Understanding CCAMLR's Approach to Management

edited by
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Foreword

Since the Convention's entry into force in 1982, the Scientific Committee of CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) has been addressing the complex issues associated with a precautionary and ecosystem approach to the management of Antarctic marine living resources. Many new initiatives have been put into place and heartening progress has been made in both the theoretical and practical management of human activities and their interactions with key Antarctic marine species. Such initiatives have had to address both scientific uncertainty and the political considerations inherent in managing a large area beyond the jurisdictional control of sovereign states.

The balance between political expediency and uncertain scientific information continues to challenge many fisheries organisations. In this respect, the Scientific Committee of CCAMLR has developed an open channel of communication with its decision-making body, the Commission. *Understanding CCAMLR's Approach to Management* was initiated as a key contribution aimed at explaining how scientific advice is formulated by the Scientific Committee. It was prompted by the need to ensure that the Scientific Committee's activities were both transparent and well informed.

As Chairman of the Scientific Committee, I am grateful to my predecessor, Dr Karl-Hermann Kock, for taking the necessary steps to develop the text for *Understanding CCAMLR's Approach to Management*. At a difficult personal time for him, he committed considerable energy and patience in drawing together a large section of the CCAMLR scientific community and to explain what they were actually doing in formulating the Committee's scientific advice. All contributors therefore bare equal responsibility in making the following document a reality.

The contributors are very grateful to Prof. Guy Duhamel, Drs Robert Hoffman, Taro Ichii, Steve Nicol and Volker Siegel for their constructive comments on the manuscript. The efforts of Ms Vivienne Mawson, the scientific editor appointed by the Editorial Committee, are also acknowledged.

This document is dedicated to the ongoing development and wise management of Antarctica's marine living resources.

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Executive Summary

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was a pioneer in the development of what has become known as the 'ecosystem approach' to the regulation of fisheries. An ecosystem approach does not concentrate solely on the species fished, but also seeks to avoid situations in which fisheries have a significant adverse effect on 'dependent and related species'. CCAMLR has to develop management approaches which assess the status of the ecosystem and its health. In the application of this ecosystem approach, CCAMLR has tackled with the difficulty of describing the full complexity of marine ecosystems by assuming that the system is dominated by the complex of species most important in the food chain. This paper describes where the Scientific Committee of CCAMLR stands 17 years after the convention came into force in 1982.

The objectives of the Convention, as laid down in its Article II, were translated into scientific meaningful working hypotheses as a first step. The precautionary approach to management was found to be most appropriate to guide all CCAMLR activities towards the regulation of exploitable resources given the considerable uncertainty associated with data collected in vast and largely unknown regions, and the complexity of the underlying marine systems. In addition to the core problem of developing multispecies exploitation strategies for the marine resources, CCAMLR is currently faced with three other problems: the incidental mortality of seabirds in fisheries, particularly longline fisheries; the entanglement of animals in marine debris; and the impact of fishing on the seabed.

CCAMLR has several approaches to regulating exploitation in the Southern Ocean. It collects data to follow as closely as possible the development of exploited stocks and newly developing fisheries. It also develops models to deal specifically with uncertainty in data collection. CCAMLR draws on five main sources to improve data collection: fisheries catch and effort statistics; biological information and data on by-catches of fish in commercial fisheries; seabirds and marine mammals caught during commercial operations and collected by national and international scientific observers; biological information collected during scientific and fishery-independent surveys; and biological information on krill and dependent species collected as part of the CCAMLR Ecosystem Monitoring Program.

A number of models have been or are currently being developed. The 'Krill Yield Model' was developed to provide precautionary limits for annual yields. By multiplying the estimate of krill biomass by a factor to take account of many uncertainties in data, and to thereby derive a precautionary catch limit. The factor is currently fixed at 0.116. A very similar approach, termed the 'Generalised Yield Model', has been applied to fisheries for finfish to account for the fact that CCAMLR lacks the time series of catch, effort, length and age available to many other fisheries organisations. Other areas of model development concern functional relationships between krill and krill predators. The development of models has just started. As a first step, the 'Critical Period Distance' model was developed but more complex models are likely to follow in the near future.

Decision rules have been developed for objective scientific analysis. Decision rules, specifying the set of decisions that are made in setting, removing, or varying management measures, using the results of assessments of the status of a harvested resource, are under development. They have so far been applied to catches in the krill fishery and the fisheries on Patagonian toothfish.

All the above steps are part of what is called the 'multispecies approach'. CCAMLR's use of the multispecies approach to this problem is innovative, so there is little experience in this type of assessment in fisheries conventions elsewhere. The first step in developing a sustainable harvesting strategy for krill was the single-species model of potential krill yield described above. The next step was to develop a model which took the needs of the krill-dependent predators into account. This is then followed by the choice of appropriate parameter estimates

for the model. Finally, the functional relationships need to be defined. Unfortunately there are yet no integrated datasets available to test the model as a whole. However, subsets of data are already available which will allow testing of various aspects of the model.

Given the complexity and dynamics of the Southern Ocean, CCAMLR is still far from reaching its ultimate goal, the ‘ecosystem approach’ to the regulation of fisheries. However, in its young history, CCAMLR has made important steps towards the development of an integrated approach to fisheries management and has, in many respects, been the fisheries organisation that has taken the lead in developing such approaches.

1. Introduction

1.1 A Brief Introduction to the Southern Ocean

Antarctica is surrounded by a vast, unbroken and dynamic body of water – the Southern Ocean – which constitutes about 15% of the world's total ocean surface. Its northern boundary – a very distinctive feature, physically and biologically – is the Antarctic Convergence, or Antarctic Polar Front. This is a zone where cold, less saline, northward-flowing Antarctic water encounters the warmer, southward-flowing, sub-Antarctic waters of the Atlantic, Indian and Pacific Oceans. The waters around islands lying in or near the Antarctic Polar Front, such as Macquarie Island and the Kerguelen, Crozet and Prince Edward Islands, are usually considered to be part of the Southern Ocean.

The Southern Ocean consists of a system of deep basins separated by three large mid-oceanic ridges: the Macquarie Ridge south of New Zealand and Tasmania; the Kerguelen–Gaussberg Ridge at about 80°E; and the Scotia Ridge, or Scotia Arc, extending from the southern Patagonian shelf in an eastward arc to the South Shetland Islands and the Antarctic Peninsula. The continental shelf is narrow, except in parts of the Weddell, Ross, Amundsen and Bellingshausen Seas: it accounts for only 3 to 5% of the total area of the Southern Ocean.

The prevailing oceanographic features of the Southern Ocean are the eastward-flowing Antarctic Circumpolar Current (West Wind Drift) in the north and, near the Antarctic continent, the westward-moving East Wind Drift, which is broken into a series of clockwise gyres and eddies, such as the Weddell Sea Gyre.

Three major ecological zones can be distinguished in the Southern Ocean. The **Ice-free Zone** lies between the Antarctic Polar Front and the northern limit of the pack-ice in winter. The intermediate **Seasonal Pack-ice Zone** lies between the northern limits of the pack-ice in winter–spring and in summer–autumn. The **High-latitude Antarctic Zone**, or Permanent Ice Zone, is adjacent to the Antarctic continent. The most productive of the three zones is the Seasonal Pack-ice Zone, where krill (*Euphausia superba*) is the dominant planktonic organism and the staple food of many whales, seals, birds and fish (Figure 1). Traditionally characterised as simple, the Antarctic marine food web has been recognised as complex only in the last decade. For example, the population processes of krill take place over ocean–basin scales and are strongly influenced by large-scale abiotic factors such as ice cover and gyres.

1.2 The History of Exploitation of the Southern Ocean

The resources of the Southern Ocean have been harvested for about 200 years. Exploitation began in the 18th century, when populations of fur seals were reduced close to extinction. In the 19th century, elephant seals, southern right whales (*Eubalaena australis*) and some sub-Antarctic penguins were hunted. The 20th century saw whaling of baleen whales (rorquals) and sperm whales, a limited harvest of male elephant seals, exploratory harvesting of ice seals and the start of fishing for finfish and krill. In recent times, exploratory fishing for stone crabs and squid has also begun.

Antarctic and sub-Antarctic fur seals

Sealing began on sub-Antarctic islands in about 1790, when Antarctic and sub-Antarctic fur seals (*Arctocephalus gazella*, *A. tropicalis*) were hunted for their pelts. Elsewhere in the southern hemisphere, other species, such as the New Zealand fur seal (*A. forsteri*) and the Juan Fernandez fur seal (*A. philippii*) were also being hunted. Sealing was indiscriminate: males, lactating females and juveniles were all taken. The sealing era peaked in the 1800/01 season, when more than 110 000 seal skins were taken on South Georgia alone. By 1822, at least 1.2 million fur seals had been harvested at South Georgia and the population was virtually extinct. The situation was similar on other sub-Antarctic islands, such as the Prince Edward, Crozet, Kerguelen and Macquarie Islands. The South Shetland Islands were first exploited in 1819/20. A year later, the catch peaked, when about 250 000 skins were taken. The smaller stocks at the South Orkney and the South Sandwich Islands were also depleted around this time.

By 1825, most populations of Antarctic and sub-Antarctic fur seals were on the verge of extinction. In the following years, sealing was resumed intermittently whenever seal populations began to recover, and continued until the early days of this century. Neither species has been exploited commercially since then.

The population of Antarctic fur seals at South Georgia began to recover rapidly from about 1940. There are now more than 2 million seals – probably more than before exploitation. Much smaller populations of fur seals, numbering several hundred to some tens of thousands of animals, occur in the South Shetland, South Orkney and South Sandwich Islands and Bouvet, Marion, Kerguelen, Heard, McDonald and Macquarie Islands. All populations are increasing, some of them rapidly. Populations of fur seals in the Atlantic Ocean sector are believed to have originated from South Georgia, which currently hosts about 95% of the world's population.

Southern elephant seal

The exploitation of southern elephant seals (*Mirounga leonina*) began at the end of the 18th century when the exploitation of fur seals declined rapidly. They were taken for oil, not for skin. They were hunted as an adjunct to whaling, particularly in the 20th century.

The large breeding colonies at South Georgia, the Kerguelen Islands, Heard, McDonald and Macquarie Islands were the main targets of the sealers. Unregulated sealing stopped in most places within the first two decades of the 20th century. It is not known how many elephant seals had been taken, but assuming the original populations totalled at least 600 000 to 750 000, the harvest was probably more than 1 million of both sexes combined. A controlled harvest of male elephant seals was continued at South Georgia from 1909 to 1964 and at the Kerguelen Islands from 1958 to 1961.

The size of the Atlantic Ocean stock of southern elephant seals appears not to have changed in the last 40 years: it has fluctuated around 400 000, of which 350 000 are on South Georgia. In the Indian Ocean sector, breeding populations were assumed to have recovered from exploitation by 1950, but all breeding populations have subsequently declined at a rate of 1.9–5.7% annually. The breeding populations on Marion Island have declined by more than 80% since 1951. However, the Kerguelen breeding stock (at the Prince Edward, Crozet, Kerguelen and Heard Islands) appeared to have stabilised by 1990 when it totalled about 189 000 seals. Some 143 000 seals were living on the Courbet Peninsula (at Kerguelen Islands) alone. The Macquarie Island stock has declined by 57% since 1949 and now comprises 78 000 seals, 99% of which live on Macquarie Island.

A number of causes of the declines in southern elephant seal populations have been suggested, including overfishing of their food resource. However, there is as yet no evidence that fishing in Antarctic waters has contributed to the decline.

