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MONITORING INDICATORS OF POSSIBLE ECOLOGICAL CHANGES IN THE ANTARCTIC MARINE ECOSYSTEM

Abstract

Fisheries assessment, directed ecological studies and ecological monitoring are necessary to provide the information required for ecosystem management. Monitoring of indicator species to indirectly detect ecological trends in the Antarctic marine ecosystem is proposed. The most suitable indicator species for the Antarctic ecosystem are krill predators. Crabeater seals, Antarctic fur seals, chinstrap and Adelie penguins appear to have characteristics which offer the greatest potential as possible indicators of krill harvest-related changes in the ecosystem.

The paper briefly reviews the history and present status of Antartic fisheries. To introduce the topic of the potential effects of harvest-related perturbations, some hypothetical impacts of past and future fisheries are presented. A section on the design of Antarctic monitoring programs discusses variation in the ecosystem, the detection of changes, the selection of indicator species, experimental design, and the application of various technologies to ecological monitoring.

INDICES DE CONTROLE DES CHANGEMENTS ECOLOGIQUES POSSIBLES DANS L'ECOSYSTEME MARIN DE L'ANTARCTIQUE

Résumé

L'estimation des pêcheries, les études écologiques dirigées et le contrôle écologique permettent d'apporter les renseignements nécessaires à l'aménagement de l'écosystème. Il est proposé de contrôler les espèces indicatrices afin de détecter de façon indirecte les tendances écologiques dans l'écosystème marin de l'Antarctique. Les espèces indicatrices les plus appropriées pour l'écosystème de l'Antarctique sont les prédateurs du krill. Les phoques crabiers, les phoques à fourrure de l'Antarctique, les manchots à jugulaire et les manchots Adélie semblent présenter des caractéristiques qui en font les meilleurs indicateurs éventuels de changements dans la population de krill survenant dans l'écosystème et liés à l'exploitation.

Le document examine brièvement l'histoire et l'état actuel de la pêche en Antarctique. Pour aborder la question des effets potentiels des perturbations liées à la capture, sont présentées des hypothèses sur les répercussions de la pêche dans le passé et à l'avenir. Une section sur le format des programmes de contrôle dans l'Antarctique traite des variations dans l'écosystème, de la détection des changements, de la sélection des espèces indicatrices, d'un format expérimental, et de l'application de diverses technologies au contrôle écologique.

ПРОГРАММЫ МОНИТОРИНГА ИНДИКАТОРОВ ВОЗМОЖНЫХ ЭКОЛОГИЧЕСКИХ ИЗМЕНЕНИЙ МОРСКОЙ ЭКОСИСТЕМЫ АНТАРКТИКИ

Резюме

Оценка промысловых участков, направленные экологические исследования и экологический мониторинг имеют большое значение для предоставления информации, необходимой при попытках управления экосистемой. Предлагается проводить мониторинг видов-индикаторов для того, чтобы косвенным путем выявить направления экологического развития морской экосистемы Антарктики. Наиболее подходящими видами-индикаторами в антарктической экосистеме являются хищники, питающиеся крилем. Тюлени-крабоеды, антарктические морские котики, пингвины чинстрап и Адели, казалось бы, обладают характеристиками, которые, возможно, смогли бы послужить наилучшими индикаторами связанных с промыслом криля изменений в экосистеме.

В докладе кратко описаны история и современное состояние антарктического промысла. Предполагаемое воздействие промысла в прошлом и в будущем представлены в целях введения проблемы возможного воздействия значительных изменений, связанных с промыслом. В разделе по разработке программ мониторинга в Антарктике рассматривается изменчивость экосистемы, выявление изменений, выбор видов-индикаторов, экспериментальное моделирование и применение различных методов экологического мониторинга.

CONTROL DE LOS INDICADORES DE LOS POSIBLES CAMBIOS ECOLOGICOS EN EL ECOSISTEMA MARINO ANTARTICO

Resumen

La evaluación de la pesquería, los estudios ecológicos dirigidos y el control ecológico son necesarios para proporcionar la información necesaria para la administración del ecosistema. Se propone efectuar un control de las especies indicadoras para detectar indirectamente las tendencias ecológicas en el ecosistema marino antártico. Las especies indicadoras más adecuadas del ecosistema antártico son los depredadores de krill. Parece ser que las focas cangrejeras, las focas peleteras antárticas, y los pingüinos Pygoscelis antarctica y Adelie, tienen características que los convierte en posibles indicadores de los cambios relacionados con la recolección del krill en el ecosistema.

El documento revisa brevemente la historia y estado actual de la pesquería antártica. Se indican ciertos impactos hipotéticos de pesca pasada y futura a modo de introducción del tema sobre los posibles efectos de las perturbaciones relacionadas con la recolección. Una sección sobre el diseño de programas de control antártico trata sobre la variación en el ecosistema, la detección de cambios, la selección de las especies indicadoras, el diseño experimental y la aplicación de varias tecnologías en el control ecológico.

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Section One: INTRODUCTION

LIVING RESOURCES CONVENTION

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) recognizes that harvesting living resources could affect the structure and productivity of the Antarctic marine ecosystem. The Convention therefore requires that fisheries in the Convention Area (Fig. 1) be conducted so as to maintain the ecological relationships between harvested, dependent, and related populations of Antarctic marine fauna. The "minerals regime" currently being negotiated by the Antarctic Treaty Consultative Parties may, if successfully agreed, include comparable provisions for conservation of the Antarctic marine ecosystem.

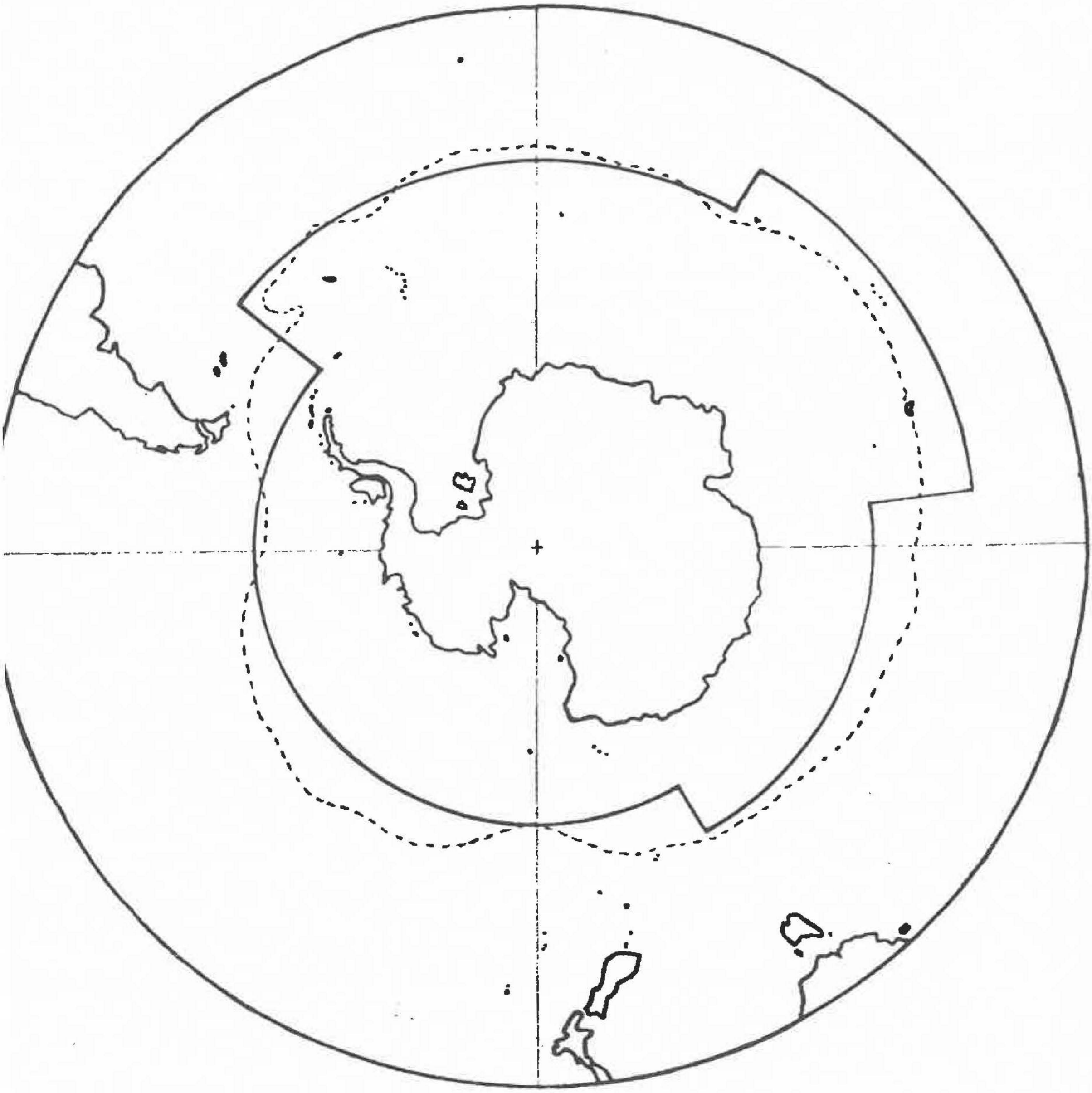
Neither past nor present research in the Southern Ocean is adequate to provide all of the data needed to reliably predict the potential ecological effects of fisheries and mineral resource exploitation. Moreover, it would be prohibitively costly, if not impossible, to assess and monitor individually each species and population that might be affected directly or indirectly by resource exploitation activities. Therefore, effective implementation of the provisions of CCAMLR will depend upon the development of programs to assess and monitor selected species or populations likely to be most sensitive to human activities.

DATA REQUIREMENTS TO SUPPORT CCAMLR

CCAMLR requires the management of fisheries and conservation of Antarctic marine living resources through an "ecosystem perspective". Target species, such as Antarctic krill (throughout this paper, the term "krill" refers to Antarctic krill, *Euphausia superba*, unless otherwise stated), as well as other ecosystem components must be considered. Just as the presence of any natural predator has some impact on the other components of the marine community, so also will commercial harvests of krill and finfish have effects on other community components. It is therefore important to frame management questions not only in terms of appropriate harvest levels before impacts would occur, but also in terms of acceptable levels of impact given agreed conservation principles. Within this context, three interrelated areas will provide information required for management:

1) Fisheries assessment
2) Directed ecological studies
3) Ecological monitoring

Fig. 1. Geographical boundaries of the area addressed under the Convention on the Conservation of Antarctic Marine Living Resources (solid dark line indicates Convention boundary, dotted light line indicates approximate location of Antarctic Convergence).



These three areas complement each other, and none should be pursued exclusively. Application of modern fisheries assessment techniques will serve as a starting point for fisheries/ecosystem conservation efforts in Antarctic waters. Directed ecological studies, including deliberate perturbation experiments, will be required to improve understanding of ecosystem structures and dynamics. Similarly, ecological monitoring studies will be required to detect changes and trends within and between key compenents of the marine community. When jointly pursued, efforts in these three areas would provide the data required for sound management of the Antarctic marine ecosystem.

Fisheries Assessment

Detailed data on fisheries activities and catch characteristics will be an important element of a comprehensive conservation strategy. In addition to providing the basis for assessing the status of harvested stocks, data about fishing effort, fishing locations, catch level, and by-catch composition will be necessary to interpret data from indirect assessment efforts (i.e., ecological monitoring of indicator species).

Ecological Studies

Understanding the structure and function of the Antarctic marine ecosystem is fundamental to management needs. Ecological investigations should include system-wide studies as well as studies that address specific data needs targeted by management questions.

The BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) program, and its broad goals as initially defined (SCAR/SCOR, 1977), should be supported to increase our general understanding of the ecosystem. The BIOMASS program, however, in focusing its attention on its two oceanographic experiments, FIBEX and SIBEX, has addressed only a subset of its original goals. Pack ice, shore-based, and process-related studies have not been satisfactorily incorporated into the mainstream of BIOMASS. For example, more attention needs to be given to predators of krill (whale and seal studies were not a part of FIBEX and SIBEX except for incidental whale sightings).

Studies conducted in pack ice and at shore-based sites will provide important data relative to management needs and ecosystem processes. The AMERIEZ (Antarctic Marine Ecosystem Research at the Ice Edge Zone) program being conducted by the U.S. is addressing some of these needs, although gaps remain in areas being investigated. For example, process-related studies, such as those on predation, have represented only a small portion of the project's initial, pilot-level focus. Presumably, in the next stage of investigation, studies of predation coupled to others on production will be given higher priority. In particular, the role of predators such as the crabeater seal (perhaps the principal predator of krill), and their strategies for dealing with seasonally changing abundances of krill needs further attention. Seabird and land-breeding seal studies at shore stations represent another valuable approach to obtaining detailed ecological information. Priority research topics should be identified for specific areas where critical information is missing:

1) Stock identification and abundance
2) Distribution and movements
3) Feeding ecology
4) Population dynamics

Ecological Monitoring

A basic challenge of the ecosystem approach to managing and conserving Antarctic marine living resources is obtaining current information on changes and trends within the system. Methods must be found whereby possible changes in the status of various components of the marine community can be detected and taken into account in management plans. However, the feasibility of simultaneously attempting to directly assess and monitor the abundance and status of harvested and dependent species is questionable. Even the independent, direct assessment of some harvested stocks, such as krill, presents some difficult challenges. Estimating the abundance of krill is difficult because: 1) they are distributed over a very large area, presenting a logistic problem; 2) their very patchy distribution creates a sampling problem, e.g., how accurately can estimates of local abundance be interpolated over large areas?; 3) their swarming behavior complicates abundance estimates because of differences in density within and between krill swarms, and the presence of non-swarming krill further confounds estimates; and 4) there is a limited understanding of the physical and biological factors affecting krill population dynamics. Given these and other difficulties, the use of indicator species has been suggested as a method to indirectly monitor ecological interactions.

Indicator species can be used to monitor the ecological status of populations or communities if selected variables respond in predictable ways to environmental changes. Parameters may respond to changes in general physical environmental conditions such as water quality and ice characteristics, or in response to density-dependent factors such as prey abundance and suitable habitat availability. Ecological habitats have been monitored by a variety of faunal indicator species including fish (Hocutt and Stauffer, 1980) and birds (Crawford and Shelton, 1978; Anderson et al., 1980). Indicator species can usefully monitor biological systems both at the individual and community levels (Cairns and Dickson, 1980).

One advantage of using indicator species and monitoring programs is that they can incorporate testable hypotheses, allowing evaluation of systems within time and spatial perspectives (Richkus, 1980). For example, one can ask the question, has the community or local population changed since a known perturbation? To answer such a question, it is important that spatial and temporal controls be designed into monitoring experiments (Green, 1978). For suitable controls, it is essential that multiple sampling sites be established both inside and outside areas where perturbations are expected to occur. It is also important to know the characteristics of the system prior to the perturbation.

The idea of using indicator variables in selected species to characterize changes in ecosystems is not new. Eberhardt (1977a) and Eberhardt and Siniff (1977), acknowledging the inherent problems of approaching management questions at an ecosystem level, proposed the use of various indices to assess the status of populations within communities. Fowler (1980) and Hanks (1981) reviewed the use of population indices with respect to large mammals. Such indices have been used more often as management plans increasingly include the ecosystem approach suggested by Holt and Talbot (1978).

REPORT OBJECTIVES

In order for the information needs of the CCAMLR Commission and its Scientific Committee to be met effectively, new assessment and monitoring programs must be developed. The main objective of this report is to encourage discussion and to facilitate development of such programs by outlining selected methods for obtaining data required for sound management. In particular, the use of ecological monitoring programs to assist management efforts is encouraged.

This paper briefly reviews the history and present status of Antarctic fisheries. To introduce the topic of the potential effects of harvest-related perturbations, some hypothetical impacts of past and future fisheries are presented. Selected studies involving indicator species are also outlined as examples of how such an approach can be useful in monitoring changes within marine food webs. The section on designing Antarctic monitoring programs discusses variation in the ecosystem, detection of changes in ecosystem trends, the selection of indicator species, experimental design, and methods and technology.

Section Two: BACKGROUND

ANTARCTIC FISHERIES

A principal motivation for the development of CCAMLR was the increasing interest in exploiting Antarctic living resources. It is useful, therefore, to briefly review these fisheries and their development.

Seals and Whales

Early in the 19th century, Antarctic fur seals (*Arctocephalus gazella*) and sub-Antarctic fur seals (*A. tropicalis*) were decimated by unregulated sealing (Stonehouse, 1972). The excesses of those harvests led to the collapse of the Antarctic fur seal stocks and the industry (Bonner and Laws, 1964; Bonner, 1968).

During the past century, overexploitation of most Antarctic whale species by commercial whaling led to a dramatic decline in these stocks (Gulland, 1976; Laws, 1977b; Allen, 1980; Tonnessen and Johnsen, 1982). Whalers switched from one species to another as stocks were depleted; only minke whales (*Balaenoptera acutorostrata*) are now harvested. Barring unforseen developments, a proposed moratorium on whaling may take effect in the 1985/86 season, suspending further Antarctic whaling.

Fish

Major fisheries for Antarctic finfish have been underway for several decades. The fisheries catch statistics for the years 1970-1980, as reported to the Food and Agricultural Organization (FAO) (Appendix 1), indicate that several fish species have been heavily harvested. Also clear from these figures is the significant change in the size of the catch for different species over the period of exploitation.

Gulland (1983) noted the large discrepancy between the early and recent catch figures for *Notothenia rossii*. This species was subjected to heavy fishing pressure in the 1969/70 season (over 400,000 tons*), but the rate rapidly declined throughout the 1970's to about 10 to 15% of previous levels. Similarly, *Champsocephalus gunnari* may have been overfished. This experience suggests that fish stocks in

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* Throughout this paper, the term "tons" refers to metric tons unless stated otherwise.

Table 1. Annual catches of Antarctic krill during early development of the fishery. Some reported catch levels do not correspond to catches later reported to FAO (see Table 2). (After Eddie, 1977; Everson, 1978).

Season	Nation	Catch Units	Notes	Total	References
61-62	USSR	4	Krill		Burukovskiy and Yaragov (1967)
63-64	USSR	70	Krill		Stasenko (1967)
64-65	USSR	306	Krill		Nemoto and Nasu (1975)
66-67	USSR	?	Krill		Nemoto and Nasu (1975)
67-68	USSR	140	Krill		Ivanov (1970)
69-70	USSR	100	UMC		FAO (1976)
70-71	USSR	1300	UMC		FAO (1976)
71-72	USSR	2100	UMC		FAO (1976)
72-73	USSR	7400	UMC		FAO (1976)
	Japan	59	Krill		Nemoto and Nasu (1975)
				7459	
73-74	USSR	4412	UMC		FAO (1976)
	Japan	643	Krill		FAO (1976); Nemoto and Nasu (1975)
				5055	
74-75	USSR	6965	UMC		FAO (1976)
	Japan	2600[b]	Krill		Nippon Suisan Kaizai (1976)
	Chile	60	Krill		Fishing News International (1975)
				9625	
75-76	USSR	6309	UMC		FAO (1977)
	Japan	5000[c]	Krill		Nippon Suisan Kaizai (1976)
	FRG	200	Krill		FRG. Ministry of Research and Technology (1977)
	Poland	575	Krill		World Fishing (1977)
	Chile	?			FAO (1977)
	Taiwan	?	Krill		Everson (1978)
				12084(-)	
76-77	USSR	?			
	Poland	30000[e]	Krill		Fishing News International (1978c)
	Japan	12000	Krill		Fishing News Internaitonal (1978b)
	Taiwan	130	Krill		Fishing News International (1978d)
				42130(-)	
	GDR	?	Krill		Eddie (1977)
	Taiwan	130	Krill		Eddie (1977)
	Chile	?	Krill		Eddie (1977)
	Norway	?	Krill		Eddie (1977)

[a]Catches of unspecified marine crustacea (UMC) by the USSR are from the areas adajacent to the Southern Ocean and are assumed to be largely of krill (Everson, 1977).
[b]FAO reports 1081.
[c]FAO reports 2841.
[d]Fishing News International (1978e) reports 7000.

some area, due to distribution and life history characteristics, may not be able to sustain continued heavy fishing as occurred in the peak years of 1969/70, 1975/76, 1976/77 (Gulland, 1983).

