerite Bay 68°00'S 69°00'W	1934-1937	G.C.L. Bertram	Collection immatures, adult males and females (n=small)
Pack ice: 60°S, 40-55°E	1964	T. Oritsland	Collection, 132 females 86 males.
Marguerite Bay 68°00'S 69°00'W	1966-1973	R.M. Laws	Age of maturity from back calculations (451=n) (Males and females).

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Bransfield Strait	1977	J. Bengtson, D. Siniff	Collection of female seals, age of maturity (n=94).
West side Antarctic Peninsula	1982	J. Bengtson (not published)	Collection, mostly adults, some immatures (n=around 500).

3. Leopard seal (Hydrurga leptonyx)

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Heard Island Macquarie Island S. Orkneys S. Georgia	1939-1951	R.M. Laws	Collection: pooled samples. 39 males and females
Pack ice; 60°; 40-55°E	1964	T. Oritsland	Collection; 33 males, 51 females.
Antarctic Peninsula	1981-1982	S. Stone & D. Siniff (unpublished)	Collection of mostly females (n=30)
Antarctic Peninsula	1982	J. Bengtson (unpublished)	Collection males and females

4. Ross seal (Ommatophoca rossi)

Very limited data exists on this species. Incidental observations and collections of small numbers of animals exists for various parts of the Antarctic, particularly the Ross Sea, Antarctic Peninsula region and the Weddell Sea. The South African Antarctic program had plans to collect animals in the eastern Weddell sea during the 1979-81 period. Results of this work seems not to have been published.

5. Southern elephant seal (Mirounga leonina)

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Signy Island 60°43'S 45°36'W	1948-1950	R.M. Laws	Collections, Population estimates vital rates. Social organization.
Macquarie Island 53°S 160°E	1960-1962	R. Carrick	Social organization. Population estimates vital rates. Collections.

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Marion Island 46°38'S 37°45'E	1974-1976 (probably continuing)	P.R. Condry	Counts by age/sex categories.
South Georgia 54°S 36°W	1977-1982	T.S. McCann	Counts, studies social organization using paint marks, collections for age at maturity.

6. Southern fur seal (Arctocephalus sp.)

<u>Location</u>	<u>Dates</u>	<u>Investigators</u>	<u>Data</u>
Prince Edward Island 46°40'S 37°50'E	1952-1977 (intermittent)	P.R. Condry	Counts. Estimate rates of increase limited marking program <u>Arctocephalus gazella</u> and <u>Arctocephalus</u> <u>tropicalis</u> .
South Georgia 54°S 38°W	1971-present	M.R. Payne	Population estimates vital rates. Collection of females for age of maturity. <u>Arctocephalus</u> <u>gazella</u> only.

- Table 1. Approximate sample sizes required to detect indicated differences in means given indicated variance, with a confidence level of 0.90 (calculations based on Steel and Torrie, 1980, equation 9.18, page 232).
- Table 2. Adelie penguin chick fledgling weights. Paired numbers indicate mean weights for the first, then the second, chick in a nest. Single values lump all chicks. Sample sizes in parentheses.
- Table 3. Locations, dates and data collected for studies of Antarctic Pinnipeds.
- Tableau 1. Tailles approximatives des échantillons nécessaires à la détection des différences indiquées dans les moyennes arithmétiques selon les variances indiquées, avec un indice de fidélité de 0.90 (calculs basés sur Steel et Torrie, 1980, équation 9.18, page 232).
- Tableau 2. Poids des jeunes manchots Adélie émancipés. Les chiffres accouplés indiquent les poids moyens du premier, puis du second petit dans un nid. Les chiffres simples comprennent tous les petits. Les tailles des échantillons sont indiquées entre parenthèses.
- Tableau 3. Lieux, dates et données recueillies pour les études sur les pinnipèdes de l'Antarctique.
- Таблица 1. Приблизительный размер проб, необходимый для выявления указанной разности в средних величинах при указанном отклонении; степень точности 0,90 (вычисления основаны на Стил и Торри, 1980 г., уравнение 9.18, страница 232).
- Таблица 2. Вес оперившегося птенца пингвина Адели. Парные цифры указывают на средний вес первого, затем второго птенца в гнезде. Одиночные цифры включают всех птенцов. В скобках - размер пробы.
- Таблица 3. Районы, даты и данные, собранные для изучения ластоногих Антарктики.
- Cuadro 1. Tamaños aproximados de muestras que se necesitan para detectar las diferencias indicadas en medios tomando las variantes indicadas, con un nivel de seguridad de 0.90 (los cálculos están basados en Steel y Torrie, 1980, ecuación 9.18, página 232).
- Cuadro 2. Pesos de los polluelos emplumados de pingüinos Adelie. El par de números indican los pesos medios del primer y luego del segundo polluelo en el nido. Las cifras únicas agrupan a todos los polluelos. Los tamaños de las muestras aparecen en paréntesis.
- Cuadro 3. Lugares, fecha y datos recopilados para estudios sobre los Pinnípedos Antárticos.