Other Seal Species

Crabeater (*Lobodon carcinophagus*), Weddell *(Leptonychotes weddellii*), leopard (*Hydrurga leptonyx*) and Ross seals (*Ommatophocarossii*) were taken regularly in small numbers to feed dog teams. They were also taken irregularly during exploratory sealing in the pack-ice, such as from 1892 to 1894 (32 558 seals in the Antarctic Peninsula region), in 1963/64 (861 seals in the South Orkney Island region), and in 1986/87 (4 802 seals in the Western Pacific Ocean sector). It is unlikely that the 39 000 seals hunted by sealers between 1892 and 1987 and the 9 200 seals killed for dog food between 1964 and 1985, all of which were taken over a wide geographical range, adversely affected any of the ice-seal species. Current estimates of stock sizes are: crabeater seals (11–12 million), Weddell seals (900 000), leopard seals (350 000) and Ross seals (130 000).

Harvesting of ice seals and other seal species in the Southern Ocean south of 60°S is regulated under the Convention on the Conservation of Antarctic Seals (CCAS), which came into force in 1978. The killing of fur, elephant and Ross seals for commercial purposes is prohibited. Although annual catch limits are set for crabeater (175 000), Weddell (12 000) and leopard seals (5 000), these species have not been harvested in recent years.

Whales

All seven species or subspecies of baleen whales (Mysticeti) that occur south of the Antarctic Polar Front have been extensively exploited. The only toothed whale taken regularly was the sperm whale (*Physetermacrocephalus*). Killer whales (*Orcinusorca*) and southern bottlenose whales (*Hyperoodon planifrons*) were taken irregularly and only in small numbers.

Commercial whaling in the Antarctic began in December 1904 at Grytviken on South Georgia and expanded to the more southerly islands of the Scotia Arc and to the Kerguelen Islands within less than 10 years. The more inshore-living humpback whales (*Megaptera novaeangliae*) were the first to be targeted, followed by blue whales (*Balaenoptera musculus*).

Until the early 1920s, whaling was land-based, with processing taking place either at shore stations or alongside factory vessels moored in sheltered fjords and bays. Whaling became an offshore (i.e. pelagic) operation and went beyond the scope of national jurisdiction from 1925, when factory vessels began to be fitted with stern slipways. Pelagic mother ship/catcher operations became the most common type of whaling and the number of mother ships and catcher vessels increased rapidly.

Whale catches peaked in 1930/31 and 1937/38, when about 40 000 and 45 000 whales respectively were taken. Fin whales (*B. physalus*) replaced blue whales as the main target species. In the 1950s, when the first major declines in whale catches occurred, sei (*B. borealis*) and sperm whales began to form a larger portion of the catch. Minke whales (*B.acutorostrata)* were not pursued in appreciable numbers before 1971, but became the main target species until 1986/87. The first conservation measures to protect whale stocks were introduced under the auspices of the League of Nations in the 1930s. They prohibited the harvesting of right whales, which 19th century whalers had already very much depleted in the breeding grounds off South America, South Africa and Australia. In 1946, the International Convention for the Regulation of Whaling (ICRW) was signed. It established the International Whaling Commission (IWC) as the body responsible for the regulation of whaling. Humpback whales were protected in 1963 and blue whales in 1964. The shift to hunting minke whales followed reduction of the permitted take of other species in the 1970s. In 1979, the IWC established the 'Indian Ocean Sanctuary', which comprises the entire Indian Ocean, including the northern waters of the Indian Ocean sector of the Southern Ocean as far south as 55°S.

In 1982, the IWC adopted a moratorium on commercial whaling, which came into effect after the 1986/87 season. Since that date, 300 to 440 minke whales have been taken annually by Japanese vessels under a scientific permit issued by the Government of Japan. A revision of the moratorium on commercial whaling will be considered after the IWC has completed a comprehensive assessment of the whale stocks of the Southern Ocean and the effects of the moratorium on their recovery. This assessment is currently in preparation.

In 1994, the IWC declared the Southern Ocean south of 40°S (except for an area of the southeast Pacific–southwest Atlantic to the south of 60°S) a whale sanctuary ('Southern Ocean Sanctuary'). In this sanctuary, commercial whaling operations, be they offshore or land-based, are prohibited. This prohibition will be reviewed in 2004. Japan objected to the establishment of the 'Southern Ocean Sanctuary' and is not bound by the IWC's decision.

The total reported catch of whales in the Antarctic from 1904 to the moratorium was more than 1.5 million animals. Catch records are currently being revised by the IWC. A portion of this catch, in particular of sperm whales, pygmy blue whales and sei whales, was taken north of the Antarctic Polar Front in the 1960s and 1970s. However, it seems reasonable to assume that, prior to Antarctic whaling, 1–1.5 million whales may have moved through the Antarctic Polar Front in austral summer–autumn every year. With the exception of minke whales, and probably killer and southern bottlenose whales, the numbers of all species declined dramatically during the harvest and are currently only small fractions of their initial sizes.

Birds

King penguins (*Aptenodytes patagonicus*) and crested penguins (*Eudyptes* spp.) were exploited for oil, food and as fuel for fire on some of the sub-Antarctic islands, such as South Georgia, Heard and Macquarie, during the sealing era of the 18th and 19th centuries. Subsequently, the numbers of king penguins have increased rapidly at all breeding sites – in the range of 8–12% per annum on most sub-Antarctic islands since the 1960s. The largest populations are at the Crozet Islands (700 000 pairs), South Georgia (400 000 pairs) and Macquarie Island (110 000 pairs).

Data on changes in the populations of crested penguins are anecdotal, but seem to indicate increases at South Georgia at least. In the late 1970s, the number of macaroni penguins (*Eudyptes chrysolophus*) at South Georgia almost halved over five years, remained stable until 1994, but decreased by another 30% in the two years thereafter.

Eggs of a number of penguin species, including true Antarctic species such as chinstrap (*Pygoscelis antarctica*) and Adélie penguins (*P. adeliae*), and of albatrosses (wandering albatross *Diomedea exulans*; black-browed albatross *Diomedea melanophrys*), were harvested by sealers and whalers into the 1950s, when the taking of eggs ended. The effects this may have had on bird populations are unknown.

Finfish

Plans to develop finfishing in the Southern Ocean date back to the early days of land-based whaling at South Georgia in 1906, although large-scale harvesting of finfish did not begin until 1969/70 around South Georgia and 1970/71 around the Kerguelen Islands. After 1977/78 the fishery expanded to more southerly grounds, such as the South Orkney Islands. These grounds yielded good catches for only a few years; they had declined rapidly by the early 1980s. Fishing off the coasts of the Antarctic continent began in the early 1980s on an exploratory scale, but never went beyond that stage. Until the mid-1980s the fishery was entirely a trawl fishery.

The target species of the trawl fisheries are, or have been, marbled rockcod (*Notothenia rossii*), mackerel icefish (*Champsocephalus gunnari*), grey rockcod (*Lepidonotothen (= Notothenia) squamifrons*), Patagonian rockcod (*Patagonotothen (= Notothenia) guntheri*), sub-Antarctic lanternfish (indiscriminately recorded as *Electrona carlsbergi*) and Wilson's icefish (*Chaenodraco wilsoni*). Frequent by-catch species of the trawl fishery have been humped rockcod (*Gobionotothen (= Notothenia) gibberifrons*), various icefish species and skates (*Raja georgiana, Bathyraja* spp.). Most species, as far as is known, have been fished primarily for human food, while the small Patagonian rockcod and lanternfish were mainly used for fishmeal.

In the mid-1980s longlines were introduced to catch Patagonian toothfish (*Dissostichus eleginoides*) around South Georgia and the Kerguelen Islands. Patagonian toothfish are also fished outside the CCAMLR Convention Area along the Chilean and Patagonian slopes (parts of which lie within the Argentinian and Chilean Exclusive Economic Zones and the Falkland/Malvinas Islands Conservation Zone), and around Macquarie Island; annual catches currently exceed those reported for the Atlantic Ocean sector of the Convention Area by a factor of 2–3. It is not known how many stocks of Patagonian toothfish there are in the Convention Area, or whether just one stock (a 'straddling stock') is fished both inside the Convention Area (Shag Rocks and South Georgia) and outside it (in neighbouring areas such as the Patagonian slope). The current high market value of Patagonian toothfish has led to a rapid expansion of the fishery for this species particularly in the Indian and Pacific Ocean sectors of the Southern Ocean, where there is a considerable amount of unregulated fishing. Since 1996/97, the closely related Antarctic toothfish (*Dissostichus mawsoni*) has become the target of a number of new and exploratory fisheries.

Substantial numbers of albatrosses and petrels are taken as by-catch in longline fisheries. These birds are killed incidentally when attempting to take bait from hooks (see section 3.3(i)).

Until 1990, commercial finfishing fleets were almost entirely from the then Eastern Bloc countries; the former Soviet Union took more than 85% of the catches. Since 1990/91, other nations have participated, with France, Chile, Argentina and Ukraine taking most of the catch in the regulated fishery.

By the end of the 1996/97 season, about 3.05 million tonnes of finfish had been taken from the Southern Ocean. About 2.08 million tonnes were caught in the Atlantic Ocean sector, with 1.74 million tonnes (83.4 %) of this from close to South Georgia. Of the 924 000 tonnes caught in the Indian Ocean sector, 872 000 tonnes (94.4%) were taken near the Kerguelen Islands.

Although on a much shorter time scale, finfishing has paralleled the history of whaling in the Southern Ocean, repeating the pattern of discovery, exploitation and depletion of each new stock (Figures 2 to 5). After most of the demersal (bottom-dwelling) fish stocks were depleted, which happened before CCAMLR came into force, benthopelagic (living off the bottom) Patagonian toothfish and mesopelagic (living in oceanic midwater) sub-Antarctic lanternfish began to be harvested in the second half of the 1980s (Figure 2; see also Figure 5). By the end of the 1980s, fishing for most species was either prohibited, as in the case of the marbled rockcod, or was limited by total allowable catches (TACs). The South Orkney Islands and the Antarctic Peninsula region were closed to fishing (Figures 3 and 4). Economic considerations prompted the cessation of the fishery for lanternfish after the 1991/92 season.

Some of the stocks, such as the by-catch species around South Georgia, appear to have recovered to some extent from overexploitation, whereas others, such as the marbled rockcod, show little sign of recovery in most areas. Currently, the only viable fisheries are for Patagonian toothfish, and for mackerel icefish when strong year classes enter the fishery.

Krill (*Euphausia superba*)

Krill fishing on a commercial scale started in the 1972/73 season. It soon concentrated in localised areas in the Atlantic Ocean sector, with the main fishing grounds to the east of South Georgia, around the South Orkney Islands and off the north coast of the South Shetland Islands (Figure 6). The development of the krill fishery is illustrated in Figure 7. After peaking with more than 500 000 tonnes in 1981/82, catches dropped substantially because of problems in processing krill and more effort being diverted to finfishing. From 1986/87 to 1990/91, annual catches stabilised at between 350 000 and 400 000 tonnes, which was about 13% of the world catch of crustaceans. When economic factors forced the Russian fleet to stop fishing, catches declined dramatically after 1991/92 to about 80 000 tonnes per annum. Since then, Chile has also stopped fishing for krill. The current krill catch is in the range of 90 000–100 000 tonnes per annum.

The South Orkney Islands and the Antarctic Peninsula region are usually fished in summer, while the South Georgia fishing grounds are mainly fished in winter, when the more southerly grounds are covered by ice.

The amount of krill harvested to date totals slightly more than 5.74 million tonnes, of which the former Soviet Union and two of its succeeding states (Russia and Ukraine) took almost 84% and Japan 14.5%. More than 90% of the catch was from the western part of the Atlantic Ocean sector (Figure 6).

In the first 10 years of krill fishing, catches, in particular those made by vessels from countries of the former Soviet Union, were largely used for animal feed. In the mid-1980s, difficulties in processing krill were overcome. Today, most krill is processed for aquaculture feed, bait and human consumption. Its use in aquaculture and its potential in biochemical products is increasing interest in krill fisheries.