Squid

Although the economic potential for a cephalopod fishery in the Southern Ocean is unknown, squids may represent a significant potential fisheries resource (Everson, 1978). Clearly, large numbers of cephalopods occur in southern waters, although estimates of abundance have been very difficult to obtain. The importance of squids as indicated by stomach contents of higher predators, suggests that squids may be abundant and widespread (Clarke, 1980).

Recent reports of fishing activity near the Falkland Islands may portend future opportunities for squid harvests in southern waters (Anon., 1983a). A fleet of 20 Spanish trawlers was reported to have taken some 20,000 metric tons of squid just offshore of the Falkland Islands, and a large Polish fleet apparently took some 100,000 tons of squid and blue whiting (*Micromesistius australis*) from this vicinity as well. The future of Antarctic squid fisheries will likely depend on further determinations of distribution and abundance, improved harvesting methods, and economic incentives.

Krill

History

The earliest reports of exploratory Antarctic krill fishing are for the 1961/62 season by the USSR (Table 1). Since that time, the annual take of krill has increased dramatically (Fig. 2). For the first ten years of the fishery, the USSR was the only nation involved. It was joined in the 1972/73 season by Japan. By the late 1970's several other nations, including Chile, the Federal Republic of Germany, Poland, Taiwan, the German Democratic Republic, Norway and Korea, had also conducted exploratory fishing. Not until the 1976/77 season did the reported harvest of krill exceed 100,000 metric tons. The reported level increased to about 500,000 in 1980/81, the last season for which FAO statistics are presently available (Table 2). Although major concentrations of krill are distributed in all principal sectors of the Southern Ocean, the commercial fishing has been concentrated in the Atlantic and Indian Ocean sectors (Fig. 3).

Fig. 2 . Total krill catches in the Southern Ocean. Data supplied by D. Robertson from FAO statistics. (From Knox, 1983).

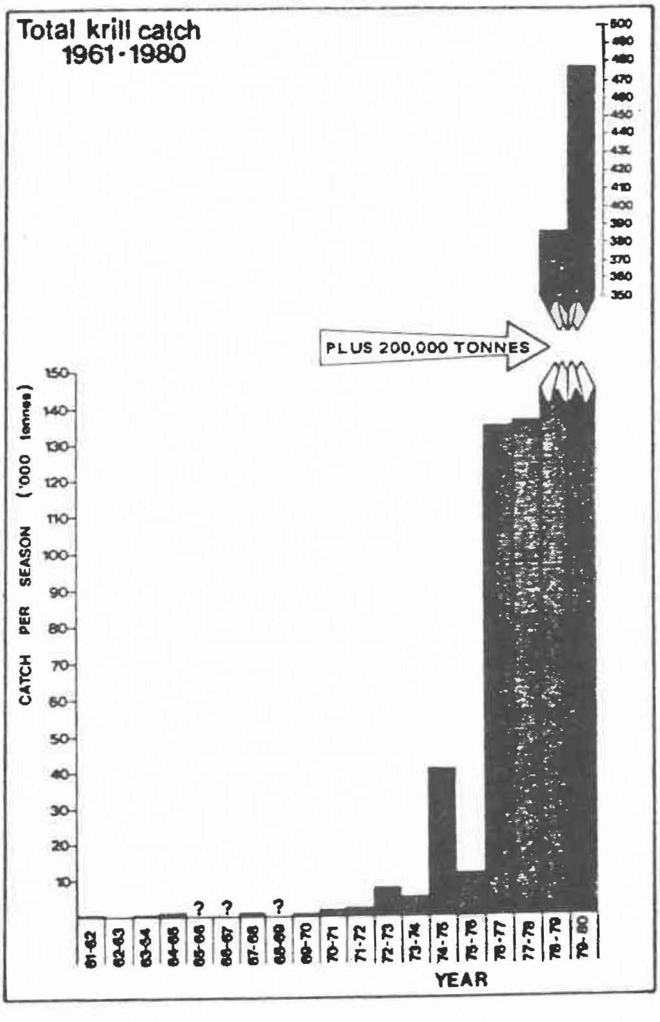
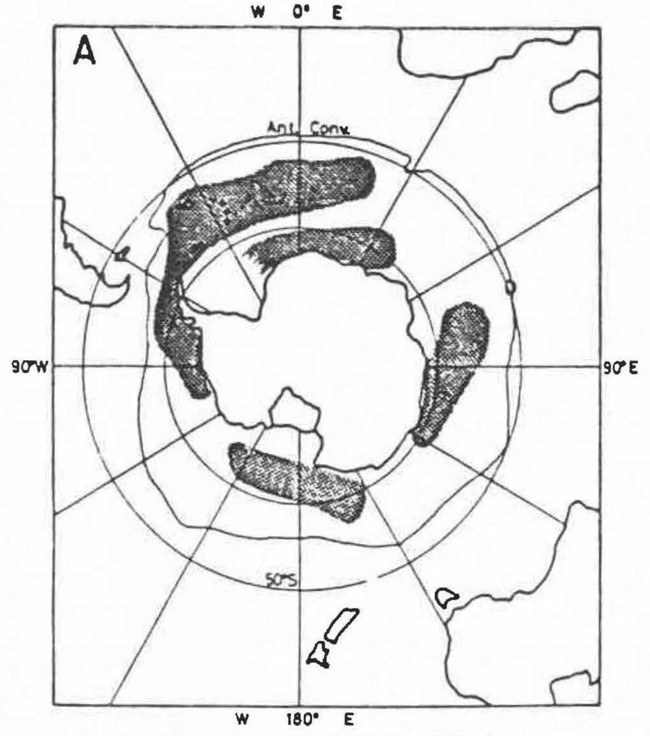


Fig. 3. (A) Distribution of principle concentrations of krill (using data from Marr, 1962 and Mackintosh, 1972) (From Everson, 1981). (B) Distribution of Euphausia superba and krill fishing grounds of Japanese and Soviet expeditions (Nemoto and Nasu, 1975). A.C.: Antarctic Convergence; N.B.: Northern boundary of E. superba; Shaded areas: Fishing grounds of Japanese expeditions; Area bounded by dashed line: Fishing grounds of Soviet expeditions. (From Nemoto, Doi, and Nasu, 1981).



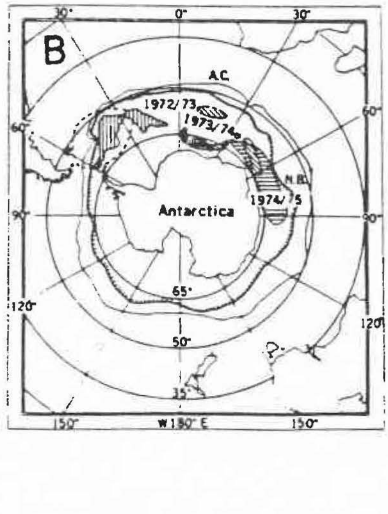


Table 2. Nominal catches of Antarctic krill by countries in various fishing areas. Catch totals given in metric tons (FAO, 1976-1982).

Country	Area	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Bulgaria	48	-	-	-	-	-	-	-	94	46	-	-
German DM RP	48	-	-	-	-	-	-	-	8	102	-	-
Poland	48	-	-	-	-	-	21	6966	1	-	226	-
USSR	48	-	-	-	21700	38900	500	99828	89820	266386	356752	285117
Total	48	-	-	-	21700	38900	521	106794	89923	266534	356978	285117
Japan	58	-	-	-	643	1081	2266	10517	26063	36909	36283	27832
USSR	58	-	-	-	-	-	-	1866	26781	28522	83764	132237
Total	58	-	-	-	643	1081	2266	12383	52844	65431	120047	160069
Poland	88	-	-	-	-	-	-	-	36	-	-	-
USSR	88	-	-	-	-	-	-	3355	-	600	-	3080
Total	88	-	-	-	-	-	-	3355	36	600	-	3080
Area 48					21700	38900	521	106794	89923	266534	356978	285117
Area 58					643	1081	2266	12383	52844	65431	120047	160069
Area 88					-	-	-	3355	36	600	-	3080
Grand Total		-	-	-	22343	39981	2787	122532	142803	332565	477025	448266

Present

Current catches of krill are far below the levels that some countries presumably are capable of taking. At least two factors may be responsible for this hiatus in harvest expansion: 1) difficulty in predictably detecting and capturing krill, and 2) problems with processing and marketing of krill products. Methods of detecting and capturing krill have been well reviewed by Everson (1978) and Eddie (1977). Echo sounders have been used extensively in locating swarms of krill, but because the original apparatus for fish was designed to disregard signals from zooplankton, modifications were required. At present, difficulties remain in distinguishing krill from some other abundant zooplankton.

Several types of fishing gear have been used experimentally and commercially for catching krill, including side trawls, purse seines and mid-water trawls. Modified mid-water trawls appear most satisfactory. The design most commonly used today has an enlarged mouth and smaller mesh than conventional nets. These modifications prevent loss of krill through the mesh. Nets and trawls used for fishing krill were evaluated by Klages and Nast (1981) and Czubek (1981).

Although some problems with detection and capture of krill apparently remain, processing and marketing appear to be the principal factors delaying expansion of the krill fishery (Everson 1978). Raw krill are unstable, and deteriorate rapidly after capture. This factor and other problems associated with handling and processing must be solved before the krill fishery can develop further (Grantham, 1977). For example, krill exoskeletons have a high fluoride content that presents a problem for animal consumption. Removing the shells has posed technical problems in the past, but these problems are reportedly being solved (Anon., 1983b).

Future

The magnitude of future Antarctic fisheries is uncertain. It is likely that considerable interest would exist in significantly expanding the krill fishery if difficulties with processing and marketing are overcome. Everson (1978) outlined three possible paths for expansion: (1) construction of new classes of factory ships, (2) diversion of fleets capable of distant water catches, and (3) deployment of fleets of trawlers and mother ships similar to those currently used by USSR and Japan (Table 3). The second two options would allow rapid expansion of harvest capacity should the economic climate and processing techniques improve. Indeed, new developments in processing, such as the improved peeling techniques recently announced in Poland, may expedite the expansion of krill fisheries and give new

Table 3. Composition of fishing fleets operating in the Southern Ocean. (After Everson, 1978).

Season	Area	Nationality	Type	No.	Reference
71-72	Iles Kerguelen	USSR	Trawler	77	Hureau (73)
			Cargo	18	
77-78	South Orkneys	USSR	Trawler	32	Hall (78)
			Tanker	4	
			Mothership	11	
			Tug	1	
			Research	1	
76-77		Japan	Trawler	5	World Fishing (77)
77-78		Japan	Trawler	9	World Fishing (77)
77-78	64 S, 120 E	Japan	Trawler	7	Fishing News Int. (78a,b)
			Research	2	
			Mothership	1	

impetus for higher catch levels (Anon., 1983b).

HYPOTHESES AND SPECULATIONS ABOUT THE MARINE ECOSYSTEM

The Dynamics of Krill and its Predators

Food webs are dynamic: various components interact through competition and predation within certain physical limits. In the Antarctic marine ecosystem, where we have just begun to understand these interactions, it is clear that Antarctic krill play an important role in the food web during summer. Similar to Paine's (1969) description of "keystone predators" (species which have a dominant influence in structuring their community), Dayton (1972) defined "foundation species" in lower trophic levels as those which contribute in a major way to community structure. Krill is certainly a foundation species. South of the Antarctic Convergence, it is the principal food for many species of whales, seals, seabirds, fish, and squid (at least during the summer). These groups presumably compete with one another for krill (although the spatial and temporal details of these interactions are still poorly understood). The success of predators comes not only at the expense of its prey (e.g., krill), but also its competitors.

It is into this dynamic system that man enters, as a commercial predator. There is evidence that man's previous predation on whales had a significant effect on the Antarctic marine ecosystem and may have led to basic changes in community structure and equilibrium (discussed below). The potential for greatly expanded krill fisheries in the future raises vital questions as to the possible further impacts of human predation on Antarctic living resources.

The concept of coupling management of multi-species fisheries and ecosystem conservation is particularly applicable to Antarctic living resource exploitation. Several authors have discussed the issue of multi-species models and fisheries management (May et al., 1979; Horwood, 1981; Tranter, 1981; Beddington and May, 1982; Yamanaka, 1982; Beddington and de la Mare, 1984). Although these models provide a framework of the different factors that may be involved in multi-species management, models allowing realistic predictions are in their infancy. Gulland (1983) noted that even for systems where our experience and knowledge are considerable, we cannot yet predict the effects of manipulating fishing effort on selected elements of the system. Therefore, although the basic framework of such models may be correct, much more information is required to specify and quantify the processes which link components.

An understanding of ecological processes is essential if we are to advance beyond simplistic models of biomass and energy flow. For example, Gulland (1983) stressed the importance of understanding species interactions, changes in behavior, and fluctuations in vital rates due to density-dependent factors. Changes in many of these parameters may be non-linear. For example, how does the abundance of blue or minke whales affect the population dynamics of sei whales? Is it the total abundance of krill or the abundance of dense krill swarms that is more critical to various predators? To what extent might the dispersion of krill swarms by commercial harvest affect prey accessibility for various predators? These and other questions regarding interactions in the marine ecosystem stress the need for further ecological research in Antarctica. They also lead to hypotheses about current ecosystem relationships as well as to speculation on possible future effects of krill harvests.

Hypotheses on Current Status of the Ecosystem

The following hypotheses concerning the present status of the Antarctic marine ecosystem include three main assumptions:

1) as a result of reduced baleen whale stocks, krill availability increased
2) non-exploited krill predators responded functionally and numerically to the increase in krill availability
3) a new carrying capacity and community composition developed

The removal this century of nearly 84% of Antarctic baleen whale biomass (Laws, 1977b) may have temporarily reduced competition among krill predators. As the whales were harvested, a so-called "krill surplus" may have occurred in annual increments throughout the period of whaling. Yet such "surpluses" would have been temporary. The increased availability of krill to other predators would have led to a period of readjustment in the marine community.

With increased prey availability, krill predators such as some pinnipeds, seabirds, fish and squid presumably experienced increased growth rates and population size. Some penguin populations apparently increased during this period (Conroy and White, 1973; Conroy, 1975). There also is evidence that the age of sexual maturity in crabeater seals (*Lobodon carcinophagus*) decreased (Bengtson and Laws, 1984). Some whale species may have demonstrated similar responses (discussed below). Despite incomplete data, there exists a general consensus that krill consuming groups "benefited" in various ways from the reduction of baleen whale stocks.

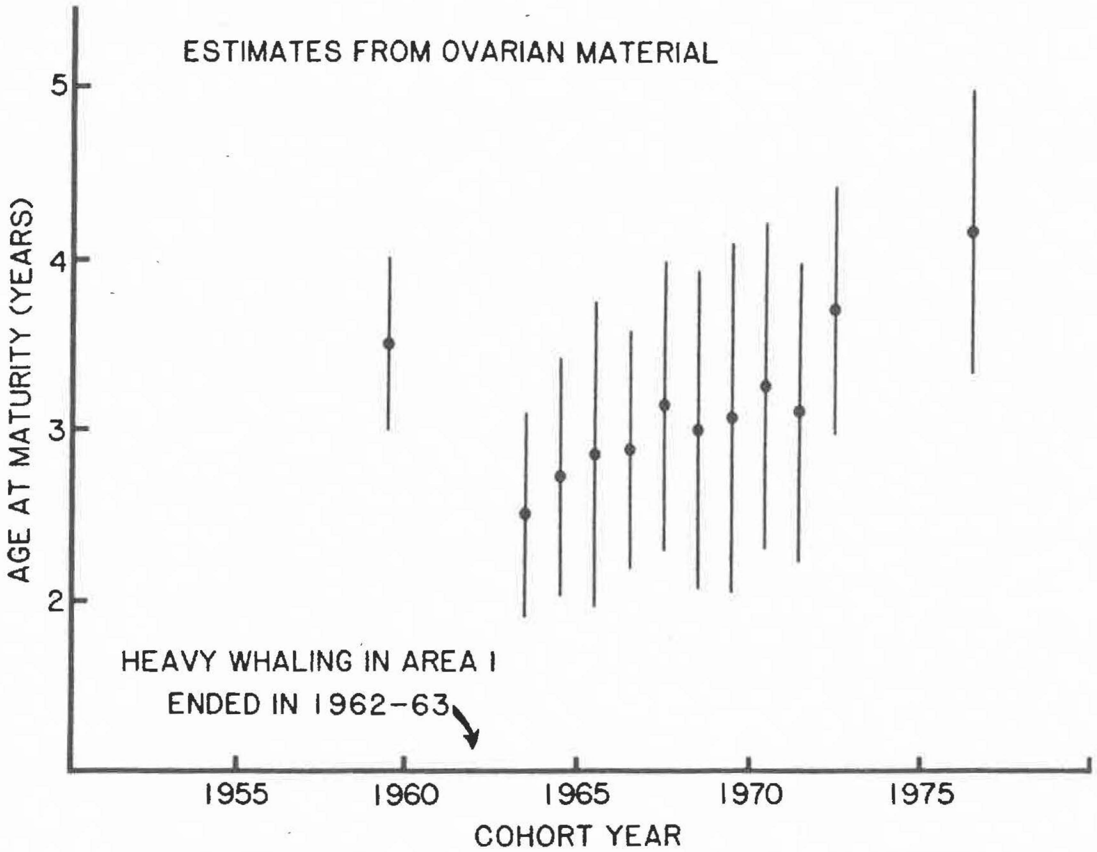
These responses are inferred from, and in turn, imply, a density-dependent food limitation in existence for krill predators prior to commercial whaling. With removal of whales, this constraint was partially lifted and the carrying capacity for krill consumers increased. Later, increased populations of krill predators consumed the portion of krill formerly eaten by the whales. A new balance in the biomass composition of the community presumably occurred.

As whaling declined and populations of krill consumers increased, competition among these groups returned; density-dependent food limitation again began to affect population parameters and population size. There is evidence that in some areas a reversal in the declining age at maturity occurred in crabeater seals (Bengtson and Laws, 1984) (Fig. 4). These data also suggest that with the cessation of whaling in Area 1, the annual increment of krill was no longer available, competition for krill caused slower body growth rate, and age at maturity in crabeater seals was delayed. The crabeater seal population is apparently stabilizing at a new level.

The apparent responses of krill consumers to the loss of large numbers of baleen whales from the environment suggests that krill abundance may have been an important limiting factor in the overall carrying capacity of the pelagic marine environment (Gambell, 1976; Gulland, 1976; Tranter, 1981). Although it was widely presumed that a decrease in whaling would lead to a recovery of whale stocks, Tranter (1981) outlined alternative views to that scenario. Citing May (1976), he noted that any recovery of whale stocks may be short-lived if increasing populations of other krill consumers have faster specific rates of growth than the large baleen whales. The total biomass of these groups would increase at the expense of the baleen whales. Crabeater seal data (Bengtson and Laws, 1984, Fig. 4), suggest that intraspecific competition for food has apparently already increased and is influencing the body growth rates of crabeater seals. The presumed recovery of protected whale stocks also may be increasingly affected by increased competition for prey. The addition of further competitors (i.e., commercial krill harvest) to the system may exacerbate this situation.