Crabs

A very recent development was an exploratory pot fishery for stone crabs (Lithodidae) in waters around South Georgia and Shag Rocks. Two species were targeted: *Paralomis spinosissima* and, to a lesser extent, *P. formosa*. The fishery is limited to sexually mature male crabs and the TAC is set at 1 600 tonnes annually. One American fishing vessel entered the fishery, taking catches of 299 tonnes in 1992/93, 139 tonnes in 1994/95 and 497 tonnes in 1995/96. The fishery was subsequently discontinued because it was not economically viable.

Squid

There are large squid fisheries directly to the north of the Southern Ocean, such as those on the Patagonian and New Zealand shelves. The range of one of the species in those fisheries, *Martialia hyadesi*, extends into the northern part of the CCAMLR Convention Area. Its standing stock in the Scotia Sea has been estimated at 330 000 tonnes, based on the amount taken by predators, primarily elephant seals. There has been considerable speculation about how much squid there is in the Southern Ocean and how important it is as a predator of krill. Beaked whales, as far as is known, feed almost exclusively on squid in this region. The presence of an estimated 600 000 beaked whales in the Southern Ocean (primarily southern bottlenose whales) supports the hypothesis that a large standing stock of squid exists there. An exploratory fishery for *M. hyadesi* in Subarea 48.3 had taken 81 tonnes by July 1997. The existing CCAMLR limit on the annual take of squid is 2 500 tonnes.

2. The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Management Tasks

2.1 The Convention on the Conservation of Antarctic Marine Living Resources

The exploitation of Antarctic marine living resources has been characterised by intense and sporadic pulses, in many cases resulting in the severe depletion of harvested stocks (as was the case for fur and elephant seals in the 19th century, and whales and finfish in the 20th century) (see section 1.2). In the mid-1970s, it was realised that the conservation of krill was fundamental to the maintenance of the Antarctic marine ecosystem (Figure 1) and vital to the recovery of depleted whale populations. Serious concerns were raised about effective management and sustainable utilisation of Antarctic marine living resources. These concerns were taken up by the Antarctic Treaty Consultative Meeting in London in 1977. In February 1978 international negotiations began. They resulted in the signing, in Canberra in May 1980, of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR came into force in 1982. In common with other international agreements, CCAMLR does not impose regulations, but rather attempts to reach agreement on issues which Members of the Convention are then obliged to implement.

In contrast to other multilateral fisheries conventions, CCAMLR is concerned not only with the regulation of fishing, but also has a mandate to conserve the ecosystem. This 'ecosystem approach', which considers the whole Southern Ocean to be a suite of interlinked systems, is what distinguishes CCAMLR from other multilateral fisheries conventions.

The Convention applies to all marine living resources (except seals south of 60°S and whales in general) inside an area whose northern boundary is roughly delineated by the mean position of the Antarctic Polar Front and thus follows the physical and biological boundaries of the Antarctic (Figure 8). In this respect it differs from other Antarctic Treaty agreements, such as the Convention on the Conservation of Antarctic Seals (CCAS) and the Protocol on Environmental Protection, whose northern boundaries are at 60°S. The Convention Area divides naturally into three sectors (Atlantic Ocean, Indian Ocean and Pacific Ocean), which for statistical purposes are termed Statistical Areas 48, 58 and 88 respectively. Each statistical area is divided into subareas and divisions (Figure 8).

The political status of regions within the CCAMLR Convention Area is dependent on a number of considerations. Under the agreements that make up the Antarctic Treaty System, claims to Antarctic territory are not prejudiced by the Convention, but in practical terms CCAMLR has jurisdiction (i.e. the authority to implement conservation measures that are binding on its Members) over all marine areas between the Antarctic continent in the south and 60°S (i.e. the northern boundary of the Antarctic Treaty). North of 60°S, a number of states retain sovereign rights over sub-Antarctic islands (France: the Kerguelen and Crozet Islands; Norway: Bouvet Island; South Africa: the Prince Edward Islands; and Australia: Heard and McDonald Islands). Sovereign rights over South Georgia and the South Sandwich Islands are disputed by the UK and Argentina. Most of the areas over which CCAMLR has conservation and management mandates are high-seas areas. The United Nations Implementation Agreement on Fish Stocks (UNIA)*, which was finalised in 1995, will, in the future, regulate exploitation on the high seas. It contains, as does CCAMLR, the obligation to introduce measures to conserve species that may not be targeted by a fishery, but may be indirectly affected by it.

CCAMLR currently has 23 Members. The CCAMLR Secretariat is based in Hobart (Tasmania, Australia). Until recently, all nations fishing in the Convention Area have been either Members

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* The UN Agreement for the Implementation of Provisions of the United Nations Convention on the Law of the Sea relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

of the Commission or have acceded to the Convention. Recently, however, countries such as Panama, Belize and Honduras, which are not Members of CCAMLR, have entered fisheries, in particular longline fisheries for Patagonian toothfish. This has made the task of managing fisheries in the Convention Area considerably more difficult.

In addition to CCAMLR, three other conventions regulate conservation and resource management in the Antarctic:

- Annex II to the Protocol on Environmental Protection to the Antarctic Treaty: Conservation of Antarctic Fauna and Flora (known prior to 1991 as 'Agreed Measures for the Conservation of Antarctic Flora and Fauna');

- The Convention on the Conservation of Antarctic Seals (CCAS);

- The International Convention for the Regulation of Whaling (ICRW), which is not part of the Antarctic Treaty System and is not restricted to the Southern Ocean.

Only recently has it been recognised that, in addition to cetaceans, other resources such as lanternfish, Patagonian toothfish and squid, as well as flying birds such as albatrosses, cross the northern boundary of the Convention Area in significant numbers. A group that influences ecological interactions in the Southern Ocean – whales – is not dealt with by CCAMLR. Clearly, many important issues related to the management of Southern Ocean resources and systems can only be tackled in collaboration with the organisations responsible for management and conservation in areas adjacent to the CCAMLR boundaries or for species not included in the Convention. Seeking closer collaboration with these organisations will have high priority for CCAMLR in the future.

2.2 CCAMLR's Management Tasks and the Definition of its Operational Objectives

Article II of the Convention is central to understanding CCAMLR's approach to the conservation of Antarctic marine living resources. It states:

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

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

3. Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:

   (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;

   (b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in subparagraph (a) above; and

   (c) prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades,

> taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources.

Article II embodies two concepts that are vital to CCAMLR's approach to management. The first is that management should follow a precautionary approach, according to which decisions taken should have a low risk of long-term adverse effects. This approach has important implications when working with uncertainty in information, for instance when the actual size of exploited stocks is not known precisely, or when new stocks are being targeted. The second concept is the ecosystem approach.

CCAMLR was a pioneer in developing what has become known as the 'ecosystem approach' to the regulation of fisheries. However, what is meant by such an approach?

A conventional definition of an ecosystem is:

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

An ecosystem approach does not concentrate solely on the species fished but also seeks to minimise the risk of fisheries adversely effecting 'dependent and related species', that is, the species with which humans compete for food. However, regulating large and complex marine ecosystems is a task for which we currently have neither sufficient knowledge nor adequate tools. Instead, CCAMLR's approach is to regulate human activities (e.g. fishing) so that deleterious changes in the Antarctic ecosystems are avoided.

By applying the ecosystem approach, CCAMLR has chosen to deal with the difficulty of describing the full complexity of marine ecosystems by designating species considered to be most important in the food chain (so-called 'indicator' species) or by focusing on stocks within somewhat arbitrarily defined geographic regions or management areas. In the case of krill, CCAMLR has considered not only krill but also a subset of dependent species, including seabirds and seals, which are monitored by the CCAMLR Ecosystem Monitoring Program (CEMP).

One of the key steps in developing workable approaches to marine living resource management is to clearly define the objectives. CCAMLR, in common with other international conventions for the regulation of fisheries, sets out general objectives that embody important principles. Where these are not scientifically meaningful (i.e. measurable), the objectives need to be interpreted so that progress towards achieving them can be assessed.

There are a number of problems in providing a precise scientific interpretation of Article II because the population level for a dependent predator that gives the 'greatest net annual increment' (GNAI) is largely a function of the amount of its prey that is eaten and fished by others. CCAMLR therefore has interpreted the GNAI of a dependent species as that which would occur if its prey were not fished. However, since even this is not known for most marine species, CCAMLR is using an interim method. Rather than trying to monitor the abundance of dependent species in relation to a specified level of GNAI, CCAMLR has adopted precautionary catch limits. These aim to ensure that the effect of fishing on prey abundance is limited to a level that is unlikely to have an impact on predators (which would be contrary to the requirements of Article II).

The objectives of fisheries management should also take into account certain aspects of fishing operations, such as the time scales over which adjustments are made to fisheries regulations, i.e. whether the regulations are to be kept as consistent as possible or are varied substantially from year to year.

The next section outlines how CCAMLR is attempting to implement the Convention's objectives through directed scientific research, modelling studies and CEMP. CCAMLR's approach to fisheries management will need to be continually refined as more is learned about functional relationships between key species within Antarctic ecosystems.

3. CCAMLR's Approach to Management

The principal institutional elements of CCAMLR are the **Commission (a policy-making and regulatory body)** and the **Scientific Committee (a scientific body providing management advice)**. This management advice is based on assessments conducted by the two working groups of the Scientific Committee. One of these, the **Working Group on Ecosystem Monitoring and Management (WG-EMM)**, is primarily concerned with assessing and developing advice on the krill fishery, and analysing data from CEMP. The other, the **Working Group on Fish Stock Assessment (WG-FSA)**, develops management advice on fisheries other than the krill fishery. It also assesses the incidental mortality of seabirds and interactions of longline fisheries with other non-target species, such as cetaceans. The advice from the working groups is submitted to the Scientific Committee, which may refine it by taking into account additional information available to the Committee. The **management advice** is then referred to the Commission for consideration.

3.1 Directed Scientific Research – Collection of Data for Assessment Purposes

CCAMLR draws on data from four main sources:

- Fishery catch and effort statistics provided by Members who fish commercially in the Convention Area.
- Biological information and information on by-catches of fish and incidental mortality of seabirds and marine mammals collected by national and international observers on board commercial fishing vessels.
- Biological information and biomass estimates obtained during fishery-independent scientific surveys by Member countries.
- Biological information on dependent species collected by Member countries as part of CEMP.

(i) Fishery Catch and Effort Statistics

The CCAMLR Convention Area is divided into statistical areas, subareas and divisions (Figure 8), internationally agreed and recognised by the Food and Agriculture Organisation of the UN (FAO), which is responsible for collecting and publishing world fishery statistics. The three statistical areas are: Area 48 (Atlantic Ocean sector), Area 58 (Indian Ocean sector) and Area 88 (Pacific Ocean sector). The boundaries of statistical subareas and divisions within these areas, which were decided on general oceanographic and biological grounds, incorporate areas thought to contain relatively discrete populations of some species.

The reason for dividing the Convention Area into subareas and divisions is twofold:

- to enable the reporting of fisheries data for individual stocks; and
- to make possible the imposition of management measures on a stock-by-stock basis.

The stock concept is therefore extremely important in the definition of discrete areas. Although most stocks in the Convention Area are still believed to be confined to specific statistical subareas or divisions, some are now thought to be distributed over two or more, or are straddling stocks as defined by UNIA. Examples of these are:

- krill in all subareas;
- Patagonian toothfish in Subarea 48.3, which is thought to form one stock together with fish from the Patagonian area (i.e. national and international waters outside the Convention Area); and
- lanternfish (myctophids, such as *E. carlsbergi*) and squid (such as *M. hyadesi*) which are found on both sides of the Antarctic Polar Front (i.e. north and south of the Convention Area).

The acquisition and analysis of data from the entire geographical range of such stocks is crucial for assessment purposes, but can be difficult because of the historical definition of statistical areas and the Convention Area itself.

Fisheries catch data are reported to CCAMLR for each of the subareas or divisions in the Convention Area. Most data are now reported in fine-scale format (1° longitude x 0.5° latitude by 10-day period) or even, in some fisheries, haul-by-haul. This means that, if required, either smaller or larger areas than the statistical subareas and divisions can be defined for assessment purposes. However, the subareas and divisions are still the basic units for management purposes.