The present community composition of the Antarctic marine ecosystem is substantially different than that prior to commercial sealing and whaling. Obviously, there is far less baleen whale biomass now than before. It also is likely that in some areas the biomass of seals, birds, and perhaps squid and fish is much higher than prior to whaling. The effect that a change from a whale-dominated system to a seal/bird-dominated system has had on ecological processes in the system is unclear. Current population trends of unexploited populations of whales and seals in the Antarctic

Fig. 4. Trends in crabeater seal age at maturity as estimated from ovarian corpora counts. Mean age ± 1 standard error are shown. (Data from Bengtson and Laws, 1984).



are uncertain. However, the increasing age at maturity of crabeater seals strongly suggests that if indeed these populations had benefited from low competition for prey during the heavy whaling years, that situation is changing.

Speculations on Possible Effects of Krill Harvest

Reduction in Krill Biomass

It is unclear as to what level of commercial krill harvest would significantly affect krill and other zooplankton. One possibility is that competition among zooplankton for food will be reduced, although there is little evidence that krill are or are not currently limited during summer by phytoplankton abundance. Similarly, data are insufficient to judge whether or at what level vital rates such as recruitment, survival, or growth of krill may be affected by an overall reduction in their biomass caused by commercial harvest. Our lack of understanding about the discreteness of krill stocks precludes forcasting of how various fishing strategies may affect these stocks. Everson (1981) noted significant differences in the potential impacts of commercial fisheries depending on whether krill stocks are continuous or discrete (Table 4). At present, however, data on the spatial integrity of krill stocks is incomplete.

Although we can only speculate on the potential responses of other zooplankton to krill harvest, a reduction in krill biomass is likely to have a direct effect on krill predators. A large-scale commercial harvest of krill would likely lower krill availability and increase competition between various krill consumers to various degrees. A similar result has occurred in other large-scale, commercial pelagic fisheries (e.g., the California sardine, *Sardinops sagax*; Peruvian anchovy, *Engraulis ringens*; and South African pilchard, *Sardinops ocellatus* fisheries). A reduced krill availability presumably would result in lower growth rates and reproductive rates. In a simple model of joint exploitation of krill and whales, Horwood (1981) showed that harvesting krill decreased whale abundance. Ultimately, significantly lower krill biomass will lead to steady or even declining populations of whales, pinnipeds, seabirds, and other groups.

The degree to which various krill consumers would be affected by krill fishing would depend on the species and its natural history. For example, Gulland (1983) noted that although all the Antarctic baleen whales consume krill, the proportion of krill in the diet of each species varies considerably. Therefore the degree to which krill availability will affect each species can also be expected to vary. Krill predominate in the diets of blue whales (*Balaenoptera musculus*) and minke whales (*B. borealis*), for example, whereas copepods are important to sei whales.

Table 4. Postulated effects of an intensive krill fishery in one limited area. (From Everson, 1981).

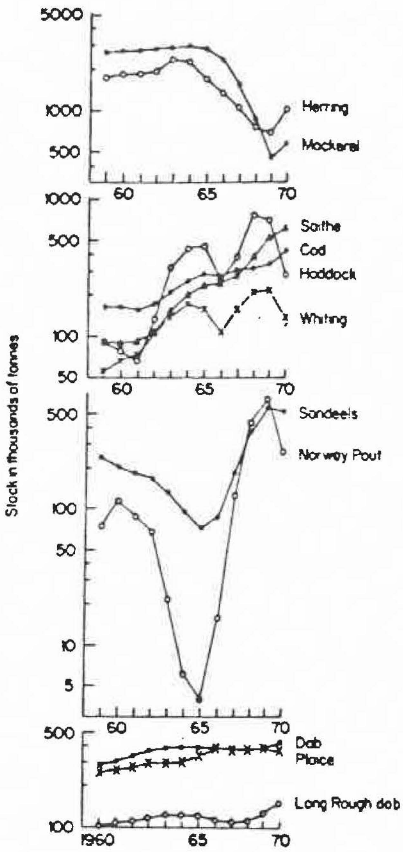
target	one single unit stock	several unit stocks (defined by area)
on krill (stock parameters)		
(*a*) growth	small	probably small
(*b*) mortality	no change (male) small (female)	may change (male) large (female)
(*c*) biomass	small	significant reduction after start of fishing
on natural consumers		
(*a*) species linked closely to fishing area (e.g., breeding birds)		
(*i*) intensive fishing prior to critical predation period each season	significant in fishing area. elsewhere minimal	significant: increasing with time to level off eventually
(*ii*) intensive fishing during and after critical predation period	small	significant in subsequent years
(*b*) species not tied to fishing area (e.g., whales)		
(*i*) intensive fishing before predator normally present in fishing area	small overall	reduced density (i.e., feeding elsewhere).
(*ii*) intensive fishing during and after predator present in fishing area	none or slight reduction in density	slight reduction in short-term major reduction in long term

Gulland (1983) also suggested that because minke whales (as important krill consumers) have increased, one could now argue that they should be harvested to allow other depleted whale stocks to recover. Tranter (1981) discussed this idea and proposed the possibility of harvesting crabeater seals, whales, and krill simultaneously. A major difficulty with this approach is that it is very difficult to devise specific management strategies on the basis of intuitive cause/effect relationships (Gulland, 1983). We have no basis, other than speculations based upon unverified assumptions, for concluding that a given harvest strategy would have a desired result. Furthermore, we have no evidence that manipulating minke whales, crabeater seals or other stocks alone would ensure desired effects. To assume that harvesting krill, seals, and minke whales simultaneously would allow recovery of depleted stocks of whales is little more than speculation. This is particularly true in light of our ignorance about the numerical and functional relationship between various components of krill-dominated food webs and the potentially major role that fish and squid may play in the ecosystem. Without more information, it is premature to initiate simultaneous harvests of krill and its predators to achieve management and conservation of multi-species systems.

Dispersion of Krill Swarms

Commercial krill fisheries may change the behavior and distribution as well as the density of krill. Gulland (1983) raised the question of whether dispersion of krill swarms by commercial harvests might affect the availability of krill to predators to a greater extent than changing the absolute abundance of krill itself. Longhurst (1981) discussed the importance that the patchy distribution of plankton has within marine ecosystems. He stressed predators' crucial need to be able to locate dense food sources in patchy environments. Longhurst (1981) discussed Lasker's (1975, 1980) work that showed the inability of some larval fish to survive if phytoplankton above a certain threshold density could not be located. In a similar example, Longhurst (1981) cited studies by Brodie et al. (1978) in the Gulf of St. Lawrence. If euphausiids were distributed uniformly instead of in dense layers, the energetic costs to baleen whales searching for prey would be higher than the caloric value of the prey themselves. If that were the case in the Gulf of St. Lawrence, the whale populations presently found there could not survive. Nemoto and Harrison (1981) further stressed the importance of dense swarms to many species of baleen whales. They pointed out that although Euphausia triacantha is distributed in high latitude waters throughout the Southern Ocean, it is not found in the stomachs of baleen whales presumably because it is not accessible to whales in the energy efficient form of dense swarms (Baker, 1959). Similarly, although Calanoides acutus is known to be abundant in Antarctic waters, it is not a prey species for many large

Fig. 5 . The changes in the biomass of 11 stocks in the North Sea as estimated by Andersen and Ursin (1977); the most prominent change is the gadoid outburst during the whole decade at a rate of increase common to the four species. (From Cushing, 1981).



predators presumably due to its lack of swarming behavior (Andrews, 1966). The likelihood of Antarctic krill swarms being dispersed or otherwise affected by fishing activities and its consequent effects on predators are unknown. If human predation on krill changes their behavior, the effects on the ecosystem could be substantial.

Shift in Composition of the Marine Community

A third area where krill harvests may potentially affect the ecosystem includes shifts in the predominant species groups. The impact of removing species from food webs have been examined by several investigators. For example, Pimm (1980) outlined the effects of removing predators from benthic and littoral systems (Table 5). Other examples involve a dominant species group that has declined and been replaced by another. Often this replacement has been brought about by a suite of natural events and/or human fisheries activities resulting among other things in changes in the relative abundance of competing species.

A well-known example of previous shifts in dominant species is the collapse of sardine stocks off the California coast in the 1930's and their replacement by anchovies (Gulland, 1983). In 1972 anchovy stocks crashed off Peru and were replaced by sardines (Idyll, 1973; Murphy, 1977; MacCall, 1984). Declines in herring and mackerel stocks in the North Sea apparently led to increases in cod, haddock and plaice (Holden, 1978) (Fig. 5). Sherman et al. (1981) presented data suggesting that depleted herring and mackerel stocks were replaced ecologically by expanded stocks of sand lance (_Ammodytes_ sp.) in the eastern north Atlantic. The over-exploitation of Alaskan sea otters (_Enhydra lutrus_) apparently led to increases in sea urchins. This shift resulted in a marked change in the structure of that marine community (Estes and Palmisano, 1974; Simonstad et al., 1978).

The removal of baleen whales in the Southern Ocean resulted in a change in the composition of dominant species of mammals. Antarctic fur seal stocks, recovering from over-exploitation in the early 19th century, have increased dramatically over the last several decades (Fig. 6). The accelerated growth rate of this population is partly attributed to increased krill availability due to declining whale stocks (Laws, 1977a). Crabeater seals, the most abundant of the pinnipeds, have also presumably increased in total abundance. The estimated population of 15 - 30 million crabeater seals (SCAR/SCOR, 1983b) is estimated to consume approximately 63 - 126 million metric tons of krill annually compared to the approximately 43 million metric tons of krill estimated to be consumed currently by all Antarctic baleen whales combined (Laws, 1977b). Whether the present dominance of seals in the top trophic level of the Antarctic marine

Table 5. Effects of removing predators. (From Pimm, 1980).

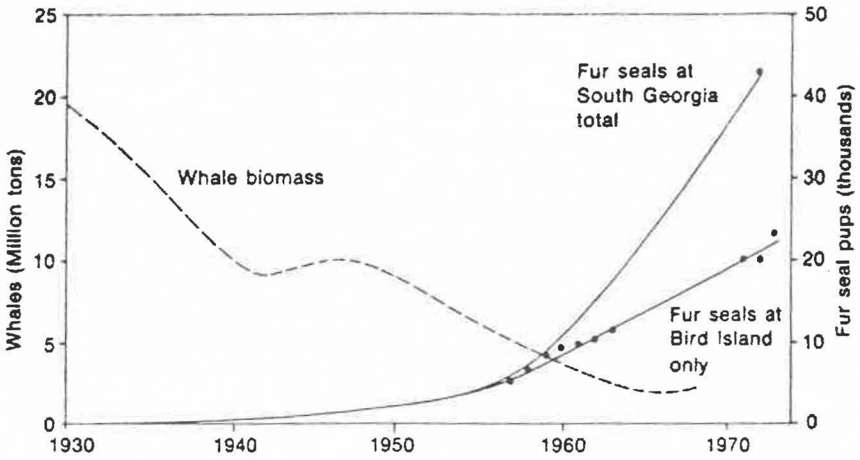
Web	Species removed	How removed	Predator's prey	Effects of predator removal	Source
1.	Enhydra (Sea Otter)	Man; local conditions - cannot feed in deep water	Strongylocentrotus (Sea-urchin), fish and molluscs	Strongylocentrotus increases dramatically	Estes et al., 1978
2.	Strongylocentrus polyacanthus	Enhydra	Laminaria and a variety of other macro-algae	Agrarum and Thalassiophylum (algae) that are resistent to the predator are out-competed by Laminaria. Increased competition eliminated various species of red algae and Alaria (algae)	Dayton, 1975a
3.	Strongylocentrotus purpuranus	Pycnopodia (starfish). Anthopleura (anemone)local conditions - strong wave action, experimentally	Drift and Hedophyllum (algae)	With predators, only coralline algae survive. Predator removal allows Hedophyllum, and the species associated with it to survive	Dayton, 1975b
4.	as 3	experimentally	not given, but presumably as 3	Lithothamnion (coralline algae) survives in presence of predator, but is out-competed by Hedophyllum when predator is removed	Paine and Vadas, 1969; Paine, 1980
5.	Strongylocentrotus frasiscami	experimentally	Laminaria is only species listed, but predator can survive in its absence	Lithothamnion survives in the presence of the predator but is out-competed by Laminaria and over-grown by diatoms, Ulva and Halosaccion (red algae) when predators are removed	Paine and Vadas, 1969
6.	Echinomeira, Diudema, Helerocentrotus (Sea urchins)	Local conditions wave action	algal lawn	With predators corals survive without them they are out-competed by the algae	Dart, 1972
7.	Paracentrotus (Sea-urchin)	Experimentally, local conditions not fully understood	algae	A variety of algal species and the animals dependent on them invade essentially bare areas following predator removal	Kitching and Ebling, 1961
8.	Stichaster (Starfish)	Experimentally	specialized: 76% of the prey are Perna (mussel)	"Rapid domination...by Perna... at the expense of the other resident, space-requiring species"	Paine, 1971; 1980
9.	Acanthaster (Starfish)	Various coral symbionts (Trapezia, Alpheus) prevent predator from feeding on coral)	prefers Pocillopora (branching corals), but will take other non-branching species	Pocillopora corals persist only in absence of predator, otherwise they are grazed close, or to, extinction	Glynn, 1976
10.	Pisaster (Starfish)	Experimentally	Very generalized	Predator removal allos Mytilus (mussels) to remove most of the other species in the community through competition or loss of food supply	Paine, 1966
11.	Pisaster	Experimentally	as 10	Predator removal did not lead to increase in Mytilus. Larval Mytilus were probably scarce in the plankton during this experiment	Connell, in prep.
12.	Katharina (Chiton)	Experimentally	Hedophyllum and other algae	Presence or absence does not affect the rate at which the algae recovers when it too has been removed	Paine, 1980**; Dayton, 1975b
13.	Acmaea (Limpet)	Experimentally	Coralline algae	One change within the 5 species coralline algae, one species became commoner at the expense of of another. Relative abundance of coralline algae versus Hedophyllum unchanged	Paine, 1980**
14.	Patella (Limpet)	Experimentally	Algae	Dramatic increase in the abundance of the algae	Jones, 1948
15.	Lepomis (Fish)	Experimentally, local conditions: dense vegetation	Principally larger zooplankton but will take smaller species if larger ones are unavailable	A large species, Ceriodaphnia (cladoceran), predominated after after predator removal at levels from 44% to 97% depending on nutrient levels in the pond. Smaller species (e.g. Bosmina, also a cladoceran) and other herbivores (rotifers and copepods) are eliminated through competition	Hall et al., 1970

Table 5. Continued

16. Odonates, coleopterans and other planktonic predators	Experimentally	Daphnia	Largest species, Daphnia (cladoceran) increases, smaller species decrease, data are described as "weak" and one predator, Chaoborus (dipteran) was not removed	Hall et al., 1970
17. Anax (naid) (benthic predator)	Experimentally	Mainly Chironomus (dipteran), but also Caenis (ephemeropteran)	Chironomus increases, Caenis decreases	Hall et al., 1970
18. Chaoborus	Experimentally	Ceriodaphnia, Bosmina, Cyclops, Diaptomus (last two are cyclopoda); under strong predation pressure, Daphnia	At high densities Chaoborus feeds on rotifers and Daphnia, at low densities smaller species (Ceriodaphnia, Bosmina, Diaptomus) can persist, but the rotifer predator, Asplancha (also a rotifer) is lost	Lynch, 1979**
19. Lepomis (fish)	Experimentally	Four species of Daphnia, Chaoborus, Cariodaphnia, Cyclops, Bosmina, Diaptomus	With predator, smaller species (Bosmina, Cyclops, rotifers) predominate: the rotifers support Asplancha. Predator removal results in larger species (Daphnia Ceriodaphnia, the predator Chaoborus). Rotifers are not sufficiently abundant to support Asplancha	Lynch, 1979**

**Indicates paper where food web has been described explicitly

Fig. 6 . Increase in the pup counts of the fur seal (Arctocephalus gazella) at South Georgia for the period 1933 to 1973 (solid lines). The decline in the biomass of antarctic baleen whales (from Mackintosh, 1970) is shown for comparison (dashed line). (From Laws, 1977a).



ecosystem represents a new, long-term equilibrium remains to be seen.

A possible result of over-exploitation of krill might be replacement by a competing herbivore species. A change in trophic relationships from a phytoplankton/*E. superba*/ predator food chain to a phytoplankton/other euphausiid or copepod/predator chain would have significant effects on the ecosystem. Most zooplankton such as *E. triacantha* and copepods do not form swarms as dense as *E. superba*. Sei and right whales, which use a skimming method of feeding, are capable of feeding on copepods which are found in lower densities than those of Antarctic krill (Nemoto and Harrison, 1981) and might benefit from a shift in dominant zooplankton composition.

Changes in the availability of zooplankton at certain densities would clearly affect baleen whales which have specialized on plankton present in particular densities within the water column (Nemoto and Kawamura, 1977). If, for example, herbivores that swarm less densely than krill became dominant in the Antarctic community, blue and humpback whales (*Megaptera novaeangliae*) would be at a competitive disadvantage. Because these whales depend heavily on very dense, heavy swarms of Antarctic krill, the recovery of these depleted stocks well could be jeopardized.

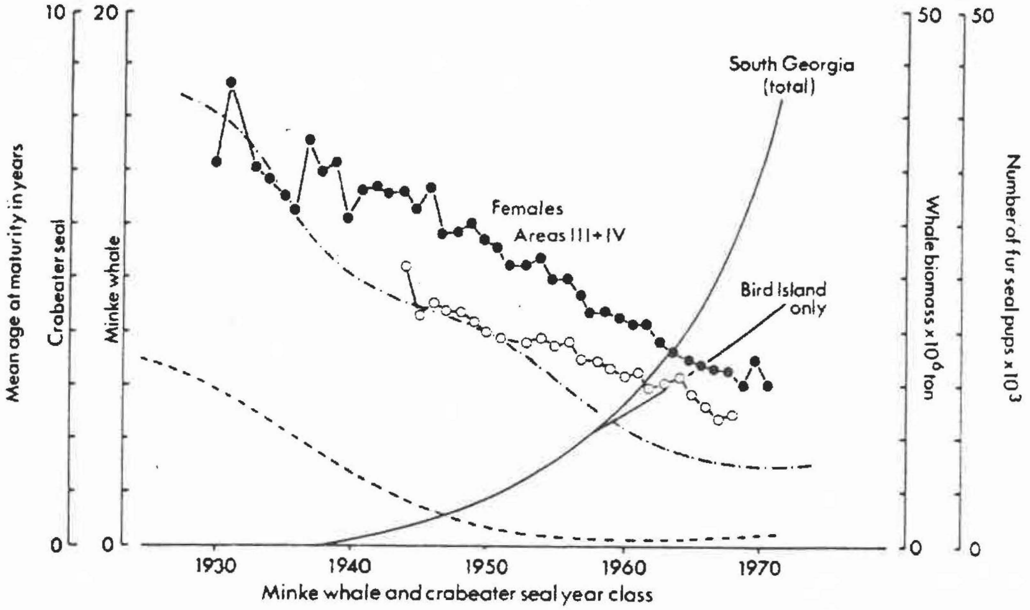
PREVIOUS STUDIES UTILIZING INDICATOR SPECIES

When considering the use of indicator species to detect ecological changes in response to fishery-driven perturbations, it may be useful to examine previous studies that have used the indicator concept. For example, is there evidence that certain indicator variables changed in response to the over-exploitation of whale stocks in the southern hemisphere? Such a consideration would be helpful in two areas: 1) demonstrating whether or not the idea of indicator species is a viable one, and 2) suggesting some specific indicator parameters which, on the basis of past responses, might also be useful in measuring the effects of future perturbations.

Pinnipeds

Changes in the reproductive rates and population size of some Antarctic pinnipeds have been correlated with hypothesized changes in the ecosystem brought about by declining whale populations.