(ii) The CCAMLR Scheme of International Scientific Observation

Central to any management regime is the acquisition of high-quality data, some of which come from scientific sampling, but many come from commercial fishing activities. Scientific observers on board a vessel can provide detailed information on its fishing operations. This is a separate responsibility from checking on compliance with conservation measures.

The CCAMLR Scheme of International Scientific Observation was first implemented in the 1992/93 fishing season. It was designed to gather information on fishing activities in the Convention Area, including details of vessel operations, biological data pertaining to the species caught, and incidental mortalities of non-target species.

The scheme operates through bilateral agreements between CCAMLR Members to exchange observers (i.e. an observer of one Member serves on a vessel of another Member). The scientific observers must be nationals of the Member that designates them, but Members fishing are still obliged to report information from their fisheries at regular intervals. Nevertheless, the CCAMLR Scheme of International Scientific Observation is often the most effective means of obtaining reliable data and information from fisheries, and also of educating the crews of vessels in the use of measures designed to reduce the incidental mortality of seabirds. The presence of observers on board longline vessels of CCAMLR Members fishing for Patagonian toothfish in the Convention Area is mandatory. In 1995, the Commission endorsed the Scientific Committee's recommendation that 100% coverage by observers should eventually become mandatory for all finfish fisheries in the Convention Area.

(iii) Estimating Abundance from Fishery-independent Surveys

Abundance estimates are essential for assessing stock sizes. Two main types of survey are used to estimate the abundance of fish, krill and squid species: acoustic surveys and net surveys.

Acoustic surveys use calibrated echosounders that transmit pings of high-frequency sound vertically down into the water column from a transducer mounted in the hull of a ship moving along a predetermined course. Sound is reflected back to the ship by the sea floor and by objects, such as fish, that are in the water. The difference in time between the sound being transmitted and its arrival back at the ship is used to estimate the depth of the seabed or the targets in the water. The proportion of the sound energy that is reflected is used to calculate the quantity of individual targets present in the water column. Different species have different acoustic characteristics but, although this helps to identify the source of the sound reflection, the best way is to sample the species in the water with nets. Electronic and data processing methods are used to integrate the total quantity of reflected sound so that the integrated signal is proportional to the density of animals along the course of the survey vessel. The absolute abundance of animals is then estimated by calibrating the echosounder with known targets, estimating the sound reflected by individuals of the species of interest, and scaling the density to the total area of the survey.

Examples of acoustic surveys are the krill surveys by the international Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) Program – FIBEX (First International BIOMASS Experiment) in 1981 and SIBEX (Second International BIOMASS Experiment) from 1983 to 1985; the US Antarctic Marine Living Resources (AMLR) Program conducted since 1988/89 in the Elephant Island/King George Island Area; and the Australian krill biomass survey in Division 58.4.1 in 1996.

In a net survey, trawl or plankton nets are towed through the water, or along the bottom, for a measured distance. A commercial trawl has a large mouth opening and a coarse mesh, so it catches large fish. By contrast, plankton nets have a small mouth area and fine mesh; although in theory they can catch fish and krill of all sizes, they cannot be towed fast and larger individuals can get out of the way.

Consequently, both types of net survey are useful for assessing a stock. Commercial nets collect information on the larger, breeding part of the stock, while plankton nets give information on juveniles that will become recruits to the fishery in the future. The total catch of each species divided by the area or volume fished gives estimates of the densities of animals in the trawled area. By carrying out such hauls at random sites, the mean density for the survey area can be estimated.

Examples of net surveys are the UK demersal fish surveys around South Georgia since 1988/89, and the krill and fish surveys conducted in the Elephant Island/King George Island region by Germany since 1977/78 and by the USA since 1988/89.

Acoustics allow a large area of ocean to be surveyed relatively quickly, but the information acquired still needs to be assessed alongside biological information derived from net catches. Nets provide detailed information about small areas, but net surveys are time-consuming.

(iv) Biological Information

Biological parameters – principally reproductive characteristics, growth curves and natural mortality rates – are key components in all the types of yield calculations outlined in section 3.2(ii). Information on these parameters is collected during both scientific surveys and commercial fishing operations.

The growth curve of a sample of fish is usually estimated by measuring their lengths and weights and plotting them against age. Length and weight are quite straightforward to measure, but estimating age is much more difficult. In the case of fish, this is usually attempted by counting the rings in scales or otoliths (bones found in the ears). These rings are laid down regularly throughout life, much like growth rings in trees, though not necessarily annually. However, reliable counts are often hard to obtain, particularly in older animals, because individual rings are either difficult to distinguish or their annual deposition cannot be validated.

For crustaceans, such as krill, this method cannot be used at all, because they moult their exoskeletons and have no hard parts (except in their eyes) that are retained throughout their lives. However, species such as krill, which have a short, once-yearly spawning season and a life span of six to seven years, often exhibit distinctive modes in their length frequencies. These can be linked to their age because individual krill born in the same year (cohorts) grow at similar rates and are distinguishable from groups born in other years. These cohorts constitute the 'structure' of a stock.

The rate of natural mortality, which is the rate at which animals die from predation, disease, parasites or senescence, is a notoriously difficult parameter to estimate for exploited populations – Antarctic fish and krill are no exception. The difficulty is that, when a species is being fished, mortality due to fishing is impossible to distinguish from natural mortality simply by examining the stock structure. A variety of methods is used in fish stock assessments to estimate natural mortality rates, ranging from general methods that relate growth rates to natural mortality for a large number of species, through to methods that involve taking a random sample (before commercial fishing starts) of animals, whose ages are then estimated. In principle, the latter methods are preferred because they make direct estimates of natural mortality, but the sample of age readings must be representative of the stock, and the population itself must be unexploited and in equilibrium. However, it is usually difficult to fulfil either of these requirements. Moreover, as in most marine species, recruitment fluctuates widely from year to year, so the numbers of fish of each age are highly variable. As a consequence, estimates of natural mortality (M) rates for a species sometimes vary considerably. Typical examples are mackerel icefish, for which reported estimates of M range from 0.2 to 0.6 and krill, with a reported range of 0.6 to 1.2.

Thus, the key biological parameters used in assessments are usually subject to considerable uncertainty. In deterministic assessment models, such as virtual population analysis and yield-per-recruit analyses, which are widely used in fisheries conventions around the world, this uncertainty is difficult to take into account; further work is needed to develop a more systematic approach to evaluating the effects of uncertainty on the results. In stochastic projections, some of the effects of uncertainty in the parameters are already incorporated in the analyses by using a different value for the biological parameters in each of the many simulations used in calculating the future states of the stock.

(v) Monitoring Dependent Species

In addition to assessing the status of exploited stocks, CCAMLR monitors selected dependent species in CEMP as part of its ecosystem approach.

This program has two broad aims: to detect and record significant changes in critical components of the ecosystem in order to provide information for conserving Antarctic marine living resources; and to distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological.

The Scientific Committee realised at the outset that monitoring the entire ecosystem would be impossible. It therefore selected species in a few key areas and the parameters that were most likely to reflect changes in the ecosystem and the availability of harvested species, especially krill. The inclusion of a species in the program is also based on its likely utility in indicating the state of some part of the ecosystem that may be affected by fisheries.

In addition, other environmental parameters, such as hydrographic and sea-ice cover information, were selected to monitor trends in the physical environment. Monitoring selected species and evaluating the numerical and functional relationships between them and other components of the ecosystem contribute to the detection and recording of significant changes in critical components of the ecosystem (Aim 1). Monitoring prey species and measuring environmental parameters and the links between these and predators helps to distinguish between changes due to harvesting and changes due to environmental variability (Aim 2).

The species, their biological parameters and sites at which they are monitored were chosen to meet specified criteria. Prey species were selected for their key positions in Antarctic ecosystems and their potential as harvestable resources. These were krill, the Antarctic silverfish *Pleuragramma antarcticum, Euphausia crystallorophias* (which replaces krill as a prey item in some regions of the High-Latitude Antarctic Zone), and early life stages of fish. Predator species were selected if they feed predominantly on the prey species identified, have a wide geographical distribution, and represent important ecosystem components. In addition, sufficient should be known of their biology and sufficient baseline data of the parameters to be monitored should exist to construct a scientific monitoring program. On the current list are crabeater and Antarctic fur seals; Adélie, chinstrap, gentoo and macaroni penguins; Antarctic and Cape petrels; and black-browed albatrosses (see Annex II).

(vi) Monitoring Sites

A core set of sites was chosen from three Integrated Study Regions (ISRs) (Figure 9), and a wide network of complementary additional sites (Figure 9) was proposed. Within the ISRs, sites were chosen so that researchers could distinguish between broad-scale and local-scale changes, and between changes in fished areas and non-fished areas. However, their position was also limited by logistics, including the presence of established bases and the availability of long-term datasets. The selection of 'control' sites was very difficult because the geographical scale of the changes to be studied was expected to be large, and the sites had to be outside such large areas but with comparable environmental and biological characteristics, and also be suitable for long-term monitoring.

Several parameters are monitored for each predator species. The geographic and temporal scales over which these parameters are expected to reflect changes in the ecosystem varies from several weeks and close to monitoring sites (e.g. the duration of foraging trips, composition of chick diets) to annual or semi-annual and region-wide (the weight of birds arriving to breed, breeding success, population size).

Monitoring methods for the environmental parameters of sea-ice cover, local weather and snow cover have already been agreed. Sea-ice and hydrographic conditions influence both the distribution, abundance, movement ('flux') and recruitment of krill (Figure 10), as well as the distribution, rate of survival over winter, time of arrival and access to breeding colonies of its predators, such as penguins. The parameters for monitoring environmental conditions and the condition of prey species are currently being refined and developed further.

WG-EMM guides CEMP, particularly the design and coordination of research, acquisition of data by standard methods, and centralised storage and analysis. This is combined with a strong emphasis on empirical and modelling-based research, which both modifies the monitoring approach in line with methodological developments and creates a sound scientific background against which the effects of management options on the Antarctic ecosystem can be assessed. The final link in the monitoring scheme is a management mechanism to regulate marine harvesting.

Field work and data acquisition for the program are carried out voluntarily by CCAMLR Members. The data they collect are sent to the CCAMLR Secretariat, which carries out standard analyses for consideration by WG-EMM. The Secretariat also collects and archives data acquired from remote-sensing initiatives – for example satellite-derived sea-ice and sea-surface temperature data. WG-EMM analyses these data to arrive at an annual ecosystem assessment. Trends in the monitored parameters and anomalous years are identified for each species and site, and explanations for these phenomena are sought by examining the monitored parameters of harvested species and the environment. Since the establishment of standard methods for monitoring these parameters in 1987, CCAMLR has collected data from over 80 combinations of site, species and parameter. For some series, data are available from the late 1950s, but most data series start in the mid-1980s when CEMP was initiated.

3.2 The Evolution of Management in Existing Fisheries

Large-scale exploitation of many fish stocks in the Convention Area began before the establishment of CCAMLR, and many stocks were already overexploited in 1982 when CCAMLR came into force. Most circumpolar abundance estimates of krill stocks were in the range of tens to hundreds of millions of tonnes, and thus were at least two orders of magnitude greater than the annual catches. CCAMLR's first priority was to conserve fish stocks, not manage the krill fishery, but krill became an important issue in the late 1980s, when krill fishing began to be concentrated in the foraging ranges of krill-dependent predators such as penguins and seals.