Fig. 7. Interspecific correlations between krill feeding animals and baleen whale biomass in the Antarctic marine ecosystem.
● - ● mean age at sexual maturity, minke whale (present study),
O - O mean age at sexual maturity, crabeater seal (Laws, 1977a),
—·—·— total baleen whale biomass (Gambell, 1975), ---- blue whale biomass (Gambell, 1975), ——— number of fur seal pups (Laws, 1977a). (From Kato, 1983).



Age at Sexual Maturity

Laws (1977a) analyzed crabeater seal data and suggested that age at sexual maturity decreased from about 4 years in the mid-1940's to about 2.5 years in the late 1960's (Fig. 7). He attributed this reduced age at sexual maturity to accelerated body growth caused by more readily available krill, the primary food of crabeater seals. Accelerated growth would have led to an earlier age at maturity for individuals throughout the population as whale stocks decreased and krill availability increased. In contrast, the decline of whaling in the late 1960's and early 1970's, and the presumed numerical increase in seals, fish, and seabirds, should have caused the availability of krill to decrease once again. With this decrease in krill availability, a reversal in the declining age at maturity would be expected. Based on a small sample of crabeater seals collected in 1977, however, Bengtson and Siniff (1981) were unable to support this prediction.

More recent work (Bengtson and Laws, 1984), intended to further test the hypothesis that age at maturity should increase during the 1970's, demonstrated that the tooth back-calculation technique used in earlier studies produced trends that were artifacts of sampling. A sub-sample of Laws' (1977a) pooled data showed that the decreasing trend found in the 1972/73 sample was also present in a similar sample taken 9 years later (Fig. 8). Data plotted against age at collection rather than birth year indicated an inherent trend in the separate samples, not in the population. Hence, back-calculation of transition zone in teeth in crabeater seals was not suitable for estimating past trends in sexual maturity.

Whereas tooth back-calculation is an inadequate method to assess trends in reproduction, direct evaluation of ovarian corpora did show an increasing trend in maturity as predicted (Bengtson and Laws, 1984) (Fig. 9): crabeater seal age at maturity increased steadily from about 2.5 years in 1962 to over 4 years by 1976. The strong correlation of this trend with whaling activities in that region suggests that reproductive parameters are indeed sensitive to perturbations in the marine ecosystem.

Crabeater seals may therefore be a useful species for future monitoring of krill availability. In a similar way that whaling affected krill abundance in the past, commercial krill harvests in the future may affect krill abundance and its availability to predators. Monitoring the age of sexual maturity in crabeater seals may allow evaluation of the level of these perturbations within the marine community.

Fig. 8. Crabeater seal ages at sexual maturity (sexes combined) by year classes, back-calculated from interpretations of tooth layers. Data from Bertram's collection (1940) are lumped as pre-1937 year classes. Mean ± standard deviation are shown. (From Laws, 1977a).

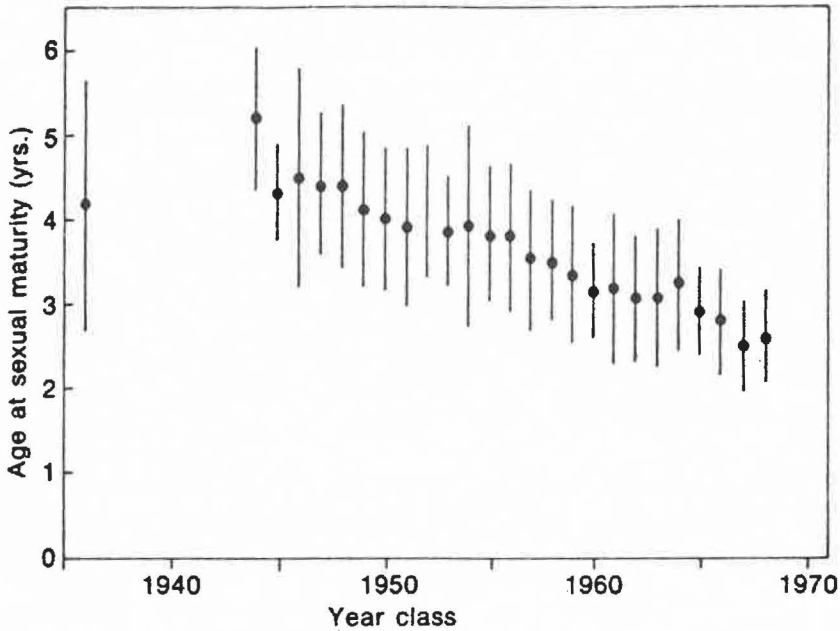
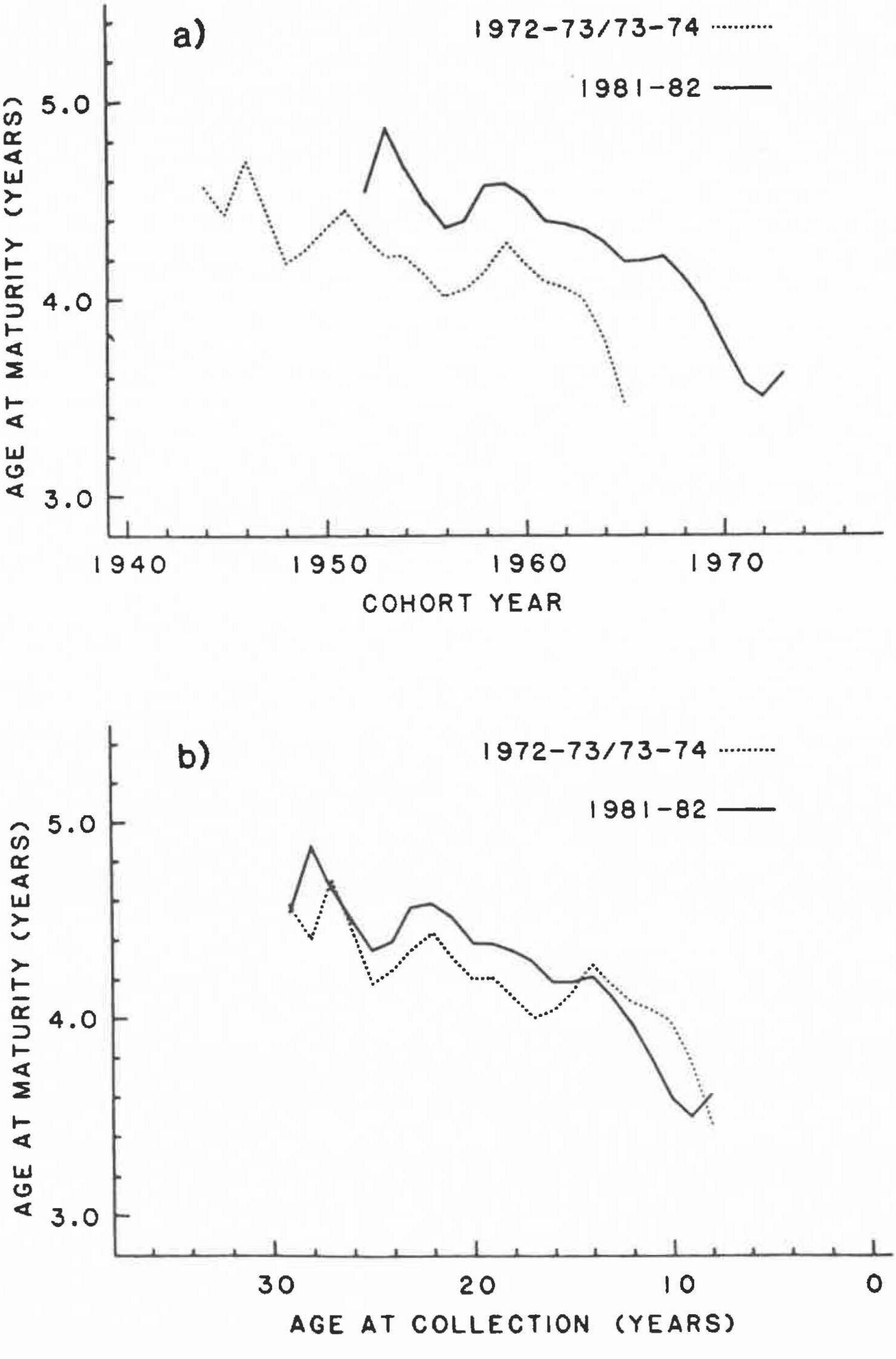


Fig. 9. (a) Mean values of age at maturity in relation to cohort year (year of birth). Sample sizes for the two collections shown are 1972-73/73-74 = 358, 1981-82 = 341. (b) Mean values of age at maturity in relation to age of seals at time of collection (year of death). Sample sizes are the same as in (a). (From Bengtson and Laws, 1984).



Population Size

The rapid rate of population growth in Antarctic fur seals may be due, in part, to an increased availability of krill (Laws, 1977a, 1977b; Payne, 1977). However, it is difficult to separate the effects of potentially increased krill availability and the recovery of fur seal populations from over-exploitation in the early 1800's. It is clear that fur seal populations have been increasing rapidly and that this increase occurred during the same time as decreasing whale stocks. But, similar to the correlated increase in crabeater seal age at maturity and whaling activity, cause/effect relationships cannot be proven without carefully controlled experiments.

Whales

The baleen whales have received considerable attention relative to the changes in their reproductive rates theoretically expected to have resulted from commercial whaling.

Pregnancy Rates

Mackintosh (1942) was the first to suggest that pregnancy rates of female baleen whales in the southern hemisphere were increasing. His figures showed pregnancy in blue whales increasing from about 48% in the 1925 -1931 period to about 66% during the 1932 - 1941 period. He also observed an increase in fin whale (Balaenoptera physalus) pregnancy rates from 65% to 80% during the same period. A similar result was found by Laws (1961) who calculated a rise in fin whale pregnancy from 46% to 76% between the years 1925 and 1930. Later analyses by Gambell (1973, 1975, 1976) suggested increases in pregnancy rates for southern hemisphere baleen whales.

Although these studies have been widely cited as illustrating density dependent responses to competition for food, more recent analyses have challenged their conclusions. Some evidence exists to indicate that the calculated trends in pregnancy rates may not reflect population trends (Mizroch, 1980, 1981a, 1981b). Mizroch (1983) further argued that the observed increases in pregnancy rates could be explained on the basis of analysis techniques--pooling data across months may have led to errors in interpretation. Furthermore, despite the large sample sizes available for analyses, the high variability in pregnancy rates may have masked any trend present in the true population pregnancy rate. Mizroch concluded that although pregnancy rates may have changed during the period of heavy whale exploitation, available data cannot be used to corroborate this possibility because of the high natural variability in pregnancy rates.

Age at Sexual Maturity

Age at the attainment of sexual maturity is another indicator parameter that has been examined in southern baleen whales. On the basis of several analyses, including transition phase in ear plugs, counts of *corpora albacantia*, and percent of mature individuals within age classes, a decline in the age at maturity has been suggested for several baleen whale species (Lockyer, 1972, 1974; Masaki, 1979). These authors suggested that the age of maturity in fin, sei, and minke whales had declined since the start of heavy exploitation of whales. Both Gambell (1973) and Masaki (1977) found evidence of large increases in pregnancy rates and decreases in age at sexual maturity in sei whales. Kato (1983) evaluated the trends in the age at sexual maturity of minke whales using all three of these methods. He found a decrease in age at maturity, which he attributed to reduced competition with harvested whales and a higher availability of krill. As supporting evidence for this trend, he cited increases in Antarctic fur seal populations and a decrease in age of maturity in crabeater seals (Fig. 10).

Just as some recent studies have re-evaluated pregnancy rates, so has recent work suggested alternative explanations for observed decreases in age at sexual maturity (e.g., Cooke and de la Mare, 1983). These analyses indicated that observed trends could be explained by biases in interpreting the ear plug transition phase data. Reader error in estimating the location of the transition phase, as well as a truncation effect caused by a sampling problem of harvested whales, could produce false trends.

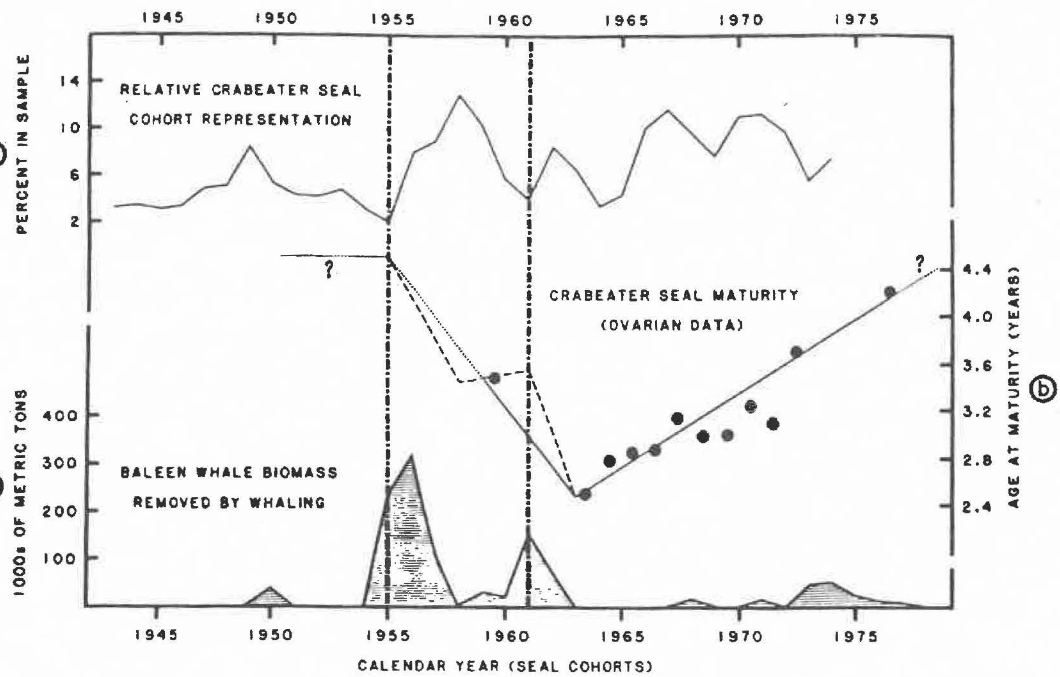
Hence, although a body of opinion supports the idea that pregnancy rates and age at sexual maturity in whales changed in response to declining whale stocks and reduced competition for krill, equally viable alternate opinions exist. The controversy as to whether observed trends reflect true population conditions or artifacts of sampling, analysis, and interpretation is a relatively new one and is as yet unresolved.

Seabirds

Population Size

Whereas some authors (Prevost, 1981) doubt that seabird populations have increased in response to reduction in whale numbers, others assert that penguin populations have increased (Rankin, 1951; Sladen, 1964). Conroy and White (1973) and Conroy (1975) presented information which suggested that populations of king, macaroni, Adelie,

Fig. 10. (a) Relative representation of seal cohorts. This curve was calculated in the following manner: 1) a subsample of each of the 13 yearly samples was selected. Only those seals 7 - 21 years old at the time of collection were included, 2) the age distribution of each of these subsamples was plotted independently against cohort year. The x-axis was the percent of the subsample that was born in any given year, 3) a composite graph of all 13 plots was made, with the separate plots overlapping cohort years included in their particular subsample, and 4) the mean value of the independent values for each cohort year was calculated and plotted as shown. (b) Age at maturity as estimated from ovarian material (earliest value estimated from the 1964-65 Norwegian sample (Øritsland, 1970)). Mean values for 2 - 7 year olds from each collection year are plotted by mean cohort year (4.5 years prior to collection year). Dotted line shows presumed trend of maturity, and dashed line shows alternative trend of decline. All lines fitted by eye. (c) Baleen whale biomass removed from Area I annually. Assumes the following average body sizes (metric tons): blue, 88; fin, 50; humpback, 27; sei, 18.5; and minke, 7. (From Bengtson and Laws, 1984).



chinstrap, and gentoo penguins had increased in the Scotia Arc region during the period of commercial whaling. During a similar period, Caughley (1960), Taylor (1962), and Ainley et al. (1983) observed no evidence of increased penguin populations in an area that lacked intensive commercial whaling. Furthermore, these studies detected no apparent change in penguin populations relative to a supposed increase in minke whale populations in the Ross Sea sector. These contrasting trends suggest that if penguins responded to greater food availability, it was only in limited areas in the vicinity of the the southern Scotia Sea. These correlations, however, are based on relatively poor census information for penguins and do not conclusively demonstrate any cause/effect relationship between prey availability and population size.

Reproduction

No studies of Antarctic seabirds are known that have attempted to relate changes in reproductive parameters to changing abundance of prey stocks. There are, however, examples of studies within other ecosystems which demonstrate the utility of using seabirds to monitor fishing perturbations and prey availability. For example, studies off the South African coast (Crawford and Shelton, 1978) examined the interaction between jackass penguins (*Spheniscus demersus*) and fish harvests. In those studies, changes of various penguin parameters foreshadowed changes within fishery stocks. Changes in avian indicator parameters were evident before it was apparent to fishermen that their fish stocks were becoming depleted.

Similar interactions between fish stocks and predators have been investigated in the Pacific Ocean, in the Peru and California Current system (Murphy, 1966; Schaefer, 1970; Ainley and Lewis, 1974; Daan, 1980; MacCall, 1980, in press). These studies addressed the interactions and dominance of anchovies and sardines and the impact that their relative availability has on seabird populations. Anderson et al. (1980) demonstrated how brown pelican (*Pelicanus occidentalis californicus*) reproduction, particularly fledging rates, can serve as an indicator to anchovy stocks and commercial anchovy fisheries (Fig. 11). There appeared to be a strong relationship between the amount of anchovies harvested by commercial fishing and the fledging success of pelicans. Similarly, MacCall et al. (1983) presented information on the relationship between anchovy spawning biomass and its effect on relative pelican productivity (the number of young fledged per pair per year) (Fig. 12). Finally, a 14 year time series of data currently being analyzed on the reproductive success, fledging weights, predation effort, and diet composition for 7 seabird species on the Farallon Islands, California, confirms interrelationships of variation in these factors and indicates their utility for monitoring

Fig. 11. (A) Anchovy catches (open circles) during the pelican breeding season (February through May only) superimposed on the various anchovy catch quotas (bar graphs) from 1971 through 1979. This does not represent the entire catch (see PFMC 1978 for those data). Catch and quota data are expressed as tons x 10^3. Pelican reproductive rates (=F=young fledged per nest attempt) at Anacapa and Coronado Norte Islands combined (closed circles). The 1979 bar graph represents the start of a new quota system for the harvest of anchovies, and the hatched portions of the 1979 and 1980 quotas represent a more conservative option for harvest under the same Anchovy Management Plan (PFMC 1978; Radovich and MacCall 1979; MacCall 1980). (B) The 1979 increase in pelican productivity was due to locally abundant concentrations of 1978 year-class anchovies near the breeding colonies (Gress et al. 1980). Southern zone (SCB) quota data are from Kaneen (1977), PFMC (1978), Stauffer and Parker (1980) and Stauffer (1980). Under the new system, only U.S. quotas are shown, and they comprise about 70% of calculated optimum yield (Stauffer 1980). A fall catch for 1979 of 5,810 tons was the lowest in recent years (K.F.M.). (C) Anchovy reduction catch (fishing activities) versus pelican productivity (fledging rate) in the Southern California Bight from 1971 through 1979. See text and Anderson et al. (in preparation) for explanation of anomalous conditions in 1973 (1972-73 breeding season). (From Anderson et al., 1980).