(i) The Early Years – Conventional Approaches in the 1980s

The methods used by WG-FSA to assess exploited fish stocks have evolved from more-or-less standard methods used in fisheries assessment worldwide since the 1970s and early 1980s. One of the first methods, which has been used with mixed success, is known as virtual population analysis (VPA). A conventional VPA reconstructs the abundance of a stock over time by adding up the catches of each year class in the stock and accounting for natural mortality. This also gives estimates of recruitment to the stock back to the early years of the fishery. A typical assessment would first use the VPA to estimate stock size and recruitment, and then estimate the future stock size under different proposed management regimes in order to advise on the consequences of these regimes. Unfortunately, accurate estimation of stock trajectories and recruitment depends not only on the reliability of catch statistics, but also on the accuracy of estimates of current stock size, to which the catches and natural deaths are added backwards in time. The VPA can be good at indicating the initial size of the stock, particularly if it has been heavily fished. However, in the absence of other data, it provides no more information on current stock size than other methods.

The basic VPA can be modified to improve estimates of current stock size by 'tuning' it to ancillary data on relative or absolute abundance. This method provides the estimate of current stock abundance that gives the best statistical fit to the relative or absolute abundance data.

Although these methods use data collected from the fisheries, such as catch-at-age and effort data, such data alone do not always lead to reliable assessments. In the Convention Area, assessments have been substantially improved by Members conducting scientific surveys in areas of key interest. The use of survey data in conjunction with fisheries-derived data has become CCAMLR's preferred approach, as it has in many other fisheries conventions. In cases where stock assessments were out of date, or where there has been substantial uncertainty, the Commission has made the conduct of a fishery-independent scientific survey (see section 3.1(iii)) a condition for re-opening a fishery.

When estimates of current abundance are available, it is common practice to calculate a target fishing mortality (instantaneous rate of fishing) for the stock. This calculation is based on estimates of growth rates and natural mortality of the species in question, and is traditionally carried out as a yield-per-recruit analysis. The abundance of, and catch of, a cohort (year class) of fish are calculated throughout the cohort's life at various levels of fishing mortality. The accumulated catch from the cohort divided by the original size of the cohort at recruitment gives the yield-per-recruit figure.

For some species, the relationship between yield per recruit and fishing mortality (the 'yield-per-recruit curve') exhibits a maximum (termed F_{max}) which has been used as a target fishing mortality for those species. However, for many other species the yield-per-recruit curve does not have a maximum, and so it has been a long-standing practice to set the target fishing mortality at the value at which the tangent to the curve has a value of 10% of the tangent at zero fishing mortality. This value is known as $F_{0.1}$. CCAMLR has used $F_{0.1}$ as one of the first elements in its management policy for finfish fisheries.

The sustainability of harvesting is largely determined by two factors: the relationship between the size of the spawning stock and the subsequent survival of the offspring on entering the fishery (recruits). The objective of fisheries management should be to maximise yield while keeping the risk of overfishing the stock to an acceptably low level. Fishing at F_{max} or $F_{0.1}$ does not necessarily maximise yield and can deplete the spawning stock biomass to a level where stock recruitment is at risk (referred to in Article II as 'unstable recruitment'). To overcome this problem, CCAMLR now uses the escapement of the spawning stock as the criterion to determine the allowable level of fishing mortality.

However, the calculations for a yield-per-recruit analysis do not take into account either uncertainty in the biological parameters or random fluctuations in recruitment. For these reasons, CCAMLR has increasingly emphasised stochastic projection methods which use computer simulations to take both these forms of uncertainty into account. Their development is described in the next section.

(ii) Current Approaches – Modelling Studies

(a) Krill

The Krill Yield Model (KYM), developed after the second meeting of the CCAMLR Working Group on Krill (WG-Krill) in 1990, raised concerns about the level of krill exploitation in Subarea 48.3. At that time, the estimates of the krill biomass in part of that subarea averaged only some 0.6 million tonnes, which was barely three times the annual commercial catch of krill in that subarea.

Attempts were made at that meeting to apply a simple approach developed for fish stocks by John Beddington and Justin Cooke in 1983. Their analyses provide a numerical factor (termed γ) that can be used to multiply a single estimate of biomass obtained from a survey before harvesting begins to give an estimate of the potential annual sustainable yield. The value of the numerical factor depends on the biological parameters of the stock under consideration. Difficulties immediately became apparent when attempts were made to determine values of some of these parameters for krill, with the result that estimates of the potential annual yield for Subarea 48.3 ranged widely, from 0.2 to 13 million tonnes.

Efforts to improve both the model and the estimates of the parameters were accelerated by the Commission's request at its 1990 meeting for the provision of best estimates of precautionary catch limits for krill in the various statistical areas.

The essential features of Beddington and Cooke's approach are:

- a single estimate of only the resource biomass is available;

- annual recruitment is assumed not to fall as the spawning stock size drops, although it does fluctuate around its average level as a result of variability in the environment (these fluctuations mean that the overall biomass will also vary even without harvesting, so the approach takes account of the possibility that the survey may have been made in a year of above (or below) average abundance);

- potential yield is evaluated on the basis of satisfying a risk criterion: that even under harvesting, the probability that the spawning biomass will fall below a level at which recruitment 'on average' might be impaired is to be kept small.

The KYM has been modified to allow for:

- strong seasonal effects – unlike the customary situation for fish, where individual animals keep growing over time, seasonal effects in the Antarctic are such that nearly all somatic growth of krill takes place in the three months from November to January;

- the possibility that the fishing season may not run throughout the full year;

- the pre-fishing survey's estimate of biomass being imprecise, rather than exact;

- uncertainties in the estimates of many of the biological parameters.

Although the results from the KYM also depend on such parameters as the age at sexual maturity and age at recruitment to the krill fishery, early calculations showed that the two key parameters (to which the model was particularly sensitive) were the natural mortality rate of krill and the annual fluctuations of krill recruitment. Initially, the values of these two parameters were little more than guesses. More recently, however, analyses of krill length-distribution data from research surveys have provided better estimates of both these parameters and also better precision of those estimates. The degree of precision is one component of the overall uncertainty, which should be taken into account in the analyses by integrating it over the range of possible values for both (as well as other) parameters. This integration gives greater weight to sets of values that are most consistent with length-distribution information from research surveys.

During the development of the KYM, scientists debated whether the effects of immigration and emigration of krill from a subarea during the course of a year should be taken into account, and if so, how. Clearly, not much (if any) of the krill detected in a survey in Subarea 48.3 would remain resident there throughout the year, because of the general northeastward movement of the water masses in that subarea. Thus, on the one hand it was argued that yield estimates should be based on the total amount of krill passing through a subarea over the year, rather than only that present over the short duration of a survey. On the other hand, such an approach would not take account of the effects of fishing on krill in the other subareas through which they are transported by the currents. Given the difficulties of adjusting properly for both these effects, the present approach is (in principle) to use the yield model to provide precautionary limits for *all* subareas, based on survey abundance estimates for each. Thus the 'extra' catch that arguably could be taken in a subarea because the survey estimate could be adjusted upward to allow for immigration, can instead be taken from adjacent subareas.

The two key outputs of the KYM that are used to decide an appropriate value for the factor γ are shown in Figures 11 and 12. The krill survey abundance estimates (termed B_0) are multiplied by γ to provide precautionary limits for annual catches. The model assumes that krill fishing takes place throughout the year, as it does in the present fishery. Both plots pertain to the results of a 20-year period of fishing under a fixed TAC. The first shows the probability that the krill spawning biomass will drop below 20% of its median value in the absence of any fishery. As the intensity of krill harvesting grows (i.e. as γ increases), so does this probability, raising the risk that the spawning biomass is depleted to a level at which recruitment success may be impaired – a situation commonly referred to as 'recruitment overfishing'. As in Beddington and Cooke's original work, a value of 10% is used as a standard for this probability. Thus, as is evident from Figure 11, this criterion requires that γ be set no higher than 0.149 in fixing precautionary limits.

The arguments of the previous paragraph consider the krill fishery only in a 'single-species' context. However, the wording of CCAMLR's Article II requires that the needs of krill predators are also given consideration in setting precautionary limits for the fishery. At present, detailed modelling of the impact the fishery might have on such predators has yet to provide reliable quantitative results, so an ad hoc approach is being followed for the moment. This is based on the output from the KYM shown in Figure 12, which plots (against γ) the median krill spawning biomass after 20 years as a fraction of the corresponding value in the absence of a krill fishery (γ = 0). If only krill were to be taken into account, an appropriate target level for this ratio in terms of conventional fisheries management might be 50%. On the other hand, the best situation for the predators would be no fishing at all, i.e. a ratio of 100%. The preliminary target adopted is halfway between these two 'extremes', i.e. 75%. Reference to Figure 12 shows that this corresponds to a value of 0.116 for γ. The final stage in the application of the results from the yield model to provide a precautionary catch limit is to select the *lower* of the two values of γ (0.149 and 0.116) corresponding to these two criteria (see section 3.2(iii)).

The KYM will be continually refined as more data become available to reduce the uncertainty in estimates of some of the input parameters and as more is learnt about the relationships between these inputs. These factors could affect estimates of the value of γ that are appropriate to avoid recruitment overfishing. Possibly more important, however, will be the refinement of the krill and krill–predator models (see section 3.2 (ii)c) to provide a sounder basis for the selection of a target krill escapement value; this would address the concerns of Article II on a more scientifically defensible basis than the ad hoc approach underlying the present selection of 75%.

(b) Finfish

A very similar approach to the KYM, termed the 'Generalised Yield Model' (GYM), has been applied to some fisheries for finfish. For certain species of finfish, such as the Patagonian toothfish, the predator criterion is not applicable because they are not important prey species. In such cases, the criterion that has been applied is to maintain populations at the level likely to give the 'greatest net annual increment' (GNAI), which is conventionally assumed to be around 50% of the unexploited level. The GYM is used to make the same kinds of calculations as the KYM (in fact the KYM can be set up as a special case in the GYM). Precautionary catch limits for the lanternfish *Electrona carlsbergi*, an important prey species for fur seals, king penguins and squid, have also been calculated from a GYM in a similar way to that used for krill.

The GYM is very flexible, allowing the use of estimates of current or pre-fishing biomass, along with estimates of their uncertainty, in projections of stock biomass. Recruitment fluctuations and uncertainty in demographic parameters are taken into account, as well as the effects of previous catches on the stock. Recruitment can be expressed either as absolute levels (i.e. as numbers of fish), or relative to the pre-fishing spawning stock biomass. For Patagonian toothfish assessments, the GYM is used with recruits drawn from a random distribution, which provides absolute numbers of recruits compatible with estimates of recruitment obtained from trawl surveys. This enables CCAMLR to use the stochastic projections of the GYM to evaluate the effects of different levels of catch even without direct estimates of absolute abundance for the whole stock.

(c) Functional Relationships between Krill and Krill Predators

Krill, the species that shaped so much of the thinking behind the conservation principles of the CCAMLR Convention (Article II, paragraph 3(b)), was initially considered from the single-species perspective, although the inclusion of krill escapement into the decision rules makes some allowance for krill predators over a larger spatial scale, such as a statistical division or subarea.

When CCAMLR first looked at this problem, the KYM had not been developed and less was known about the dynamics of the krill stocks and their interaction with predators. Nevertheless, it was known that the areas of highest krill fishing activity were often close to the land-based breeding colonies of krill-eating birds and seals. These predators depend on krill being within reach of their colonies in order to feed and rear their offspring during the Antarctic summer. The recognition that the most sensitive interactions are probably occurring at much smaller scales than division or subarea means that information from fishing grounds near predator colonies will need to be incorporated into any conservation plan.

To quantify any overlap between the areas in which krill was being fished and the areas in which predators foraged for krill, the concept of the Critical Period Distance (CPD) was developed. This concept is based on the fishery's catch of krill within 100 km of predator's land-based breeding colonies between December and March when krill availability to such predators is critical. When expressed as a percentage of the total catch in a subarea, the CPD provides information on the distribution of krill catches in relation to predator colonies.

The CPD is simply a description of the potential spatial and temporal overlap between the fishery and predators foraging for krill. Whether this overlap would have any effect on predators depends on the relationship between the krill fishery, local and regional krill abundance, and the availability of krill to predators. Initial attempts to model these relationships are currently being revised to incorporate temporal aspects of penguin foraging into the model, and new standardised indices based on the niche-overlap theory are being developed to better reflect the foraging–fishery overlap.

Investigations of the interactions of a fishery, the species it harvests and other species dependent on the harvested species are part of what is termed the 'multi-species approach'. Despite various attempts worldwide to base fisheries management on multi-species approaches, most of the world's fisheries are still managed on a single-species basis – i.e. the impact of harvesting on only the harvested species is assessed. CCAMLR's use of a multi-species approach to this problem is innovative; there is little experience elsewhere in this type of assessment.

The main difficulty with a multi-species approach is that a relatively large number of parameter values must be estimated. Furthermore, each parameter estimate has an associated level of uncertainty; the more parameters used in the prediction, the greater the uncertainty that the prediction will prove correct. A multi-species approach is also likely to take longer to develop because of its great complexity. Given these difficulties, the first step in developing a sustainable harvesting strategy for krill was the single-species model of potential krill yield described above.

The next step was to propose a way in which the needs of krill-dependent species could be taken into account. In 1992, WG-Krill suggested, as a first approach, a 'one-way' model in which fluctuations in the krill resource have an impact on a predator population but not vice versa (Figure 13). The krill population is represented by a simplified form of the yield model. A simple population dynamics model is used to represent the predator population. The link between these two models ('consumption by predator' in Figure 13) is given by a functional relationship between krill abundance (expressed as a proportion of its level in the absence of fishing) and the survival rate of the predator (Figure 14).

The next step in developing the approach outlined in Figure 13 was to choose parameter estimates for the model. The parameter values used in the KYM are retained (including krill recruitment variability), but parameters that have a range of possible values are fixed at the midpoint of their presumed range. The biological parameters required by the predator model had already been monitored by CEMP. This left the functional relationship to be defined. Ideally, this could be determined by using time series of krill biomass data and predator survival rates measured simultaneously in the same areas. Measured krill biomass could then be plotted against measured predator survival and a curve could be fitted to these data, although it would then be necessary to link local krill availability (which is a function of krill abundance and distribution with time) to krill abundance as calculated by the yield model for a particular spatial area.

Unfortunately no such integrated datasets are available. Annual estimates of survival rates of certain predators at various CEMP sites are, however, available. In the absence of estimates of local krill abundance, annual krill abundance values can be calculated from the yield model. These are converted to krill availability values by adding some level of random error. To link these two datasets together, it must be assumed that any changes in the measured predator survival rates are primarily due to fluctuations in krill availability.

An assumption must also be made about the shape of the functional relationship (the example in Figure 14 uses a sigmoidal shape) between predator survival rates and krill availability. Typically, the form that is chosen is defined by the latter two parameters. Given these and the level of variability that relates krill abundance to krill availability, the set of krill abundance values from the yield model can be converted into a set of predator survival rates, which can then be compared to the observed predator survival rates. The parameter values of the functional form are varied until the simulated set of survival rates most closely matches the measured set. This is achieved by comparing their moments – mean, variance and skewness. This 'one-way' approach (Figure 13) was applied to data on Antarctic fur seal and black-browed albatross populations from South Georgia.

The nature of the relationship between the krill and predator models is of fundamental importance to the procedure as a whole. It is extremely important, in the future development of this work, that this relationship be carefully investigated. For example,

- Can most variation in predator survival rates be directly attributed to changes in krill abundance?

- How much (including local distribution, size, sex, maturity) of the krill stock is actually available for consumption by seabird and seal predators, and do fluctuations in the availability of krill mask fluctuations in absolute krill abundance?

- What is the impact of environmental conditions such as sea-ice extent and the nature and timing of local weather conditions?

- What is the true shape of the functional relationship and how robust is the model to errors in the assumption of this shape?

- In the krill fishery, factors other than fishing intensity (e.g. timing, extent and location of the fishery in relation to predators' breeding colonies) might influence krill availability to predators. Does the influence of these factors change from year to year, independently of fishing intensity?

As part of its ecosystem approach, CCAMLR is concerned about 'indirect effects' of fishing, i.e. that the removal of prey (krill) at one trophic level can indirectly affect other trophic levels, such as seabirds or marine mammals. Consequently, a second model has been developed.

This model investigates the influence of krill fishing on an Adélie penguin population by linking predator survival and reproductive success to local krill availability. This model of the indirect effects of a fishery on krill predators has four main components:

- the spatial and temporal patterns of krill availability;
- the mode of operation of the fishery and its effects on krill;
- the foraging performance (determined by empirical methods or 'rules of thumb') and survival of a predator through each of the five stages of its breeding season, incorporating a detailed empirical energy budget for chick rearing; and
- the effect of the removal of krill by the fishery on the reproductive success and adult survival of the penguins.

As with all models, there is a compromise between the level of tractability and the level of biological detail. The model focuses on parental foraging to meet requirements for the growth of a single chick. Parents and offspring are characterised by the difference between the amount of krill they need for maintenance (parents) and development (chick) and the amount of krill that they have actually eaten. Thus, variations in krill availability, due to either natural causes or fishing, will affect the breeding success of penguins.

The model uses 'offspring survival to fledging' as a measure of parental reproductive success. Offspring survival and parental survival depend on foraging behaviour, timing of breeding, and the availability of krill. The main aim of the model is to determine possible answers to the following question: 'If a certain fraction of the available krill is removed by the fishery, what is the reduction in parental reproductive success and survival?'

A typical result is shown in Figure 15(a) for chick survival and in Figure 15(b) for parental survival. The x-axis is the fraction of available krill removed by the fishery. The y-axis is the ratio of survival in the presence of the fishery to survival in the absence of the fishery; hence, it is a relative measure of survival.

Both offspring and adult survival are approximately linear functions of the fraction of krill removed. However, the slope of the relative survival of the chick is about 1.5; thus, for example, removal of 1% of the available krill leads to a reduction of 1.5% in offspring survival and parental reproductive success. On the other hand, the slope of the relationship between adult survival and the fraction of krill removed is less than one (about 0.65 for breeders and 0.5 for non-breeders). Work is continuing on incorporating more detailed spatial structure into the distribution of krill and incorporating krill abundance into post-fledging survival of the offspring.

(d) Other Predator–Prey Relationships

In the early years of CCAMLR, krill was viewed as the central component of the food web and was therefore the focus of CEMP. It is now clear that similar approaches to those developed for krill need to be developed for other important species of the food web. Exploitation of lanternfish in the second half of the 1980s and the recent interest in harvesting squid have highlighted the need to look at some other food chains. Lanternfish are the staple food of king penguins, and also of fur seals in the Indian Ocean sector. Squid feed on zooplankton, including krill, and lanternfish. They are preyed on by toothfish, albatrosses, larger penguins, seals and toothed whales. The life histories of commercial squid species are quite unlike those of finfish and krill. Consequently, although the general principles of ecosystem assessment currently applied to krill might also be used for lanternfish and squid, specific procedures will need to be developed for such assessments.

(iii) The Concept of Decision Rules

The operational objectives described in section 2 go some way towards interpreting the principles set out in Article II of the Convention. However, they are still not sufficiently specific for objective scientific analysis of different management options. 'Decision rules' have therefore been developed. A decision rule specifies the set of decisions that are made in setting, removing or varying management measures, using assessments of the status of a harvested resource.

The determination of the potential yield in the krill fisheries discussed in section 3.2(ii)a is an example of a decision rule that has three parts:

1. choose γ_1 so that the probability of the spawning biomass dropping below 20% of its pre-exploitation median level over a 20-year harvesting period is 10% (this is illustrated in Figure 16);

2. choose γ_2 so that the median escapement in the krill spawning biomass over a 20-year period is 75% of the pre-exploitation median level (this is illustrated in Figure 17); and

3. select the lower of γ_1 and γ_2 as the level of γ for calculation of krill yield.

As the values of γ_1 and γ_2 will be different, the third part of the decision rule results in the lower of the two values being applied. A similar decision rule is applied to the fisheries for Patagonian toothfish.

Additional decision rules will be needed as new fisheries or new methods of assessment are developed. For example, they will be needed to enable assessments based on CEMP data to be taken into account when adjusting catch limits or other management measures. Decision rules link the general principles set out in the Convention with the scientific assessments of specific fisheries. Thus they form a fundamental component of a scientific approach to fisheries management.

(iv) Strategic Modelling as a Scientific Basis for Developing Management Strategies

Applying the ecosystem approach to management presents new scientific challenges. As outlined earlier, this task has to be undertaken in a system with a high level of complexity, even when it is limited to a few key prey and predator species and their interactions with the environment. To make matters more difficult, the scientific research required has to be carried out in a harsh and remote environment, with limited scientific and logistical support. As one way of overcoming these difficulties, CCAMLR has started to develop strategic modelling, using computer simulation, as a tool for setting scientific priorities and developing and evaluating management options.

Strategic modelling relies on the integration of existing computer models used in CCAMLR with new models, which can then be linked together to form ecosystem models. Figure 18 shows an example of how models are linked to form a strategic model for the krill fishery. These integrated models are designed to incorporate the features of an ecosystem that may affect, and may be affected by, conservation and fisheries management. The aim is not to attempt to develop a comprehensive ecosystem model of Antarctica, but rather to develop models that can cast light on particular scientific and management questions. For example, such models can be used to help decide which factors are critical for determining the likely success of a management system for a given fishery, and give guidance on what information is needed to ensure that success. Thus, strategic models can help us to set scientific priorities in terms of critical uncertainties and the scientific resources required to resolve them. As an example, strategic models can be used to answer such questions as how many species and what geographical spread should be monitored to be reasonably certain of detecting adverse effects of krill fishing on dependent species before they exceed those permitted under Article II.

No model of an ecosystem can ever be complete, nor does any one model necessarily include all the important features of an ecosystem. For these reasons a range of models needs to be developed so that the validity of any conclusions drawn from them can be determined.

3.3 Application of the Ecosystem Approach – Incidental Mortality of Seabirds and Environmental Impacts of Fishing

CCAMLR has tackled three substantial problems relating to mortality of marine animals caused directly or indirectly by the activities of humans, mainly (if not exclusively) relating to fishing. These are:

- incidental mortality of seabirds in fisheries, particularly longline fisheries;
- entanglement of marine mammals in marine debris; and
- impacts of fishing on the seabed.

(i) Incidental Mortality of Seabirds in Fisheries, particularly Longline Fisheries

Longline fisheries were introduced in the mid-1980s to catch Patagonian toothfish. They were initially confined to the waters around Shag Rocks, South Georgia and the Kerguelen Islands. In recent years, however, longline fisheries rapidly expanded to other fishing grounds, many of which are near sub-Antarctic islands with large breeding colonies of albatrosses and petrels or are within the feeding range of these birds. Substantial numbers of albatrosses and petrels die when attempting to take squid or fish bait from hooks attached to lines being set during longline fishing. This poses a major conservation problem for CCAMLR in the Convention Area, as well as in respect of species of interest to CCAMLR in regions to the north of the Convention Area.

The problem has two facets:

- deaths of albatrosses and petrels caused by fishing within the Convention Area; and

- deaths of albatrosses and petrels breeding within the Convention Area but caught by longliners outside it (e.g. in the albatrosses' wintering areas).

In 1989, the Commission urged all Members conducting longline fishing to introduce, as soon as possible, methods to minimise the incidental mortality of seabirds (particularly albatrosses) arising from the use of longlines. In 1991, CCAMLR adopted the first conservation measure requiring vessels longlining for Patagonian toothfish in the Convention Area to use these methods (especially streamer lines to deter birds from attempting to take baits). The reporting of incidental mortality of seabirds by scientific observers on these vessels was also given much higher priority than hitherto.