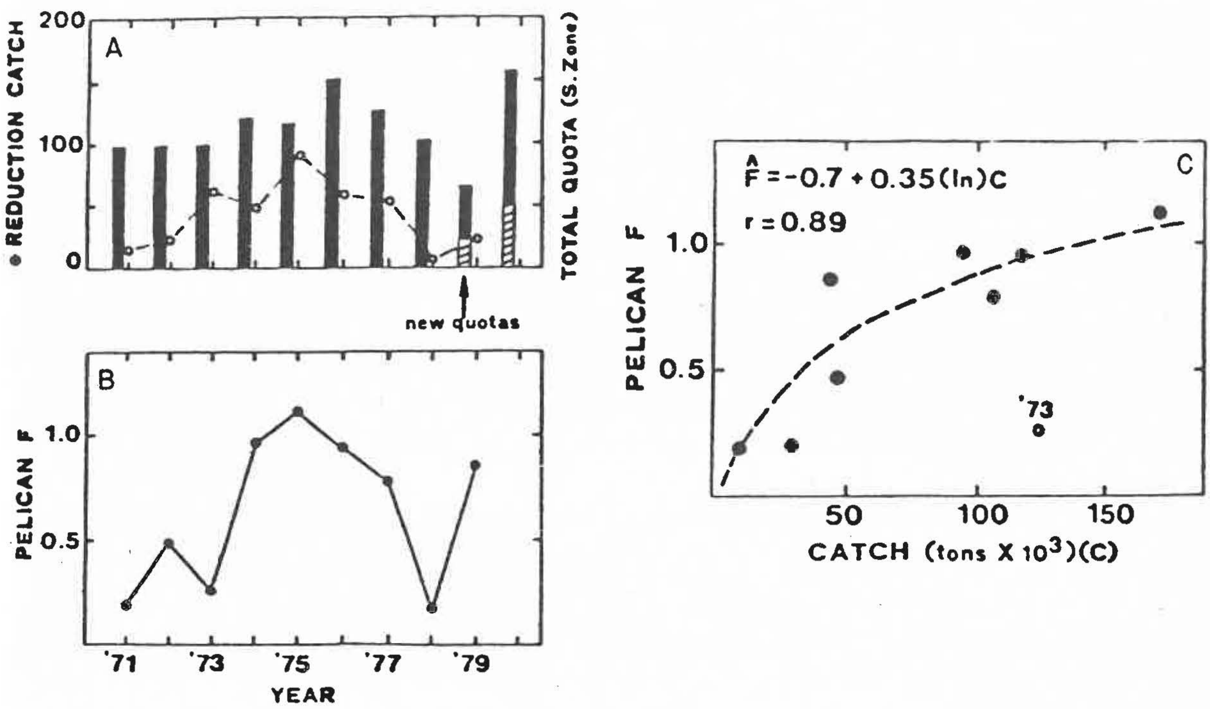
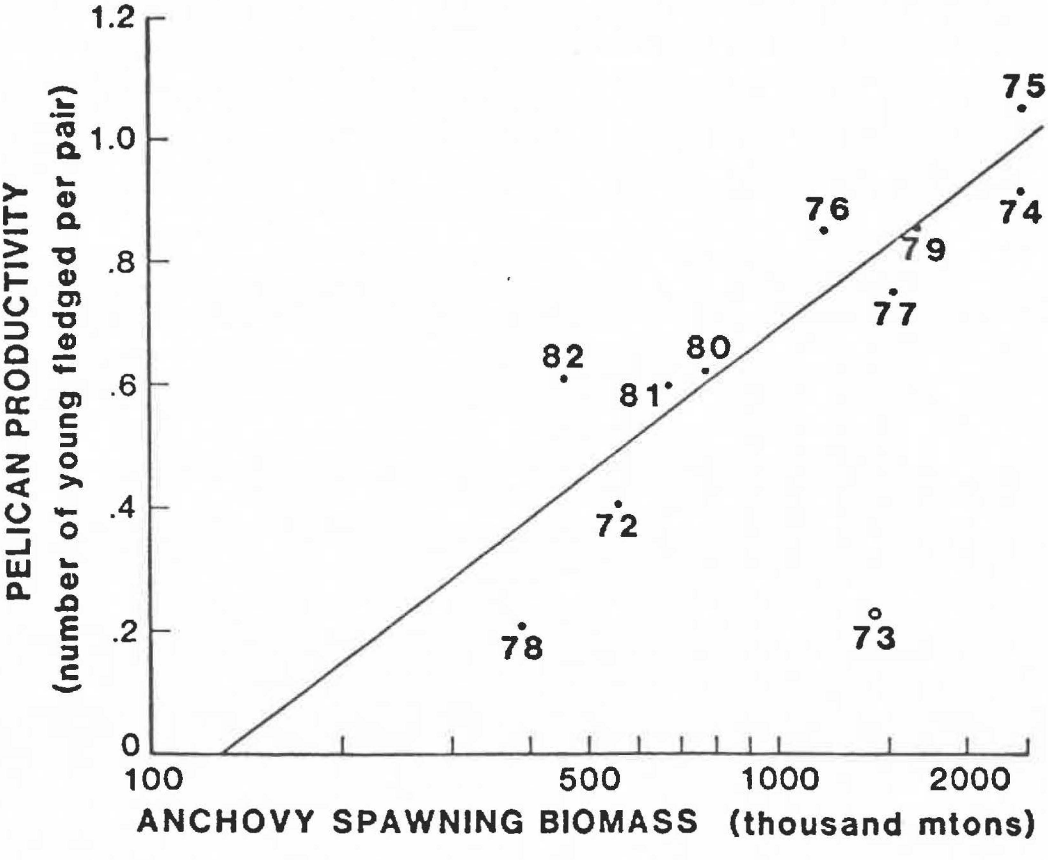


Fig. 12. Relation between brown pelican productivity (Anderson et al., 1980; Anderson, Gress and Mais, 1982) and anchovy spawning biomass. The 1981 and 1982 productivity values are unpublished data from Anderson and Gress (UC Davis). The 1973 value is biased and is excluded from the regression for reasons described in Anderson et al. (1980). (From MacCall et al., 1983).



prey availability (Ainley, unpublished data). These studies as well as others (MacCall, in press) illustrate the potential usefulness of seabirds in Antarctic waters for detecting and assessing impacts of fisheries.

Section Three: DESIGNING MONITORING PROGRAMS

DETECTING CHANGES IN THE ECOSYSTEM

The assessment of potential impacts on the marine community by various harvest regimes can be approached in at least three different ways:

1) Assessing target species directly
2) Evaluating target competitors and by-catch species
3) Monitoring predators

Monitoring all species and variables in all of these areas would be unrealistically expensive and logistically difficult. Yet complementary measurements in all three would be helpful in evaluating harvest impact and ecosystem status. Therefore, future monitoring programs should focus on selected variables that appear most promising within each category.

Target Species

The data required to monitor target stocks of krill and fish include attempts to estimate stock size and fishing effort. Characteristics such as age class and reproductive condition of krill caught might also be considered if suitable techniques can be developed. Relatively detailed information on the size and location of catches will be crucial for detecting potential perturbations through monitoring programs.

Gulland (1983) discussed the challenges involved in directly estimating krill abundance and evaluating changes which occur in response to harvest. The patchy distribution of krill swarms, plus the uncertainty of how much krill is present outside of swarms makes it difficult to interpret the relationship between catch and effort data. Data reported on the catch per haul or catch per hour of fishing effort can provide an index of swarm density, but incorporating these data into estimates of standing stock in wide areas will require measures of time spent searching for swarms and swarm size. Even if some of these difficulties are overcome, Gulland (1983) feels that this method may be inadequate to provide evidence on potential impacts of the fishery. To support this idea, he recalled that the reporting of statistics from other fisheries has been incomplete. Even if all data were available, satisfactory monitoring of stock abundance would not necessarily be assured. He noted that fishery catch statistics for krill may reflect processing capacity and temporary abundance at fishing sites rather than regional population densities and standing stocks. These arguments further support the need for assessing the relative status of krill stocks indirectly by monitoring selected parameters of krill predators.

Target Competitors and By-Catch Species

Competitors of krill include other herbivores such as salps, copepods, or juvenile fish. If the abundance of krill were changed by fisheries pressure, these competitors might manifest compensatory responses resulting from altered competition. Although it is unlikely that by-catch information will be useful for monitoring in early stages of the krill fishery, it is important that such data are recorded. Both the composition and relative abundance of by-catch species would provide an important reference point should changes in relative species abundance occur. Monitoring by-catch species will help evaluate whether non-target zooplankton manifest responses to krill fishing pressure (e.g., competitive replacement).

Predators

Fluctuations in food availability may be reflected in responses by primary and secondary predators of krill. For many species, variables such as growth, reproduction, and behavior are flexible parameters that change in response to density-dependent factors (e.g., prey availability). The variety of life history strategies present among some pinniped and seabird species (e.g., specialist v.s. generalist feeders) allows interspecies comparisons to be made and comparative studies to be undertaken. As discussed below, some seals and penguins in the Antarctic food web seem to be best suited for indicator species.

SELECTING INDICATOR SPECIES

General Concepts

Green-Hammond et al. (1983) discussed the criteria for selecting optimal indicator characteristics to indirectly detect changes in the availability of Antarctic krill. They noted that "ideal" indicator species or populations should:

1) be predators, prey or competitors of Antarctic krill
2) occur in areas where krill are found and are being harvested
3) be sensitive to changes in krill availability, but

relatively insensitive to natural fluctuations in physical environmental conditions

4) have perturbation response times that are relatively short
5) have variables which can be measured relatively simply and inexpensively at accessible locations

The natural variance of an indicator variable (within a population and between seasons), as well as the sampling variance, should be low or precisely quantifiable. Variation will affect the sample sizes and frequencies required in a monitoring program. It is likely that for most variables, large samples will be required in order to detect relatively small changes in populations.

In addition to the work by Green-Hammond et al. (1983), the BIOMASS Working Party on Bird Ecology (1983a) and the SCAR Group of Specialists on Seals (1983b) also considered the question of indicator characteristics. These groups, identified feeding effort, growth, and reproductive success as variables well-suited for monitoring purposes. They considered parameters such as population counts to be less useful due to the substantial logistic difficulties involved in making such counts. Furthermore, total population size is likely to be less sensitive, with longer lag times, than behavioral or reproductive variables (Eberhardt and Siniff, 1977). To be useful for management decisions, timely data must be available on parameters' recent responses in order to detect potential changes in ecosystem status.

Of the three areas of potential assessment, the best indicator species to provide indirect evidence of changes in ecosystem trends appear to be krill predators. Hence, the remainder of this paper will focus on predators, particularly seabirds and pinnipeds.

Krill Predators

Fish

Studies on fish might be considered for inclusion in future coordinated monitoring programs. Commercial finfish fisheries should provide opportunities to obtain biological samples and data available from areas inside and outside of krill fishing zones. Moreover, fish have been useful in monitoring studies elsewhere (Hocutt and Stauffer, 1980). Biological parameters such as reproductive rates, growth rates and population size appear compensatory to density dependent effects (Goodyear, 1980). For example, Lett and Kohler (1976) observed a lowered age at maturity in Atlantic herring (*Clupea harangus*) in the Gulf of St. Lawrence in those cohorts which were less abundant and faster growing. Similarly, Shuter and Koonz (1977) reported a lower age of maturity under similar conditions with walleye (*Stizostedion vitreum*) in Lake Erie. It is likely, however, that before Antarctic fish can be used as indicator species, more information on their basic ecology is needed. To put potential changes of fish populations in a useful management context, additional data on natural history, distribution, and species' ecological role will be required.

Cephalopods

Limited knowledge on Antarctic squids makes them, at present, an inappropriate group around which to develop a monitoring program. Furthermore, squids are logistically difficult to work with, being hard to catch with nets or jigs. Therefore, despite their presumed abundance and consequent importance in the Antarctic marine ecosystem, further basic ecological work must be undertaken before squid should be used as indicator species in a monitoring program.

Whales

Whales are another group that appears unsuitable for inclusion in monitoring studies. This unsuitability is due to:

1) low whale population levels
2) the logistic difficulty and expense of working with whales
3) the reduction in biological material available for study (if the proposed moritorium on whaling begins as expected, in 1985)

In addition, the present controversies over measurement and detection of possible trends in whale reproductive and growth parameters in response to past perturbations in the ecosystem cast doubt on how reliable whales are as optimal indicator species. Hence, for the foreseeable future, whales should not be considered as indicators to assess potential impacts of fisheries.

Seabirds

Seabirds appear to offer good opportunities for monitoring local abundance of prey and status of the marine community. The suitability of Antarctic seabirds as potential indicator species in monitoring programs has been addressed in several reports (SCAR/SCOR, 1979, 1980, 1982a, 1982b, 1983a; Green-Hammond et al., 1983). The BIOMASS Working Party on Bird Ecology in 1983 responded to a set of six questions submitted by the CCAMLR Scientific Committee addressing the suitability of seabirds in monitoring programs (Appendix 2). The Working Party also outlined current seabird monitoring studies (Appendix 3) and recommended specific priorities for future work (Appendix 4).

These documents describe objectives, species, sites and general principles of possible monitoring programs as well as outlining recommended methods and techniques for using seabirds as indicator species in an ecosystem monitoring program.

Several criteria must be considered in selecting bird species for monitoring studies. Species must feed primarily on krill, be located at reasonably accessible sites and possess flexible characteristics that change with fluctuating prey abundance. To allow controlled experiments, deliniating cause/effect relationships with fisheries activities, species should be present at sites both inside and outside areas being fished for krill.

Penguins fulfill these requirements well and are desirable as indicator species for several reasons. First, because penguins are flightless, their geographic range is limited, especially during the breeding season. Hence, changes in various penguin parameters during the breeding season are more likely to reflect localized perturbations. Second, the high energetic costs of swimming are likely to have a greater, more observable effect on penguins if food supplies become limited locally. If prey abundance declines in one area, flighted seabirds can more readily exploit food stocks elsewhere. Penguins, which have a higher energetic cost in searching for food, are both restricted to a smaller foraging range and are more subject to stress due to local prey depletion. Because of a lack of data on the winter distribution and feeding habits of penguins, it is not yet possible to predict changes in variables related to winter prey availability. Third, penguins are accessible and easy to handle. This aspect is especially important if some types of automated equipment are to be implemented. Fourth, penguins represent the dominant group of avian biomass in the Southern Ocean, and therefore are principal competitors for krill and other prey within the community.

Although penguins appear best suited for the initial focus of seabird monitoring programs, other avain species such as wandering albatrosses (Diomedea exulans) may be useful in certain special situations as indicator species. These birds feed primarily on squid, but may reflect indirect system perturbations caused by commercial fisheries. Albatrosses, however, and especially the wandering albatross, possess an extremely conservative reproductive strategy, and thus, are probably less likely to manifest a range of responses to changes in the ecosystem than penguins. The potential use of albatrosses and other flighted seabirds to complement penguin monitoring programs is further discussed in the BIOMASS reports cited earlier.

Pinnipeds

The feasibility of using pinnipeds to monitor the relative availability of krill in the marine community was recently reviewed by the SCAR Group of Specialists on Seals. The Group also considered and responded to a set of six questions from the CCAMLR Scientific Committee regarding the utility of seals in monitoring programs (Appendix 5). The following paragraphs rely heavily on the report of their September, 1983, meeting (SCAR/SCOR, 1983b).

Antarctic pinnipeds all depend, directly or indirectly, on the availability of krill. Crabeater seals feed nearly exclusively on krill, while leopard seals (Hydrurga leptonyx) may feed on this species mainly during the winter. Weddell (Leptonychotes weddelli), Ross (Ommatophoca rossi), and elephant seals (Mirounga leonina) do not use krill directly, but likely feed on species of cephalopods or fish that in turn depend on krill. The Antarctic fur seals are also greatly dependent on krill, particularly the females during the period of lactation. Therefore, certain parameters in the life history of seals will be influenced if krill harvests change the relative availability of krill in the ecosystem.

Two species particularly well suited for monitoring programs are crabeater seals and Antarctic fur seals. Crabeater seals are specialist predators of krill, alone accounting for approximately twice the krill consumption of either penguins or whales (Laws, 1977a). Therefore, changes in krill abundance should be reflected in the species' biological and demographic parameters. Moreoever, because this species has a population estimated at between 15 - 30 million individuals (Gilbert and Erickson, 1977), sacrifice for specimen material is not likely to significantly affect the population.

Because Antarctic fur seal populations in some areas are at relatively low levels, still recovering from previous exploitation, sacrifice and collection of specimen material at some sites would be innappropriate. Behavioral characteristics of this species, however, may be valuable as indicies of local krill availability.

Due to fur seals' limited distribution and breeding sites, however, it is essential that crabeater seals be monitored in the pack ice. Because crabeater seals are circumpolar in distribution, it would be possible to sample them both in and out of krill fishing areas. It is important that additional research on the pack ice seals' movements, food habits, and general ecology be undertaken to put results from monitoring studies in a meaningful context.

SEABIRD AND PINNIPED INDICATOR PARAMETERS

Seabirds

Parameters that may be useful to assess winter food availability include:

1) arrival weight of breeding adults
2) breeding population sizes on the rookery
3) overwinter survival (percentage of adults returning from the previous year)
4) fecundity (percentage of marked, breeding adults that also bred in the previous year)

Of these, the arrival weight and overwinter survival rate would be relatively easy to measure.

Using these parameters to assess winter food availability would be complicated by physical factors that vary from year to year. For example, pack ice fluctuations may affect the arrival weight of breeders. In heavy ice years, arriving adults must walk further to colony areas and therefore will arrive relatively thinner. Because these events would be independent of winter prey availability, it is essential that information on annual weather and ice conditions be included in any monitoring program. It is also necessary that a series of years, rather than "spot checks" at irregular intervals be incorporated into research plans.

Potential indicators of summer food availability include:

1) the length of time spent on incubation shifts (particularly the length of the first male shift)
2) breeding success
3) composition of the diet
4) meal size obtained for chicks
5) frequency and duration of adult foraging trips to sea
6) chick fledging weights
7) adult weights at fledging time
8) adult weights before and after molt periods

Of these variables, three would be relatively easy to measure by automatic recording equipment: frequency and duration of feeding trips, chick fledging weights, and adult weights at fledging time.

Population counts of penguins have not been recommended as a priority parameter for monitoring studies for several reasons. The high variance that can be associated with these counts and the logistic difficulties of consistently censusing large colonies discourage their use. The timing of counts from year to year is also critical. One or two weeks difference in the time of counts will account for large differences in the number of individuals present on the colony. Moreover, because of the logistic and manpower constraints of placing personnel at multiple sites at the appropriate timing each year, counts are not as feasible as other monitoring methods.

The length of time between perturbations and a detected response is crucial. It seems likely that local changes in prey availability would be more quickly reflected in parameters such as individual growth, feeding patterns, and reproduction than in population size. Changes in overall population size may take years to become evident. Variables with quicker response times will provide data more useful to year-to-year management decisions; population counts may be valuable to assess long term (decades) trends.

Pinnipeds

Past collections of crabeater seals have provided valuable data on ecosystem changes and should be continued. The following 4 types of samples can provide useful data on the variables listed:

Teeth:	age determination relative cohort strength
Reproductive tracts:	pregnancy rates age at maturity
Stomach contents:	comparison with krill caught by nets monitor changes in food item prey composition
Body measurements:	length/age relationship growth rates blubber thickness/food availability

Age at sexual maturity and annual reproductive rates have been correlated with resource availability (Laws, 1977a; Bengtson and Siniff, 1981; Bengtson and Laws, 1984). These two parameters appear to hold the most promise for monitoring studies in the near future. Efforts should be made to incorporate other variables into pinniped monitoring programs as well.

Shifts in age structures may reflect changes in resource availability. It appears from reported age structures of crabeater seal populations that pulses of high annual reproductive success are reflected in strong year classes (Bengtson and Laws, 1984; Laws and Baird, unpublished). Correlations of the troughs in recruitment with fishery catches by area may be a useful long-term monitoring device.

Feeding patterns of seals are likely to be sensitive to krill abundance and distribution. Duration and frequency of feeding bouts could serve as indices of krill availability, and could be easily monitored by telemetry or by tag-resighting methods. Recent work at Bird Island, South Georgia, has indicated that the amount of time that lactating females spend feeding at sea may be related to the relative abundance of their primary food, krill (Doidge et al., 1983). Approximately 5 to 7 days post-partum, female fur seals depart to sea to feed and replenish energy reserves before returning to suckle their pups. Over the next 4 months, females may make as many as 20 feeding trips prior to weaning their pups. Their movements and behavior during this time can be monitored easily by telemetry with techniques recently implemented on fur seals at Bird Island (Bengtson and Schneider, 1983). Additional studies have explored the potential value of using feeding behavior, nutrition-related fine tooth structure, and growth rates as indices of krill availability (Bengtson, unpublished data).

Crabeater seal feeding cycles are likely to be sensitive to changes in krill abundance because of this seal's specialist life style. However, very little is known about their feeding patterns. The use of standard monitoring equipment has been hampered by the uncertainty of recapture and the lack of dedicated ship support. Dedicated ship support and the development of satellite-linked transmitters are essential for such studies.

During the period of lactation, Antarctic phocid pinnipeds all probably undergo considerable weight loss. It seems likely that analyses of rate of weight gain after the lactation period would reflect environmental conditions and be correlated with local food availability. Use of hydroxy proline/creatinine ratios in urine has been shown to be an accurate reflection of instantaneous growth rate in some mammals (McCullagh, 1969) and might be applicable in seal studies. At present, though, no work of this nature has yet been carried out on marine mammals.

PROGRAM DESIGN

Sampling

Frequency of sampling required for different species and indicator parameters cannot yet be adequately determined. There are insufficient data on parameter variances to design sampling schemes or experiments to measure possible effects from fisheries (see SCAR/SCOR 1983a, 1983b; Green Hammond et al., 1983). Therefore, annual sampling must be initiated for several years in order to assess the natural variation prior to designing long-term studies. Replicate, comparable data baselines should be collected throughout the areas of focus as soon as possible.

Sites

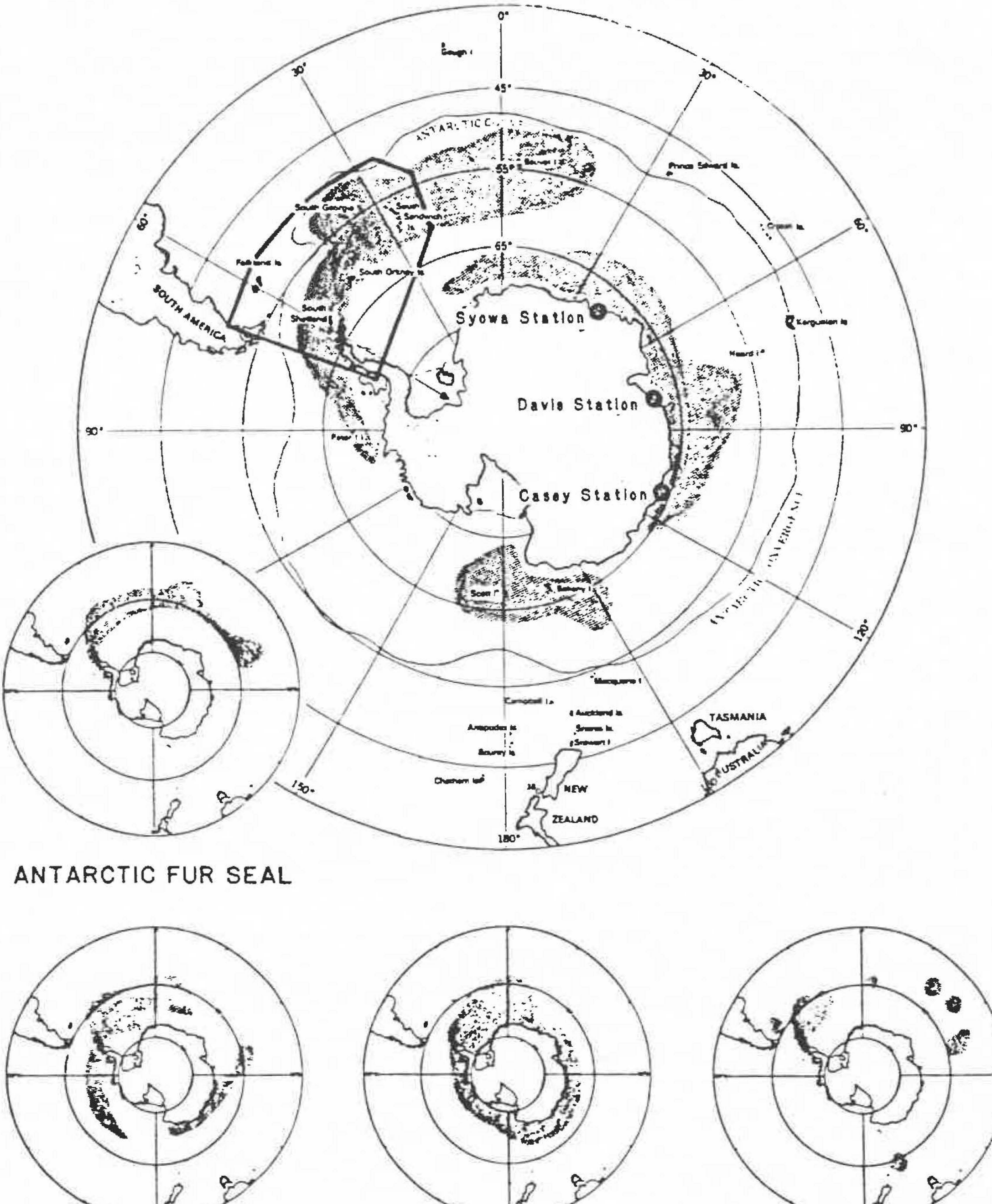
The importance of multiple study sites for monitoring programs has been stressed by several authors (Green Hammond et al., 1983; SCAR/SCOR, 1983a, 1983b). In order to experimentally control for the effects of fishing, circumpolar sampling sites in pack ice and on-shore should be selected both inside and outside of areas heavily fished for krill or finfish. Studies also need to be undertaken both in and out of the breeding seasons of respective indicator species.

Because the boundaries of CCAMLR encompass a very large area it would be desirable to limit initial efforts for a monitoring network and controlled experiments to well defined areas. Establishing land-based monitoring sites and performing pack ice sampling programs in a relatively restricted area such as a portion of the Scotia Arc would be preferable.

Figure 13 shows the distribution of krill and selected indicator predators. Crabeater seals, not shown on the figure, have a circumpolar distribution in the pack ice. Shore-based monitoring sites would support studies of fur seals and Adelie, chinstrap and macaroni penguins. The three continental sites (Fig. 13) were recommended for monitoring Adelie and chinstrap penguins in eastern Antarctica. For the vicinity of the Antarctic Peninsula, a series of sites along the Scotia Arc would be desirable (Fig. 14, Table 6). Pack ice sampling of crabeater seals could be undertaken at several sites around the Antarctic continent.

In the early stages of the proposed program, it would probably be most feasible to test techniques and procedures at sites with active programs eg., King George Island

Fig.13 . Location of proposed sites in a shore-based network for ecological monitoring of Antarctic resource exploitation (✪ = recommended site). For detail of sites in Scotia Arc (area inside heavy lines), see Fig. 14. Distribution of major concentrations of Antarctic krill (data from Marr, 1962) is shown on larger map. Distribution of Antarctic fur seals (data from Bonner, 1981), Adelie, chinstrap, and macaroni penguins (from Watson, 1975) are shown on smaller maps.



(U.S./Poland) or Bird Island (U.K.). In later field seasons, consideration should be given to establishing monitoring stations at other sites in the Scotia Arc such as in the South Sandwich Islands or on Elephant Island. If logistically feasible, another site at Bouvet Island would provide a useful comparison.

Experimental Aspects

In designing and implementing monitoring programs, it is important to demonstrate cause/effect relationships. Changes in the trends of index parameters may not necessarily be caused by fisheries, but may instead be related to physical environmental factors. Therefore, adequately controlled experiments must be designed and tested over a long enough series of seasons to indicate the nature and the magnitude of effects that various perturbations have on the system.

After adequate baselines are established, fishing effort should be directed to heavily exploit stocks within portions of the monitoring area. Comparing heavily exploited areas and less exploited areas would significantly increase our understanding of ecological interactions and the degree to which perturbations affect these processes. Coordinated experimental scientific fishing and ecological monitoring could provide a powerful management tool to assess future trends within the Antarctic marine ecosystem.

METHODS AND TECHNOLOGY

Automatic Monitoring Equipment

Because taking equivalent data sets at several study sites simultaneously is essential for the proposed monitoring network, it would be desirable to deploy automatic data collecting systems. The development of automatic monitoring systems would be a highly cost-effective way to accomplish this objective. Monitoring beach attendance of penguins or fur seals could be done by remote recording stations deployed at various sites and retrieved later. Several systems have been used successfully to remotely monitor marine mammal behavior (Siniff and Kuechle, 1974; Bengtson and Schneider, 1983). Improving these systems to allow the unattended operation proposed here could probably be accomplished with reasonable costs.

Feeding trip duration and fledging weights could be measured manually or visually as in previous studies (Ainley

Fig. 14. Detail of Fig. 13 showing location of six suggested shore-based monitoring sites (circled) in the Scotia Arc. Active ecological research programs are present at Bird Island (U.K.), Signy Island (U.K.), King George Island (U.S.A./Poland), and Anvers Island (U.S.A.).

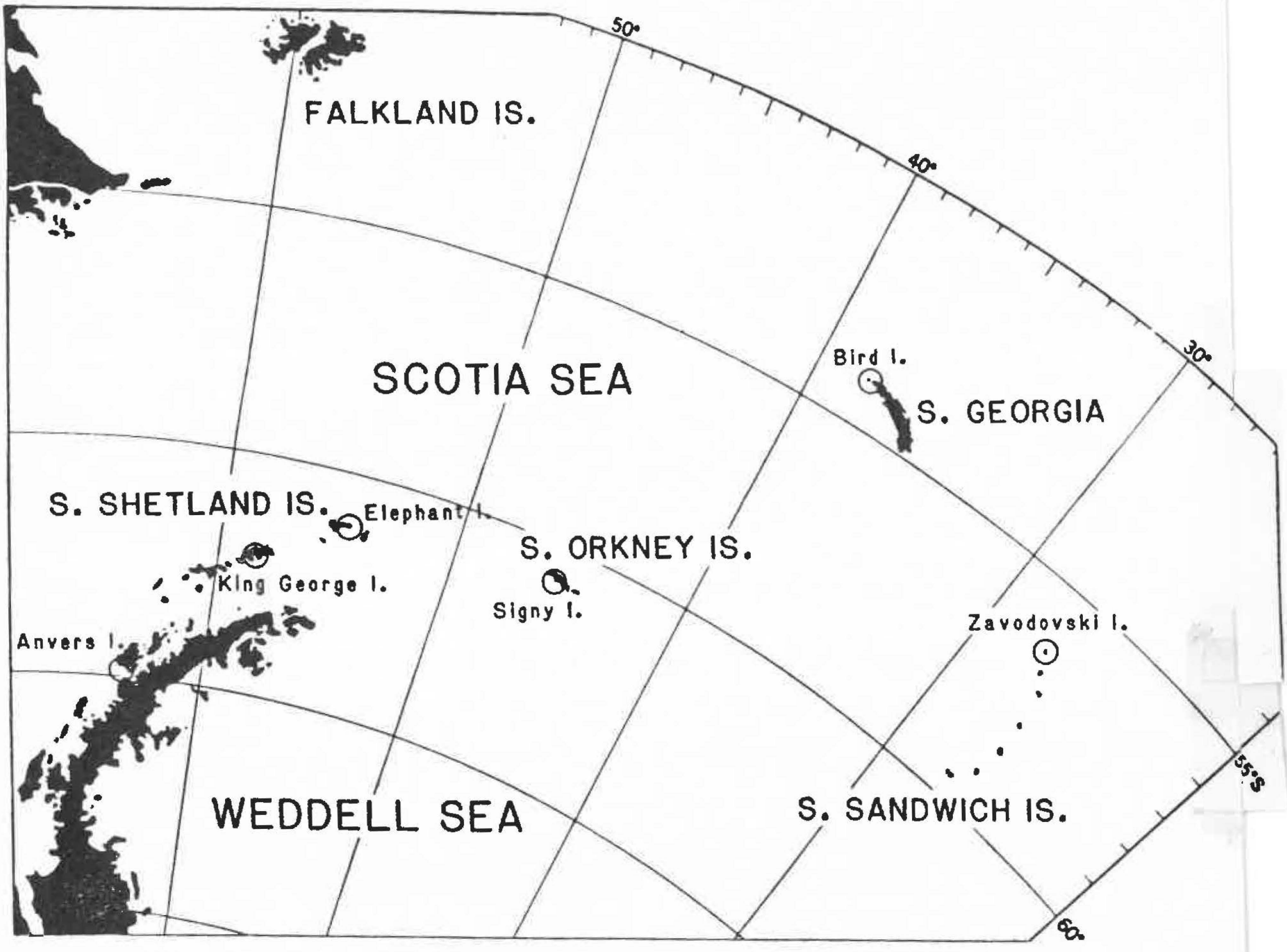


Table 6. Indicator species present at proposed land-based monitoring sites in the Scotia Arc (and at Bouvet Island). Not present (-), small numbers or visitors (*), breeding populations (+).

Locale	Adelie penguin	Chinstrap penguin	Macaroni penguin	Antarctic fur seal
Bird Island	-	*	+	+
Zavodovski Island	+	+	+	+
Signy Island	+	+	+	*
Elephant Island	+	+	-	+
King George Island	+	+	-	+
Anvers Island	+	+	-	-
Bouvet Island	+	+	+	+

and Schlatter, 1972; Volkman and Trivelpiece, 1980). However, larger samples using fewer man-hours could be obtained by attaching radio frequency transmitters to birds and automatically monitoring presence in the colony. Automatic recording stations could monitor several hundred penguins or seals at one site. Such a system has been used successfully with fur seals (Bengtson et al., in prep) and Adelie, chinstrap, macaroni, and gentoo penguins (Trivelpiece et al., in review; Bengtson, unpublished data).

Fledging weights and weights of arriving breeders could be measured manually or automatically. Automatic gates and weighing platforms have been suggested as possible techniques. The development of an automatic weighing system would be of considerable value. However, such equipment would require careful design, testing, and selection of appropriate sites.

Satellite Technology

An increased use of satellite technology would greatly expand the scope of ecological research and monitoring in Antarctica. Although satellite imagery has been utilized for navigational and meteorological purposes, it has not been fully integrated into research programs dealing with Antarctic marine living resources. Three potential areas of application include evaluations of sea ice dynamics, oceanographic patterns, and ecology of krill predators.

The use of passive microwave imagers to obtain data on the extent and distribution of Antarctic sea ice is a valuable technique that has application to marine ecosystem studies. Instruments such as the Electrically Scanning Microwave Radiometer (ESMR) on the former Nimbus-5 satellite provided a clear picture of the seasonal fluctuations of sea ice around the Antarctic continent (Zwally et al., 1983). System-wide assessment and monitoring on the scale outlined by CCAMLR would be greatly enhanced with satellite information. Not only can peculiar hydrographical features be identified from satellite ice images, but year-to-year patterns and variation can be analyzed. Broad-scale data on ice, a highly dynamic physical feature of the marine habitat, will provide an important background against which to compare other ecological data.

Satellite technology could effectively be used to assess large oceanographic patterns such as water temperature or chlorophyll levels. The Nimbus-7 Coastal Zone Color Scanner (CZCS) has been successully used to determine the ocean chlorophyll concentrations at a level of ± 30% in waters relatively clear of sediments (Ocean Color Science Working Group, 1982). These data allowed periodic estimation of primary production for different oceanic areas. The specific objective was to measure algal biomass and primary production in order to detect future changes in productivity caused by regional over-fishing or nutrient run-offs. A second generation CZCS, the Ocean Color Imager (OCI) has been designed to measure primary productivity and nutrient fluxes for fisheries management purposes. This device had been proposed as a part of an experimental oceanographic program called Marine Resources Experiment (MAREX) (Ocean Color Science Working Group, 1982).

A third area of potential satellite applications is the study of krill predators. There is a major need for information on the movements, behavior, and physiology of predators such as whales, seals, and penguins. Data for pelagic and pack ice species can only realistically be obtained by remote telemetry communicating with satellites. In addition to transmitting the geographic position of individuals (as has been successfully implemented on polar bears (Lentfer et al., 1977)), new technology should be integrated to transmit data on feeding (diving) rates and physiological parameters. Obtaining these data would markedly increase our understanding of competition, predation, and the role that predators play in structuring the Antarctic marine ecosystem.

Section Four: CONCLUSIONS

The use of indicator species to indirectly monitor ecological trends in the Antarctic marine ecosystem appears promising. And yet, there is only the barest foundation of information upon which to build a monitoring program. To develop the strong program upon which management decisions can be based, steps must be taken now to begin laying the groundwork for a monitoring network and database. Initial steps should include three points:

1) Consultations among scientists to begin planning and coordinating monitoring efforts
2) Evaluation of baseline data that may be available and initiation of pilot projects to begin the acquisition of baseline data at monitoring sites
3) Begin monitoring studies on selected indicator species

SCIENTIFIC CONSULTATIONS

This paper sought to present ideas and to stimulate discussion relative to monitoring Antarctic marine living resources. At this point it seems desirable to encourage as wide a participation as possible in that discussion to ensure that ideas from diverse quarters are considered. It may be advantageous to have interested scientists from CCAMLR nations meet to discuss the value and format of potential monitoring programs.

For monitoring programs to be optimally successful, they must be coordinated. It seems likely that for the foreseeable future, responsibility for initial monitoring studies may fall within national research programs. The CCAMLR Commission and Scientific Committee can fulfill a critical role by assisting in the coordination of such programs.

BASELINE DATA

Because a principal objective of ecological monitoring is to identify trends, adequate baseline data are essential. Ideally, replicate data for indicator parameters should be available for a series of years or seasons preceding perturbations. These time series would give an indication of natural variation associated with various parameters, and essential part of any monitoring program. Despite the growing interest in using indicator species in Antarctica, there is currently very little baseline information;

moreover, no serial baseline data on recommended indicator parameters are available from sites around the continent.

Some time series data are available from commercial whaling over the past several decades and may represent a type of baseline of past events. However, relative to future monitoring programs, the whale information does not appear to be too helpful (see discussion on previous studies). Limited baseline data for selected parameters are available for crabeater seals. Biological samples taken during 1964 - 1982 by Norwegian, British, and United States investigators in the vicinity of the Antarctic Peninsula provide a baseline for growth and reproductive parameters. There do not appear to be any seabird studies that have suitable time series of data on potential indicator parameters. Clearly, these few examples of baseline data are inadequate for a future comprehensive research and management plan for Antarctic fisheries. Therefore, if indicator species are to be used to indirectly detect krill availability, it is imperative that comparable baselines at multiple sites be established as soon as possible to allow future comparisons.

The length of time required to establish adequate baselines depends on the amount of variation inherent in different parameters and associated with the sampling method. This question as was addressed by the BIOMASS Working Party on Bird Ecology (Appendix 2) and the SCAR Group of Specialists on Seals (Appendix 5). Our limited knowledge of the characteristics of indicator species in Antarctica does not allow estimating how long it is likely to take to establish suitable baselines. Neither do we know enough about specific parameters' variance to be able to state how long it will take to design and prepare coherent experiments. Therefore, the establishment of baselines and the initiation of pilot programs to investigate indicator variables must be a priority.

INITIATION OF SELECTED MONITORING STUDIES

The information discussed and summarized in the preceeding pages indicates that crabeater seals, Antarctic fur seals, and chinstrap and adelie penguins have the greatest potential as possible indicators of second-order effects of krill harvests.