In 1993, the Scientific Committee established the ad hoc Working Group on Incidental Mortality Associated with Longline Fishing (WG-IMALF) to review the whole topic, with special reference to the Convention Area and to data reported from vessels fishing in this area. The group's report to the Scientific Committee in 1994 called attention to the potential seriousness of the problem for Southern Ocean albatrosses and to the fact that they were currently at even greater risk outside the Convention Area than within it. It also noted that the removal of bait by seabirds can reduce the catch of fish significantly and that fishers themselves would benefit from helping to resolve the problem.

After reviewing methods of reducing incidental mortality, CCAMLR decided to include in its conservation measures the requirement that longlines be set at night and that offal discharge (which attracts birds) be prohibited during line-setting. In addition, CCAMLR established the requirement that international scientific observers be present on all longline vessels fishing outside national waters in the Convention Area. In 1995, the ad hoc WG-IMALF, now meeting as part of WG-FSA, emphasised that data from scientific observers were critical to ensure accurate reporting of incidental mortality, that night-time setting of longlines reduced albatross mortality (by about 80%) and that streamer lines, when correctly set, were also effective in reducing catch rates of birds.

Three new concerns were raised:

- Setting at night may increase the numbers of white-chinned petrels (*Procellaria aequinoctialis*) caught.

- The large number of vessels conducting unregulated fishing operations in the Convention Area (presumably taking no measures to avoid catching birds) is a serious threat to albatrosses.

- Some albatross species are particularly at risk at those times of the year when their foraging areas overlap very extensively with the longline fishery (e.g. black-browed albatross generally and wandering albatross in March–April).

Examination of these problems is continuing.

The most recent data (from the 1997/98 fishing season) confirmed that setting at night-time, combined with the correct use of streamer lines, almost eliminated albatross mortality, but still resulted in some mortality of white-chinned petrels. Large catches of seabirds still occur when vessels set lines during the day, at dusk, or on moonlit nights without using streamer lines.

A comprehensive analysis of the relationship between time of year and risk of albatross and petrel mortality from longline fishing in the Convention Area indicated that moving the opening of the longline fishing season for toothfish from 1 March to 1 May would bring substantial benefits (particularly until all vessels comply with the night-time setting and streamer line requirements). Therefore, in 1997, the Commission agreed to delay the start of longline fishing in most of the toothfish fisheries until 1 April in 1998 and indicated its wish to move the start date to 1 May in 1999. A compromise date of 15 April 1999 was eventually agreed in 1998.

The issue of illegal, unregulated and unreported (IUU) longline fishing was of particular concern at the 1997 meeting of CCAMLR. Ad hoc WG-IMALF estimated that the seabird by-catch in the regulated longline fishery in 1997 had been about 5 700 birds (40% albatrosses; 48% white-chinned petrels) in the Atlantic Ocean sector and about 1 000 birds (23% albatrosses; 73% white-chinned petrels) in the Indian Ocean sector. Based on known relations between fish catch and seabird by-catch and estimates of the fish catch in the IUU fishery, the seabird by-catch in the IUU fishery was estimated at 16 600–26 900 birds (if vessels operated like the average vessel in the regulated fishery in terms of compliance with the conservation measure to minimise seabird by-catch) or 66 000–107 000 birds (if they operated like the least effective regulated vessel). In either circumstance it was clear that seabird by-catch in the IUU fishery was likely to be at least 20 times that in the regulated fishery. This would be unsustainable for the albatross and petrel populations concerned, which include two albatross species (wandering albatross and grey-headed albatross (*Diomedea chrysostoma*)) of 'globally threatened' status. The Commission viewed this as a most serious problem, which it tried to resolve at both its 1997 and 1998 meetings.

Nevertheless, CCAMLR's prompt action in developing and implementing methods to reduce albatross mortality, coupled with the willingness of many fishing masters to cooperate with scientific observers, has done much to alleviate the problem within the regulated fishery until even more effective long-term solutions (e.g. setting longlines underwater) can be tested and implemented on board all longliners fishing in the Convention Area. To help fishers to minimise the by-catch of seabirds in bottom longline fisheries, CCAMLR has published the booklet *Fish the Sea Not the Sky*, which describes techniques to avoid seabird by-catch. The booklet has been distributed to all CCAMLR Members, and many international fisheries organisations and fishing companies. It is expected to be held on board longliners fishing in the Convention Area.

CCAMLR has been very active in publicising the plight of Southern Ocean albatrosses and petrels and its efforts to combat the problem in this domain. It has requested many other agencies, conventions and fisheries commissions to take appropriate action in the wintering areas of albatrosses and petrels, particularly in respect of pelagic longlining for tuna and of coastal shelf and shelf-slope longlining for a variety of other fish species.

A second, albeit minor, cause of mortality in albatrosses (and other seabirds) was collision with netsonde cables which are used to monitor the performance of bottom trawls. The Commission prohibited the use of these devices in the Convention Area from the start of the 1994/95 season.

(ii) Entanglement of Marine Mammals in Marine Debris

Entanglement of marine mammals in debris from humans' activities is a continuing problem in the Convention Area. In 1988, the Scientific Committee was advised that Antarctic fur seals at South Georgia were becoming entangled in marine debris (principally fragments of fishing net) at rates that indicated several thousand were being killed each year. CCAMLR intensified its campaign for compliance with the provisions of Annex 5 of the Marine Convention for the Prevention of Pollution from Ships (MARPOL) in its Convention Area and, in particular, targeted all fishing vessels with information (placards, posters) on the need to avoid jettisoning debris overboard, but if this was unavoidable, to ensure that any material capable of forming loops was cut.

The field program monitoring the incidence of entanglement of Antarctic fur seals at South Georgia showed that the number of animals entangled in nets declined markedly after the introduction of this measure (albeit at a time when trawl fisheries were also decreasing in the area), but that numbers entangled in polypropylene packaging bands increased. CCAMLR then introduced a conservation measure requiring that the use of these bands, used mainly for securing bait boxes, be phased out on fishing vessels by 1995/96 – and on all vessels in the Convention Area by 1996/97. Entanglement rates of fur seals in packaging bands subsequently decreased. Furthermore, most of the few packaging bands washed ashore had been cut before being discarded. The main material entangling fur seals nowadays is fragments of longlines, so there is still a need to remind fishers not to throw any material overboard, especially anything that can endanger the lives of marine animals.

At a more general level, CCAMLR attempts to monitor levels of marine debris in the Southern Ocean by recording, in a standardised fashion, rates at which debris comes ashore on selected beaches in the Antarctic and sub-Antarctic. In general, levels of debris, most of which originates from fishing vessels, have shown little sign of decrease (except possibly as a result of reduced fishing effort in recent years) and are still sufficiently high to indicate that there is much room for improvement in compliance with the provisions of MARPOL by vessels fishing in the Southern Ocean. CCAMLR also requires Members to compile registers of fishing gear lost in the Convention Area.

(iii) The Impact of Fishing on the Seabed

Most of the finfishing in the Southern Ocean up to the end of the 1980s was conducted with bottom trawls. Trawl gear affects the environment by scraping and ploughing the seabed, which resuspends sediment and destroys benthos (the fauna living in and on the bottom). The richness and diversity of the benthic fauna of the Southern Ocean are comparable to those of tropical regions, with a large number of long-lived and slow-growing forms. The extent of the impact of bottom trawls on the Antarctic benthic fauna and of the destruction of habitats and fish spawning grounds, are unknown. However, any effects are likely to be long-lasting owing to the fragility and slow recovery rate of benthic faunal communities.

To minimise the impact of trawling on non-target species in the fishery and on the seabed, and in accordance with its ecosystem approach, CCAMLR has prohibited the use of bottom trawls in the fishery for mackerel icefish around South Georgia and directed fishing for some demersal fish species that can be taken only by bottom trawls.

3.4 Application of the Precautionary Approach – the Protection of Non-target Species in Trawl Fisheries

(i) Bottom Trawling

The single-species approach, which establishes conservation measures on a stock-by-stock basis, involves a considerable risk for untargeted fisheries, such as bottom trawling, which exploit mixed-species assemblages. As a consequence, many of the species taken as by-catch in the bottom trawl fishery near South Georgia and the South Orkney Islands, such as the humped rockcod, Scotia Sea icefish and South Georgia icefish were overexploited by the mid-1980s.

CCAMLR has improved the conservation of such species by taking a more adaptive approach. TACs for target species are tied to TACs for by-catch species, so that a fishery may be closed when the TAC for one of the by-catch species is reached (even if the TAC for the target species has not been fully exploited). In other cases, fishing a target species may either be prohibited due to the risk of depleting by-catch species, as is the case of the mackerel icefish fishery around the South Orkney Islands, or be permitted only if conducted by midwater trawling, which produces low by-catches of non-target species.

(ii) Midwater Trawling for Krill

Krill is harvested in midwater with fine-mesh trawl nets. Krill catches can sometimes include a substantial by-catch of larvae and juvenile fish, such as mackerel icefish on the South Georgia shelf. By-catches are often largest when less dense or scattered krill aggregations are being fished. It is unknown whether the extent of the by-catches, for example of mackerel icefish, impair recruitment. The by-catch of juvenile fish may become a critical issue when the spawning stocks of exploited species have been reduced to such low levels that recruitment starts to decline.

CCAMLR has requested Members who fish for krill in the Convention Area to provide information on the by-catch of juvenile fish in the krill fishery, and has developed a standard protocol for scientific observations on board krill trawlers. The first results from these investigations suggested there are large spatial and seasonal differences in the occurrence of fish in krill catches, which makes it extremely difficult to assess the extent of these by-catches and their effects on the recruitment of fish stocks. Moreover, most of the studies have been undertaken during the austral summer. CCAMLR has asked Members to intensify their investigations into the by-catch of juvenile fish and to extend them to other seasons so that CCAMLR can assess more precisely where and when fish are most vulnerable to the krill fishery, and take appropriate action.

3.5 Application of the Precautionary Approach – New and Exploratory Fisheries

The preceding sections have examined two key elements in CCAMLR's approach to management – the ecosystem and precautionary approaches. In accordance with the latter, CCAMLR has recognised that fisheries should be managed from the outset, and has adopted conservation measures that set out requirements for any Member planning to initiate a fishery for any species, or in any area, that has not previously been exploited (Figure 19). At this 'new fishery' stage, the measures require that Members notify CCAMLR of their intention to start a new fishery and supply information on the nature of the proposed fishery and as much as they can on the biology of target species and the possible effects of the fishery on any dependent and associated species. In such cases, CCAMLR has limited catch or fishing effort (or both), and has also made scientific observation of the fishery obligatory. The conduct of a new fishery is limited to the Member(s) who made the notification(s).

A new fishery is designated an 'exploratory fishery' after its first year. The conservation measure that the Commission has implemented for exploratory fisheries allows for continued regulation of the fishery while the scientific information required for a full assessment of the fishery and stock(s) concerned is being collected. A major component of the exploratory phase is the implementation of a plan to collect the data required for such an assessment (Figure 19).

CCAMLR aims to ensure that an exploratory fishery is not allowed to expand faster than the information to manage the fishery in accordance with the principles of Article II is collected. To ensure information is adequate, the Scientific Committee is required to develop (and update annually as appropriate) a Data Collection Plan. This plan identifies the types of data required and how to obtain them from the exploratory fishery. Participating Members are required to provide a Research and Fishery Operation Plan for review by the Scientific Committee and Commission, as well as to submit annually the data specified by the Data Collection Plan. The Scientific Committee also sets a precautionary catch limit at a level not substantially above that necessary to obtain the information specified in the Data Collection Plan and to undertake assessments and evaluations.

CCAMLR's discussions about new and exploratory fisheries have highlighted the need to clarify the decisions and management procedures at the various stages of fishery development. In particular, the focus has been on developing uniform criteria for the resumption of 'lapsed' fisheries (i.e. those that have ceased operating for some period) and 'closed' fisheries (i.e. fisheries closed by a conservation measure) (Figure 19). While there is fundamental agreement with the general principle that a notification procedure (as for new and exploratory fisheries) should be followed for the resumption of closed or lapsed fisheries, the details of how and to what extent additional procedures (e.g. for data collection) should be implemented have yet to be finalised.