Crabeater Seals

These abundant, pack ice seals are well suited to detecting regional or area-wide changes in krill availability. Past studies investigating their reproductive and growth parameters have provided evidence of responding to ecosystem perturbations caused by commercial whaling. A collection program, carried out at various pack ice sites around the continent, should be implemented to provide specimen material for analysis of aspects of reproduction, growth, and feeding.

Antarctic Fur Seals

This species can provide information on local krill availability near shore-based sites during the pup-rearing season. Particularly promising are studies of feeding trip and pup attendance behavior. Because fur seals do not have a circumpolar distribution south of the Antarctic Convergence, monitoring studies of this species will only be possible in the Scotia Arc region and east to Bouvet Island.

Adelie and Chinstrap Penguins

These species seem to have the greatest probability for responding in detectable ways to localized changes in krill availability. Replicate data sets taken over a series of years at a network of monitoring sites would provide a good basis for assessing relatively small-scale harvest-related perturbations. The deployment of automatic recording equipment and telemetry gear will greatly facilitate efforts to monitor behavior of large numbers of penguins simultaneously.

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Appendix 1. Fisheries tables for Antarctic living resources.

Table	Description
A	Nominal catches by species in Area 48
B	Nominal catches by species in Area 58
C	Nominal catches by species in Area 88
D	Nominal catches of fish, crustaceans, and molluscs by countries or regions in Area 48
E	Nominal catches of fish, crustaceans, and molluscs by countries or regions in Area 58
F	Nominal catches of fish, crustaceans, and molluscs by countries or regions in Area 88

Table A. Nominal catches by species in Area 48 (Southern Atlantic Ocean). Catch totals given in metric tons.

Species	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Micromesistius australis	-	-	-	-	-	-	3	-	-	27	-
Merluccius hubbsi	-	-	-	-	-	-	1682	-	-	-	-
Gadiformes NEI	-	-	-	-	-	-	1	-	-	9	-
Notothenia rossii	11800	-	-	-	-	11400	8320	5143	8662	45382	1504
Notothenia gibberifrons	-	-	-	-	-	5100	3070	15997	13363	10306	8354
Notothenia squamifrons	-	400	400	1600	300	500	5100	468	280	272	621
Notothenia guntheri	-	-	-	-	-	-	-	3004	15011	7381	36758
Nototheniidae	-	-	-	-	-	-	4751	2277	2505	1853	210
Chaenocephalus aceratus	-	-	-	-	-	-	293	154309	4018	3790	1272
Champsocephalus gunneri	5200	2100	-	1000	-	22400	109603	13674	58010	13910	32607
Pseudochaenichthys sp.	-	-	-	-	-	-	1608	-	2100	3122	1661
Chionodraco sp.	-	-	-	-	-	-	-	-	1949	233	-
Chaenodraco wilsoni	-	-	-	-	-	-	-	-	10130	956	-
Channichthyidae	-	-	-	-	-	-	-	-	269	1668	4554
Dissostichus eleginoides	-	-	-	-	-	-	1656	922	331	261	322
Rajiformes	-	-	-	-	-	-	-	8	1	224	120
Marine fishes NEI	600	-	-	1900	-	300	22296	7495	5633	6804	14313
Euphausia superba	-	-	-	21700	38900	521	106794	89923	266534	356978	285117
Squids NEI	-	-	-	-	-	-	1	-	2	-	-
Total	17600	2500	400	26200	39200	40221	265178	293220	388798	453176	387413

Table B. Nominal catches by species in Area 58 (Southern Indian Ocean). Catch totals given in metric tons.

Species	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Notothenia rossii	149700	37400	2500	24100	7800	4300	35255	10997	-	1723	6866
Notothenia squamifrons	26500	51000	3100	29400	6900	5300	20600	12796	1307	15642	9142
Pleuragramma antarcticum	-	-	-	-	-	-	-	234	-	-	-
Champsocephalus gunnari	49900	15700	7200	46100	9900	7400	54208	29135	101	1433	519
Channichthys rhinoceratus	-	-	-	-	-	-	-	82	-	4	-
Dissostichus eleginoides	-	-	-	-	-	-	-	201	3	188	38
Marine fishes NEI	3400	8700	300	2000	400	400	254	1174	1218	239	396
Euphausia superba	-	-	-	643	1081	2266	12383	52844	65431	120047	160069
Total	229500	112800	13100	102243	26081	19666	122700	107463	68060	139276	177030

Table C. Nominal catches by species in Area 88 (Southern Pacific Ocean). Catch totals given in metric tons.

Species	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Trematomus trematomi	-	-	-	-	-	-	-	-	-	-	583
Pleuragramma antarcticum	-	-	-	-	-	-	-	-	-	-	1517
Marine fishes NEI	-	-	-	-	-	-	-	23	200	-	-
Euphausia superba	-	-	-	-	-	-	3355	36	600	-	3080
Squids NEI	-	-	-	-	-	-	-	391	-	-	
Total	-	-	-	-	-	-	3355	450	800	-	5180

Table D. Nominal catches of fish, crustaceans, molluscs by countries or regions in Area 48 (Southern Atlantic Ocean). Catch totals in metric tons.

Country or region	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Bulgaria	500	-	-	-	-	-	-	2088	3408	1225	-
German DM RP	-	-	-	-	-	-	790	10313	4961	9970	8279
Poland	-	-	-	-	-	21	17054	63524	37486	17928	17656
USSR	17100	2500	400	26200	39200	40200	247334	217295	342943	424053	361478
Total	17600	2500	400	26200	39200	40221	265178	293220	388798	453176	387413

1981: this fishing area excludes the waters lying between 55° and 60° south latitude and between 50° and 60° west longitude.

1970-80: this fishing area includes the above mentioned waters.

Table E. Nominal catches of fish, crustaceans, and molluscs by country or region in Area 58 (Southern Indian Ocean). Catch totals in metric tons.

Country or region	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Japan	-	-	-	643	1081	2266	10517	26063	36909	36283	27832
Poland	-	-	-	-	-	-	-	432	-	383	-
USSR	229500	112800	13100	101600	25000	17400	112183	80968	31151	102610	149198
Total	229500	112800	13100	102243	26081	19666	122700	107463	68060	139276	177030

Table F. Nominal catches by country or region of fish, crustaceans, and molluscs in Area 88 (Southern Pacific Ocean). Catch totals in metric tons.

Country or region	1970/71	1971/72	1972/73	1973/74	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Japan	-	-	-	-	-	-	-	391	-	-	-
Poland	-	-	-	-	-	-	-	59	-	-	
USSR	-	-	-	-	-	-	3355	-	800	-	5180
Total	-	-	-	-	-	-	3355	450	800	-	5180

Appendix 2. Response of the BIOMASS Working Party on Bird Ecology to questions submitted by the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources. (SCAR/SCOR, 1983a).

1. What, if any, species or populations of Antarctic birds might function as useful indicators of local, regional, or area-wide changes in the Antarctic marine ecosystem caused by harvest of krill or other populations of Antarctic marine living resources?

The use of seabirds as potential indicators of changes in Antarctic marine resources resulting from commercial harvesting was formally addressed by SCAR in 1978 (SCAR Bulletin No. 60, Polar Record 19: 304-307) when species (penguins and albatrosses) and sites (widely distributed in the Antarctic and sub-Antarctic) were selected according to specified criteria. This initiative was subsequently developed by the BIOMASS Working Party on Bird Ecology which discussed the principles and aims of this approach and appraised some of the basic methods available for use with the selected species (BIOMASS Research Series 8 : 15-21 (1979)). The Working Party reviewed the progress of development of field studies in 1980 (BIOMASS Report Series 18 : 16, Table 2 and numerous tabled papers referenced in Annex 2) and 1982 (BIOMASS Report Series 27 : 2-4, Annexes 2 and 3), when the results of questionnaires, circulated to all scientists and groups involved in current and prospective studies relating to monitoring objectives were published.

These documents all affirm the desirability and potential feasibility of using selected species of Antarctic seabirds to monitor changes in the Southern Ocean ecosystem.

2. What are the factors that should be considered, including the possible use of controlled experiments, in order to determine whether, what, and how selected bird populations might function as indirect indicators of harvest-caused changes in krill or other harvested populations of Antarctic marine living resources?

The Working Party found this question difficult to interpret. It was assumed that the requirement was to assess how evidence of relationships between changes in prey stocks and the predator parameters selected for monitoring might best be obtained:

1) By integrated studies of krill abundance and distribution within the foraging range (both area and depth strata) of breeding populations of penguins, where concurrent monitoring studies are being carried out. Such studies, which should ideally be conducted during the chick-rearing period, will need repeating over several seasons.

2) By assessing the responses of the monitored parameters to programmes of experimental overfishing within the foraging range of breeding penguins.

In conducting such experiments the following criteria are important:

a) adequate baseline data from monitoring studies should already exist at the experimental site(s).

b) The actual fishing operations should be preceded and followed by detailed evaluation of stock levels, demography and distribution. The fishery catch should be similarly analysed in detail.

c) Relevant biological and physical oceanographic parameters should be monitored throughout the whole period surrounding and including the experiment. If possible, comparable sets of data covering several seasons should already be available for the area. Because krill distribution and abundance is intimately related to such phenomena in the absence of such data it may be difficult, if not impossible, to interpret the results.

d) Control sites, in the same general area but outside the influence of the overfishing experiment, should be established at least for the season of the experimental study and, if possible, for several seasons before, so that natural variations between control and experimental colonies may be assessed. Oceanographic data for such areas are also desirable.

3. What is the nature and adequacy of existing population data and what are the types of studies that would be required to establish a suitable basis (baseline) for detecting and monitoring changes and trends in potential indicator species and populations?

The nature and adequacy of existing population data has been discussed in the publications mentioned in the response to question 1. The types of studies potentially suitable for detecting changes in indicator species are discussed in more detail in the response to question 4 below.

Basically there is a fundamental need to maintain long-term studies. It should be recognised, however, that without extensive financial and logistic support, it may be impossible to annually monitor the full range of selected variables. Short-term (3-5 year) periods of intensive study at the appropriate intervals may be a suitable complement to annual, long-term, less intensive studies. Intensive studies will, in any case, be needed in order a) to develop a knowledge of which are the most sensitive parameters to measure, and b) to allow the development of technology appropriate to handling the sample sizes required to give adequate prospect of statistically valid results.

4. What are the types of long-term monitoring studies, including possible study locations and sampling frequencies (periods), that are likely to be most useful for detecting and assessing the possible significance of changes and trends in selected indicator species or populations?

In response to this question there are a number of fundamental points that need consideration.

1) An important and probably critical element of predator-prey relations occurs during winter and thought should be given to assessing the results of interactions during this period as well as the more direct investigation of summer interrelationships.

2) There has been no analysis to determine which are the most sensitive or the most important parameters to measure either in terms of a) comparing variances associated with them, or b) assessing their response to known changes in environmental features. Consequently, selection of parameters must presently be based chiefly on relatively limited experience, educated intuition and, to some extent, judgement of feasibility.

3) While it is useful to record breeding population size and breeding success, variances associated with these are large and detection of change therefore requires extensive data series. Interpretation of the causes of any changes would be difficult, if not impossible, without additional, more detailed, information.

4) Only the use of penguins as indicator species is considered here, and then only those species known to depend largely (in summer at least) on Antarctic krill Euphausia superba. In the sub-Antarctic (and possibly the Antarctic) there are some additional seabirds (e.g. Black-browed Albatrosses) that may also be suitable indicator species and much of what follows would apply equally to them.

Potential indicators of winter food availability

1 Arrival weight
2 Breeding population size
3 Overwinter survival (of marked adults from the previous year)
4 Fecundity (percentage of marked adults that bred last year breeding this)

Potential indicators of summer food availability

1 Length of incubation shifts (especially first male shift)
2 Breeding success (and especially the proportion of desertions during the first male shift)
3 Composition of diet
4 Size of meals delivered to chick(s)
5 Duration of foraging trips to sea
6 Chick weights at fledging
7 Adult weights at time of chick fledging
8 Adult weights before and after moult.

A number of other parameters could have been added to this list but those above are judged to be the most important. The following comments should also be noted:

i) Large samples will be required if there is to be a realistic chance of detecting changes in the relative short-term.

ii) To measure adequately all of the above parameters would require at least two people full-time on site from November-March, plus suitable time and facilities for data and specimen analysis.

iii) The feasibility of such work would be greatly enhanced by the development and deployment of suitable automatic recording equipment.

In particular, the use of weighing platforms (perhaps with guide fences) across the main access route to the colony, coupled with data logging recorders (and perhaps even time-lapse cameras) would greatly improve the quality of monitoring of at least four of the above parameters.

Use of radio transmitters together with automatic recording equipment in the colony is probably the only way to obtain adequate samples of the duration of foraging trips to sea throughout chick rearing.

It should be emphasised that neither of these methodologies has yet been adequately developed or field tested. If experience with other seabirds is any guide then at least two seasons of field trials will be needed. It is obviously desirable to start such work as soon as possible so that detailed monitoring studies may commence without delay.

iv) Changes in the parameters listed above may also be manifest as changes in the structure and dynamics of the study populations. Research on seabird population dynamics is a major undertaking and we have not recommended such studies as part of monitoring operations.

Nevertheless such work is fundamental to understanding the significance of changes in population size and other parameters in terms of their long-term influence on the structure and functioning of populations. We strongly recommend that such research be supported, especially in conjunction with the type of monitoring studies outlined above.

Sites

Ideally there is a requirement for a network of sites, covering areas within and without zones of imminent potential exploitation of krill. However, the type of monitoring operations envisaged above are only feasible at sites where the existing logistic support and facilities are adequate. Bearing these considerations in mind the following sites were recommended:

Adelie penguin : Syowa* (Japan), Pointe Geologie* (France), Davis (Australia), ? Casey (Australia), Palmer Station (USA), Point Thomas, King George Island (USA/Poland), Signy Island (UK). [*Providing E. superba not E. crystallorophias is the main constituent of the crustacean diet.] At least one other continental site and perhaps one in the Elephant Island group would be desirable.

Chinstrap Penguin : Palmer Station (USA), Point Thomas, King George Island (USA/Poland), Signy Island (UK). A site at the South Sandwich Islands would be highly desirable.

Macaroni Penguin : Bird Island, South Georgia (UK). A second possible site might be at Kerguelen.

Frequency of sampling

This will need to be annually initially in order to establish pre-harvesting baselines. Analysis of these data should indicate the extent to which less intensive programmes are feasible and suggest what frequency of repetition is desirable.

Collateral information

1. It is axiomatic that data on krill abundance and availability from the vicinity of monitoring sites would be of the greatest utility.

2. Meteorological data from the study site would also be advantageous and the use of automatic weather stations to collect such information should be considered.

3. Ice cover information, especially during the breeding season but also in winter, is of particular significance, as it is known that ice can be a major influence on penguin breeding success. Relevant satellite imagery in respect of all appropriate sites would be necessary.

Protection of sites

All sites selected for these main monitoring programmes should be gazetted as SSSIs in order to minimise disturbance and interference.

5. What is the possible utility of sighting data or other data that could be collected opportunistically from vessels engaged in fishing or other activities in the Convention Area and, if potentially useful, what are the types of data that should be collected and how should they be recorded and reported to be optimally useful?

There is no prospect at present that such data could serve any useful function either in a monitoring capacity or even as an adjunct to such studies.

6. What is the time that would be required to develop meaningful baselines and to detect different levels of change in selected indicators?

To develop meaningful baseline data at least ten years of long-term low intensity study or five years of high intensity research will be required. However, to obtain valid data for many key parameters, considerable development of techniques is required in order to ensure adequate samples and that measurements are being made in the best way. It is estimated that this would require seasons of field work.

Appendix 3. Current seabird monitoring studies. (SCAR/SCOR, 1982a).

Species	Site	Nation	Start	Frequency	Main count of: Incubation	Main count of: Rearing	Method: Colony	Method: Sample	Breeding Success
Emperor penguin	Kloa	(AUS)	1957	8 in 25 y		X		X	
	Fold Is	(AUS)	1956	13 in 25 y		X		X	
	Taylor Gl	(AUS)	1954	annual		X		X	
	Auster	(AUS)	1957	10 in 25 y	X			X	
	Pte Geologie	(FR)	1952	annual		X	X		X
King penguin	Possession I	(FR)	1980	5 y	X			X (photo)	
	Baie du Marin	(FR)	1980	annual	X		X		X
Adelie penguin	Mawson	(AUS)	1955	c 5 y	X		X		
	Davis	(AUS)	1960	c 5 y	X		X		X
	Casey	(AUS)	1961	9 in 20 y	X		X		
	Palmer base	(US)	c1974	annual	X		X		
	Palmer Islands	(US)	1978	annual	X		X		some
	Pt Thomas	(US/POL)	1977	annual	X		X		X
	Signy I	(UK)	1978	annual	X		X		X
Chinstrap penguin	Pt Thomas	(US/POL)	1977	annual	X		X		X
	Signy I	(UK)	1978	annual	X		X		X
Gentoo penguin	Pt Thomas	(US/POL)	1977	annual	X		X		X
	Signy I	(UK)	1978	annual	X		X		X
	Bird I	(UK)	1976	annual	X		X		X
	Possession I	(FR)	1978	annual	X		X		
Macaroni penguin	Bird I	(UK)	1976	annual	X		X		X
	Possession I	(FR)	1980	5 y	X			X(photo)	
	Marion I	(SA)	1980	annual	X		X		X
Rockhopper penguin	Possession I	(FR)	1980	5 y			X	X	
	Gough I	(SA)	1982	annual planned	X		X		
Wandering albatross	Bird I	(UK)	1970	annual	X		X		X
	Pr Edward	(SA)	1973	5 in 9 y		X	X		
	Marion I	(SA)	1980	annual	X		X		X
	Possession I	(FR)	1966	annual	X		X		
	Macquarie I	(AUS)	1950	annual	X		X		X
	Gough I	(SA)	1979	annual		X	X		some
Black-browed albatross	Bird I	(UK)	1975	annual	X		X		.
	Macquarie I	(AUS)	1974	annual	X		X		X
Grey-headed albatross	Bird I	(UK)	1975	annual	X		X		X
	Macquarie I	(AUS)	1974	annual	X		X		X
Yellow-nosed albatross	Gough I	(SA)	1982	annual planned	X	X	X		X
Sooty albatross	Possession I	(FR)	1980	5 y	X		X		
L M Sooty albatross	Possession I	(FR)	1980	5 y	X		X		
	Macquarie I	(AUS)	1970	annual	X		X		X
Southern giant petrel	Pte Geologie	(FR)	1951	annual	X		X		X
	Bird I	(UK)	1978	5 y	X		X		
	Possession I	(FR)	1980	5 y	X		X		
Northern giant petrel	Bird I	(UK)	1978	5 y	X		X		
	Possession I	(FR)	1980	5 y	X		X		
Antarctic fulmar	Pte Geologie	(FR)	1952	annual	X		X		X
Snow petrel	Pte Geologie	(FR)	1963	annual	X		X		X
	Signy I	(UK)	1976	annual	X		X		X
Cape petrel	Pte Geologie	(FR)	1964	annual	X		X		X
Antarctic prion	Signy I	(UK)	1976	annual	X		X		X
Wilson's storm petrel	Pte Geologie	(FR)	1962	annual	X		X		X
Antarctic skua	Pte Geologie	(FR)	1968	annual	X		X		X
sub-Antarctic skua	Bird I	(UK)	1976	5 y	X				
	Possession I	(FR)	1980	5 y	X		X		

Appendix 4.

SCAR/SCOR/IABO/ACMRR
GROUP OF SPECIALISTS ON
LIVING RESOURCES OF THE SOUTHERN OCEANS

MONITORING STUDIES OF SEABIRDS

BIOMASS Working Party on Bird Ecology

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BIOMASS HANDBOOK NO. 19
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PREFACE

The Working Party on Bird Ecology produced the basis for the information in this Handbook as an Annex to BIOMASS Report No. 8 - Antarctic Bird Biology.

Because of the practical importance of longterm monitoring studies of seabirds to the objectives of BIOMASS, it was thought useful to make information on the current situation more readily and conveniently available.

INTRODUCTION

A fundamental objective of BIOMASS is the development of management plans and strategies designed to promote and ensure rational commercial exploitation of marine living resources (especially krill, but also fish and squid) within the Southern Ocean system. Extensive harvesting of a resource by man will not only affect the status of exploited stocks but must inevitably be at the expense of other consumers.

Because Antarctic fisheries are in their infancy, it is not possible to determine the magnitude of these effects by evaluating catch statistics and fishery data. It is therefore important to determine the present status of populations of selected predator species, and to seek to correlate any subsequent changes in breeding numbers and reproductive performance with changes in abundance of prey stocks and especially those which may arise following the advent of commercial exploitation.

Seabirds are clearly the most convenient and accessible group with which to attempt to do this. Already for most Antarctic and sub-Antarctic penguins it has been possible to demonstrate, at some locations, increases in breeding population size over the last 20-30 years. These changes have been widely interpreted as due to the increased availability of krill to penguins following the large-scale reduction of baleen whale stocks. Had the population changes been smaller or data only available for a shorter period, however, it is doubtful whether most changes would have been noticed. To meet the present requirements it is therefore essential to establish a comprehensive system of detailed monitoring studies on a longterm basis. This also fulfils recommendation 24 of the BIOMASS Group of Specialists' Technical Group on Data, Statistics and Resource Evaluation.

AIMS

1. To establish a series of monitoring studies to provide regular information on breeding population size and aspects of breeding success on a longterm basis.
2. To ensure that these studies are conducted so as to provide prey population status indices which are potentially sensitive to possible changes in resource abundance.

SPECIES AND SITES

At XV SCAR in 1978 the subcommittee on Bird Biology presented an interim list of recommendations for longterm monitoring of selected seabirds at certain localities and specified intervals and requested information on such programmes involving these sites and species. On the basis of the information provided, a revision of current and recommended monitoring sites and species is presented in Table 1.

The criteria on which these recommendations are based are as follows:

(a) Species that are the major component of bird biomass either in the Antarctic zone (Adelie Penguin), sub-Antarctic zone (Royal/Macaroni Penguin) or in a large, but more restricted area (Chinstrap Penguin on the Antarctic Peninsula), and which feed on krill.

(b) Species that are major consumers of squid and hence probably important krill predators at the secondary level (e.g. King Penguin).

(c) Species, with a small world population, which might be particularly vulnerable to prey stock changes (e.g. Wandering Albatross).

(d) Sites at which relevant baseline data are already available or appropriate research being undertaken.

(e) Sites which provide a good geographical change in latitude and longitude and which include those both near and far from areas likely to be subject to extensive exploitation.

It should be noted that there are at present actively monitoring programmes on species not indicated in Table 1, e.g. on Emperor Penguin at Adelieland, Black-browed and Grey-headed Albatrosses at South Georgia.

TABLE 1. Location of populations of indicator species selected for monitoring together with status of monitoring programmes.

Species	Location	Responsible country	Status
Wandering Albatross	Iles Crozet	France	Recommended
	Marion Island	South Africa	Active
	Gough Island	South Africa	Active
	South Georgia	U.K.	Active
	Macquarie Island	Australia	Active
	Campbell and Auckland Islands	New Zealand	Recommended
King Penguin	Iles Crozet	France	Recommended
	Kerguelen	France	Recommended
	Marion Island	South Africa	Active
	South Georgia	U.K.	Active
	Macquarie Island	Australia	Active
Adelie Penguin	Cape Crozier	U.S.A.	Recommended
	Palmer Station area	U.S.A.	Active
	Point Thomas, King George Island, South Shetlands	U.S.A./Poland	Active
	Cape Bird	New Zealand	Recommended
	Signy Island	U.K.	Active
	Harmony Point, Nelson Island, South Shetlands	Chile	Recommended
	Balleny Islands	New Zealand	Recommended
	Mawson and Casey areas	Australia	Recommended
	Enderby Land	Australia, South Africa	Recommended
	Mawson and Casey areas	Australia	Recommended
	Enderby Land	Australia, South Africa	Recommended
	Adelieland	France	Recommended
	Syowa Station	Japan	Active
Royal/ Macaroni Penguin	Bird Island, South Georgia	U.K.	Active
	Macquarie Island	Australia	Active
	Marion Island	South Africa	Initiated
	Ile de la Possession	France	Recommended
	Kerguelen	France	Recommended
Chinstrap Penguin	Dream Island, Antarctic Peninsula	U.S.A.	Active
	Point Thomas, King George Island, South Shetlands	U.S.A./Poland	Active
	Harmony Point, Nelson Island, South Shetlands	Chile	Active
	South Orkney Islands	U.K.	Initiated
	South Georgia	U.K.	Initiated
	Signy Island	U.K.	Active

GENERAL PRINCIPLES

In the present context there are essentially three types of monitoring study that may be undertaken:

(a) **Breeding numbers**

Counts of the number of breeding pairs of a species at a particular site, repeating such counts at a similar date (normally as soon after egg laying as possible) in succeeding seasons.

(b) **Breeding success**

Annual counts of pairs breeding, eggs hatched and chicks fledged.

(c) **Detailed breeding performance**

Periodic weighing of large samples of chicks of known age to determine population mean growth rates, complemented by the collection of data on meal size and feeding frequency.

Type (a) studies represent the minimum requirement for a monitoring programme.

Type (b) studies enable data on breeding performance to be compared with any available information on the status of appropriate prey stocks.

With type (c) studies, the information on feed size, feeding frequency and growth rate forms a potential index of the status of prey stocks. Although this is the most useful type of study, it must be emphasized that it required very careful planning, large samples of birds and extensive field manpower.

It is recommended that:

1. Each type of study should:

   (a) be conducted using separate colonies, or separate areas of large colonies (if the use of suitable photographic techniques is feasible, it may be possible to conduct type (a) and (b) studies at the same colony).

   (b) have appropriate control colonies or areas established to assess the effect of the monitoring disturbance.

2. All studies should be given a regular long-term commitment (at least 20 years).

3. Studies should be established in areas free from other disturbance. Wherever possible, the sites should be clearly marked and access restricted to the monitoring visits. It may be desirable to investigate the possibility that once the monitoring work is established, some sites should be proposed as Sites of Special Scientific Interest. It is also important to consider whether these restrictions on land-based disturbance should be complemented by the establishment at some sites, designed to serve as control experiments, of a ban on fishing for krill within the foraging range of breeding penguins. This topic needs further investigation.

4. Study colonies or areas of large colonies should be selected bearing in mind that:

   (a) breeding success may be influenced by:

      (i) colony size - large colonies tend to have better success;

      (ii) nest position - birds at the centre of colonies have greater success;

   (b) a nearby vantage point may permit photographs to be taken and enlargements used to make counts, thus reducing disturbance to a minimum.

5. Suitable ground-controlled aerial photographic techniques should be developed to minimize monitoring disturbance.

6. As the age of breeding birds also influences reproductive success, studies should ideally be conducted or established at colonies containing a substantial proportion of known-age birds.

7. The quantitative composition of the diet of the species monitored at each site should be determined and data on inter- and intra-season variations obtained. This work should not be carried out in the actual colonies selected for monitoring.

8. Counts should be made on approximately the same data each season, whenever possible.

9. As physical environmental conditions are important variables influencing changes in size or success of a breeding population (e.g. by causing direct mortality in cold weather, or acting indirectly by causing poor feeding conditions, or delaying onset of breeding), attention should be given to keeping a basic record of the principal meteorological phenomena.

10. Interpretation of results is likely to be greatly assisted by conducting monitoring studies on several species in the same general area.

METHODS AND TECHNIQUES

On the basis of information provided on methods and techniques currently being used in monitoring studies on the selected species, the following comments and recommendations are made:

Wandering Albatross

The breeding population of this species has been declining over recent years at Macquarie Island and South Georgia, although there is no evidence that this is related to changes in prey stocks in the vicinity of the breeding sites.

1. Counts of breeding birds should be made as soon after egg-laying as possible (end of January).
2. Counts of chicks hatched should be made in early April.
3. Counts of chicks that will fledge should be made by about mid-November.
4. As the species breeds biennially, if successful, it is:
   (a) important to ensure that counts are made in successive seasons;
   (b) useful to establish what proportion of birds failing in one season breed in the next.

King Penguin

Most breeding populations of this species have increased in recent years, in some cases substantially (e.g. a four-fold increase since 1936 at South Georgia).

1. Current breeding biology information is inadequate to determine the precise nature of breeding periodicity. As breeding is also poorly synchronized, it is impossible at present to obtain sufficiently accurate data to make monitoring studies on an annual basis worthwhile.
2. Mid-March is probably the best time for counts, as at the Indian Ocean islands early breeders are brooding small chicks and late breeders incubating, while at South Georgia there will be a mixture of incubating and brooded adults and also well developed chicks.
3. Aerial photographic census techniques are ideal for this species which breeds on large expanses of level ground, providing adequate ground data can be obtained for

calibration purposes. Flying altitudes of approximately 500 m probably represent the best compromise between minimizing disturbance and maintaining adequate resolution.

Adelie Penguin

This species has increased in numbers in the more northerly parts of its range (e.g. South Orkney Islands) but insufficient evidence is presently available for Antarctic continent colonies to assess the situation there.

1. Counts of breeding pairs should be made, as soon after egg-laying as possible, on an annual basis.

2. When counts of chicks near fledging time are required, the colony chosen should be well isolated from others to prevent the chicks joining those from other colonies in a single creche.

3. If photographic census techniques cannot be used, small colonies can probably be counted individually without undue disturbance. Large colonies would need to be estimated by some kind of subsample counting techniques (see Royal/Macaroni Penguin).

Chinstrap Penguin

This species has increased dramatically in both breeding range and numbers over the last 30 years. At a South Orkney Island site, its rate of increase has been three times that of Adelie Penguin over the same period. The procedure outlined above (1-3) for the Adelie Penguin should be followed.

Royal/Macaroni Penguin

1. Counts of breeding pairs should be made, as soon after egg-laying as possible, on an annual basis.

2. At some localities, this species breeds in large colonies on flat ground. Vertical aerial photography (at approximately 300-500 m) is probably most suitable both for calculating the overall area of the colony and for obtaining enlargements of photographs from which breeding densities in sample areas can be determined.

3. More typically, however, the vast colonies are situated on steep slopes. Oblique photography may be appropriate in these circumstances.

4. For accurate monitoring it is recommended that:

(a) the area of the colony be determined by a plane table survey and subsequent planimetry;

(b) for counting purposes a belt transect, not less than 5 m wide and divisible into contiguous quadrants of not less than 25 m^2 in area, be established from edge to edge across a colony. The transect line should be permanently marked;

(c) a subsequent count of chicks hatched should be made by a similar belt transect positioned on the opposite side of the line of permanent markers from that used to determine the number of breeding pairs.

INFORMATION EXCHANGE

It was proposed that reports on active monitoring studies should be submitted to the Working Party on Bird Ecology for circulation in advance of each meeting of SCAR.

Appendix 5 . Response of the SCAR Group of Specialists on Seals to questions submitted by the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources. (SCAR/SCOR, 1983b).

The Scientific Committee of CCAMLR posed six questions concerning the use of pinnipeds as indicator species.

Question 1

What, if any, species or populations of Antarctic seals might function as useful indicators of local, regional, or area-wide changes in the Antarctic marine ecosystem caused by harvest of krill or other populations of Antarctic marine living resources?

Answer 1

In order to determine which species are suitable as indicators of local, regional, or area-wide ecosystem changes, it is necessary to define the size of these areas and the species likely to reflect changes in krill availability on that scale.

Local: is taken to mean areas with a radius of approximately 300 miles.

Fur seals, both *Arctocephalus gazella* and *A. tropicalis*, are expected to reflect local conditions during the pup-rearing period. This is because the females feed locally, but then return to known sites on land. The foraging ranges of these seals define the food resources that influence their indicator parameters. Weddell seals should be considered as possible local indicator species. Because so little is known about the foraging range and movements of crabeater seals, they are not yet to be recommended as local indicators. However, it is recognized that crabeater seals may indicate local changes if their foraging and movements are found to be restricted to specific areas at certain times of the year.

Regional: is applied to areas on a scale, measured in up to thousands of miles, that delineate the main breeding stocks of seals. For pack ice seals, these may be associated with the distribution of the six residual pack ice areas in summer. Crabeater seals (specialist feeders), leopard seals (generalist feeders, and elephant seals can be expected to be indicator species at the regional level. For elephant and fur seals these areas are centred on the main island groups.

Area-wide: is taken to be the whole region south of the Antarctic Convergence. Crabeater seals, as circumpolar specialist krill-consumers, are the only seal species likely to reflect ecosystem changes operative throughout the entire Convention area. However, it is critical that the unit populations, their abundance and movements be defined in order to understand the impacts of perturbations in different areas.

Question 2

What are the factors that should be considered, including the possible use of controlled experiments, in order to determine whether, and how selected seal populations might function as indirect indicators of harvest-caused changes in krill or other harvested populations of Antarctic marine living resources?

Answer 2

Several factors can serve as useful indices of change within the Antarctic marine ecosystem. Parameters describing growth, reproductive rates, population dynamics, and feeding ecology may all be useful in this regard. Census studies and estimates of population abundance are unlikely to be useful as indices in the short-term because of the relatively high variance associated with estimates and the probable long lag times required before trends can be identified. Such parameters can, however, be useful in two general ways:

1. By making replicate measurements of parameters at selected sites over a wide area as part of a long-term monitoring programme and

2. By indicating the degree of response to planned perturbations as part of controlled experiments.

The first of these, long-term monitoring programmes, is discussed further below. The second, controlled experiments, should be considered for implementation as soon as practicable. Experimental evaluation of parameter response will not only help to demonstrate the nature of responses, but will help to identify which parameters provide the most appropriate indices.

The most practicable type of experiment appears to be one in which a suite of index parameters in several species, including

birds, would be monitored for a period before subjected to a perturbation of their prey. Presumably this could be accomplished by establishing a monitoring baseline and then conducting locally intensive krill fishing. It would not be necessary to attempt completely to remove krill from a certain locale; one or more levels of significant fishing intensity would suffice. It is necessary, however, that adequate baseline data on indicator parameters be available before the experiment, both in the experimental and control areas.

In designing an experiment, it will be of critical importance to ensure that the effect of variables such as krill distribution, ocean currents, physical factors and time of year are minimised. The importance of the distribution and movements of krill consumers has already been identified, and to obtain this information on krill itself is of equal importance. For example the influence that various ocean currents have on krill distribution may very well determine which areas show a response to krill fishing. In other words, krill fishing and potential responses to it may not necessarily be evident in "indicator species" in the same area, but "downstream" of it.

Physical factors between control and experimental sites must be compatible or at least well understood otherwise experimental results will be difficult, if not impossible to interpret. Controlling for time of year is essential also. Variations in the behavior of consumers at different times in this annual cycle, as well as reproductive and size differences in krill throughout the year, must be considered in the experimental design.

Question 3

What is the nature and adequacy of existing population data and what are the types of studies that would be required to establish a suitable basis (baseline) for detecting and monitoring changes and trends in potential indicator species and populations?

Answer 3

This question comprises two parts relating to data on populations that could serve as indicator parameters.

1. How much do we currently know about these parameters, and

2. What studies need to be undertaken to establish suitable baselines?

The status of our current understanding of various growth, reproductive, population dynamics, and feeding parameters is very variable and is discussed in more detail in the report of the Group of Specialists on Seals. Likewise, there are differing priorities for further research to establish meaningful baselines. Relevant research recommendations are also made in the Group of Specialists on Seals' report.

Question 4

What are the types of long-term monitoring studies, including possible study locations and sampling frequencies (periods), that are likely to be most useful for detecting and assessing the possible significance of changes and trends in selected indicator species or populations?

Answer 4

In designing monitoring studies it is clear that long-term programmes must be a priority. To be effective, studies need to obtain replicate sets of comparable data over a period of years from several sites. Only in this way will it be possible to separate fluctuations in indicator parameters caused by the neutral inherent variance, natural environmental changes, and/or those resulting from human perturbations. Such programmes will, of course, require a commitment to long-term funding to ensure continuity in data acquisition and so to their successful conclusion.

A suggested design for monitoring studies is one in which several comparable study sites are chosen both in and out of target areas for the krill fishery. Ideally, these sites would have a similar complement of species, physical factors, and krill availability. Moreover, the ideal sites would be those expected to be commercially fished at differing intensities. It is unlikely that these ideal conditions can be met, but it should be possible to select some sites that will fulfill some if not all of these requirements. For example, a string of monitoring sites established from South Georgia to the Palmer Archipelago could monitor ecosystem status throughout the Scotia Sea. Consideration should be given to establishing study areas in the vicinity of Bird Island, Signy Island, Elephant Island, King George Island, Low Island and Anvers Island.

Fur seals, which have now reestablished breeding sites throughout the Scotia Sea, should be a fruitful study species in these areas (pygoscelid penguins are found also at these sites). The sub-Antarctic islands of South Georgia, Kerguelen, Macquarie, Marion, and Heard may be useful areas for monitoring studies using elephant seals. Study sites in pack ice would be highly desirable. But here, again it must be emphasized our need to learn more about crabeater and leopard seals' movements. Without that information, it will be difficult to monitor local changes in krill availability in areas without land-breeding seals. Because most areas of the Southern Ocean are without fur seal breeding aggregations to serve as monitoring sites, the importance of further studies on crabeater seals is emphasized.

The sampling frequencies required at monitoring sites will vary according to the parameters being measured and the extent of the area over which trends are being monitored. The detection of changes at the local level would probably require annual sampling at comparable times, whereas sampling every five years might be sufficient to detect changes at the regional level. Similarly, indices with short lag times (eg feeding behavior, instantaneous growth rate) will merit annual sampling; for those with a longer lag time (eg age at sexual maturity, counts of land-breeding and pack ice seals), less frequent sampling would suffice.

Question 5

What is the possible utility of sighting data or other data that could be collected opportunistically from vessels engaged in fishing or other activities in the Convention Area and, if potentially useful, what are the types of data that should be collected and how should they be recorded and reported to be optimally useful?

Answer 5

It is very unlikely that seal sighting data or data acquired incidentally from fishing or support vessels will be useful in indicating changes within the marine ecosystem. It should be emphasized that effective monitoring studies must be tightly designed, carefully controlled, and periodically repeated (under similar circumstances), with specific objectives in mind. Incidental observations from vessels of opportunity will not meet these criteria. Neither are seal census data from such vessels likely to be of value for estimating population size. However, data on diel haulout rates can be useful in helping to correct census data, but if useful observations of such haulout rates are to be made, trained observers should be used. It is likely that scientific and relief vessels will be more useful in this regard than commerical fishing vessels. Random censuses and opportunistic sightings reports should be discouraged.

Question 6

What is the time that would be required to develop meaningful baselines and to detect different levels of change in selected indicators?

Answer 6

The time required to develop meaningful baselines and to detect significant changes of indicators will vary according to the parameter involved. It will take at least five observations (at similar times of the year) of each parameter to calculate meaningful estimates of year to year variance in unperturbed systems. Hence, as a minimum, five years are required to establish baselines. The amount of time required to detect changes will depend on the variance associated with each parameter and on the actual rate of change if any. It may be possible to detect changes of parameters with very low variance within a year or two. Changes of parameters with a very high variance may not be detected for periods of a decade or more. A second variable will affect the time required to detect changes in parameters in the lag time associated with each. The longer the lag time between a perturbation and a subsequent change in the associated indicator variable, the longer the time needed to detect a change. Therefore, the parameters expected to be most sensitive to change on a short time scale will be those with low inherent variance and short time lags.