4. Conclusion

CCAMLR stands at the forefront in the development of precautionary and ecosystem-based fisheries management. The various scientific initiatives and details explained in this document represent the current wisdom within the CCAMLR Scientific Committee at the time of writing. However, it should be obvious that much of the work outlined is only in an early stage of development and its impact will only be assessable at some time in the future. The key challenge therefore is to ensure that the Scientific Committee not only communicates its findings to the rest of the world, but that it also keeps abreast of global developments in fisheries management.

Despite its perceived simplicity compared to other systems, the Antarctic marine ecosystem is as complex as any and its dynamics are further complicated by a harsh and variable environment. The added complexity of human activities has not served this ecosystem well in the past, and CCAMLR's precautionary approach to management was a novel attempt to ensure that future exploitation of Antarctic marine living resources do not repeat the excesses of recent history in the area. This has posed a grave challenge for the scientists involved in formulating CCAMLR's management advice. Consequently, the approach developed has had to be dynamic and has had to take account of high levels of uncertainty in a way which strives to ensure effective practical implementation. *Understanding CCAMLR's Approach to Management* serves as a benchmark as well as an attempt to publicise the work of the Scientific Committee in a way which is both understandable and comprehensive.

Annex I

A Brief Description of the Main Species Exploited in the Southern Ocean

Krill (*Euphausia superba*)

Distribution
Circum-Antarctic south of the Antarctic Polar Front, with centres of abundance in the Scotia Arc and some regions close to the continent in the Indian Ocean sector. Usually confined to the Antarctic surface water (0–100 m depth) in oceanic areas, krill has also been found close to the sea floor down to 350–400 m depth in shelf areas.

Size and Age
Krill grows to a maximum of 64 mm in length and may live for six to seven years.

Biology
Krill attain sexual maturity at two (females) and three (males) years of age. They spawn up to 10 000 eggs between December and March, with considerable interannual variation in timing. Recruitment success appears to be closely linked to the extent of pack-ice in the winter before and after spawning. In summer, krill preys on microscopic plankton, such as flagellates and diatoms, while in winter it feeds largely on ice algae from the undersurface of ice flows. Aggregations of krill can cover many square kilometres and may contain hundreds of thousands of tonnes of krill. Krill is the staple food of many baleen whales, seals, seabirds, fish and squid. Because of its position in the food web between the microscopic phytoplankton and the large vertebrate predators, and its abundance, krill is considered the key species in the Seasonal Pack-ice Zone and parts of the Ice-free and High-latitude Antarctic Zones.

Exploitation
Krill harvesting started in 1972/73 and peaked in 1981/82 (Figure 7). By the mid-1980s annual catches had stabilised at 350 000 to 400 000 tonnes, but they declined substantially at the beginning of the 1990s when countries of the former Soviet Union stopped fishing for krill. Annual krill catches are currently in the order of 90 000 to 100 000 tonnes.

Status
It is unlikely that the present level of fishing will have an adverse effect on the stock(s).

Marbled rockcod (*Notothenia rossii*)

Distribution
Marbled rockcod is a widely distributed species, found at the northern end of the Antarctic Peninsula, around the Scotia Arc, off Prince Edward, Crozet, Kerguelen, Heard, McDonald and Macquarie Islands, and on Ob and Lena Banks.

Size and Age
The species grows to a length of 85 to 92 cm and a weight of 8 to 10 kg. It can live for 15 to 20 years.

Biology
Three stages of the life cycle of this species have been distinguished: the fingerlings are pelagic for the first 6 to 12 months of their lives, after which they settle on the bottom in near-shore waters, often in kelp beds. They remain in shallow waters for four to six years. On reaching maturity at a length of 43 to 48 cm and an age of five to seven years, they migrate offshore to

deeper water, where they recruit to the spawning stock. They spawn from April to June at South Georgia and in June and July near the Kerguelen Islands. The eggs are 4.5 to 5.0 mm in diameter. Fecundity ranges from 19 000 to 130 000 eggs. The larvae hatch in September and October. The marbled rockcod's food habits are related to the life-history stage: fingerlings feed on small planktonic copepods, hyperiid amphipods and fish larvae; juveniles on amphipods, isopods, fish, euphausiids and algae; and adults mainly on euphausiids, ctenophores, fish and jellyfish.

Exploitation
Marbled rockcod was the target species in the early days of Antarctic fisheries (late 1960s and early 1970s) around South Georgia and the Kerguelen Islands (Figures 2 and 5). Catches exceeded 100 000 tonnes in some seasons, with the highest catch of about 400 000 tonnes at South Georgia in 1970/71 (Figure 2). The species was fished at the South Orkney Islands (Figure 3) and the South Shetland Islands in the late 1970s, with catches reaching about 20 000 tonnes in 1979/80 around Elephant Island. Directed fishing for marbled rockcod was prohibited by CCAMLR in 1985.

Status
Despite being protected for more than 10 years, all exploited stocks still appear to be only fractions of their pre-fishing sizes. Only around the Kerguelen Islands is marbled rockcod beginning to show signs of recovery.

Mackerel icefish (*Champsocephalus gunnari*)

Distribution
Mackerel icefish is found along the Scotia Arc from Shag Rocks and South Georgia in the north, to west of Adelaide Island (Antarctic Peninsula) in the south, around Bouvet Island and on the Kerguelen–Heard Plateau (Kerguelen, Skif Bank, Heard Island and some nearby seamounts). Mackerel icefish is a shallow-water coastal species found mainly between 100 and 350 m depth, although it is found as deep as 700 m.

Size and Age
This species attains lengths of 60 to 66 cm in the Scotia Arc region and 45 cm on the Kerguelen–Heard Plateau. Maximum ages at South Georgia were estimated as 12 to 15 years, and at Kerguelen 5 to 6 years.

Biology
Mackerel icefish is dependent on the availability of food, preferably euphausiids, in midwater. Krill is its staple food in the Atlantic Ocean sector, with pelagic amphipods and mysids as additional prey at South Georgia. In the Indian Ocean sector, euphausiids other than krill and pelagic amphipods make up the bulk of the diet. The fish becomes sexually mature at about 25 cm (=3 years old) at South Georgia and the Kerguelen Islands, and at about 35 cm (4 to 5 years) in the southern Scotia Arc region. Spawning, with a few exceptions, occurs in coastal waters from February to July in the Atlantic Ocean sector and from April to August/September in the Indian Ocean sector, but with differences in the timing between stocks. Fecundity ranges from 1 200 to 31 000 eggs, depending on the size of the fish and the stock the fish belongs to. Egg diameter is from 3.5 to 4.1 mm in the Atlantic Ocean sector and 2.6 to 3.2 mm in the Indian Ocean sector. The larvae hatch in winter–spring at South Georgia and in spring–summer on the other grounds.

Exploitation
Mackerel icefish was one of the main target species in the trawl fishery for 15 to 20 years after the stocks of marbled rockcod were depleted (Figures 2 to 5). The fishery off the South Orkney and South Shetland Islands ended in the first half of the 1980s, after the two good year classes forming the backbone of the fishery were exhausted (Figures 3 and 4). Harvesting at

South Georgia was no longer viable after the end of the 1980s, although a low total allowable catch (TAC) was set to reopen the fishery at a lower level (Figure 2). Currently, the species is exploited at South Georgia and Heard Island, and at the Kerguelen Islands only when a strong year class enters the fishery (Figure 5).

Status
The South Georgia stock recovered from three episodes of heavy exploitation in the mid-1970s and in the early and mid-1980s. However, stock size remained low after a fourth decline following the 1989/90 season. The stocks around the South Orkney and the South Shetland Islands are still only fractions of their sizes at the beginning of the fishery in 1977/78. The stock around the Kerguelen Islands supports a fishery only when a strong year class enters the fishery, and there is evidence that this stock has declined over the last decade. A low TAC has recently been set for the stock – probably never before commercially exploited – living on banks near Heard Island.

Grey rockcod (*Lepidonotothen squamifrons*)

Distribution
The grey rockcod has a circum-Antarctic distribution around the sub-Antarctic islands and seamounts that lie between them, such as the Ob and Lena Banks in the Indian Ocean sector. The species is found down to 800 m.

Size and Age
The maximum sizes observed were from 50 to 55 cm and the weights from 2 500 to 3 000 g. Fish may live as long as 16 to 20 years.

Biology
Although mostly found at the bottom, the grey rockcod feeds primarily on macrozooplankton, such as euphausiids, pelagic amphipods, jellyfish and salps. The fish becomes sexually mature at 28 to 36 cm (from 5 to 9 years old) at South Georgia and in the Kerguelen Islands. They spawn from October (Kerguelen, Crozet) to February (South Georgia). Fecundity varies from 58 000 to 196 000 eggs, depending on the size of the fish. Egg diameter is from 1.4 to 1.7 mm. The larvae hatch from the end of November.

Exploitation
This species has been exploited commercially, mainly off the Kerguelen Islands and on Ob and Lena Banks. At South Georgia, grey rockcod has been harvested only irregularly, and generally less than 1 000 tonnes per annum has been taken. In the Kerguelen Islands, grey rockcod was the third most important species (after marbled rockcod and mackerel icefish) for almost two decades of fishing (Figure 5). The fishery was closed by the French authorities at the beginning of the 1990s after it became evident that the stock was heavily depleted. The fishery on Ob and Lena Banks, where grey rockcod was the only target species, was closed by CCAMLR at the beginning of the 1990s for the same reason.

Status
Recent surveys suggest that the stock off the Kerguelen Islands is still at a low level; consequently, the fishery remains closed. The status of the two stocks on Ob and Lena Banks is unknown. In recent years, a low TAC was set to provide an incentive to reopen the fishery and to conduct a scientific survey to assess the status of the stock. This TAC was not taken and the fishery was closed again in 1997/98. The status of the stock around South Georgia is also unknown. Directed fishing for this stock is prohibited.

Patagonian toothfish (*Dissostichus eleginoides*)

Distribution
Patagonian toothfish is widely distributed, from the slope waters off Chile and Argentina south of 30 to 35°S, south of South Africa and south of New Zealand, to the islands and banks in sub-Antarctic waters of the Atlantic and Indian Ocean sectors and Macquarie Island on the Indo–Pacific boundary of the Southern Ocean. Southernmost records of the species are for the South Orkney Islands and the South Sandwich Islands. It is found as deep as 2 500 to 3 000 m.

Size and Age
The maximum size and weight observed are, respectively, 238 cm and about 130 kg. Reliable age estimates for individuals larger than 100 to 120 cm are scarce. However, individuals close to the maximum size are likely to be from 40 to 50 years old or even older.

Biology
Patagonian toothfish feed on a variety of other fish, octopods, squid and crustaceans. They become sexually mature at 70 to 95 cm when they are 6 to 9 years old and spawn over the continental slope from June to September. The species' fecundity ranges from 48 000 to more than 500 000 eggs, varying with fish length and geographical locality. The eggs, which are from 4.3 to 4.7 mm in diameter, are generally found in the upper 500 m of the water column in waters from 2 200 to 4 400 m deep. They probably hatch in October–November.

Exploitation
Patagonian toothfish are being exploited by longline and bottom trawl both inside and outside the Convention Area where catches were first reported in 1976/77. Longline fishers targeted fish around South Georgia from 1985/86, with annual reported catches of 4 000 to 9 000 tonnes (Figure 2). Fishing was by Soviet longliners in the first few years, but is now mostly by Chilean and Argentinian vessels. Around the Kerguelen Islands, Patagonian toothfish has been targeted since 1984/85, first by the former USSR fleet (later Ukrainian) and later by French trawlers. In recent years, it has also been exploited by Ukrainian longliners. Annual reported catches in this region have been in the order of 1 000 to 9 000 tonnes (Figure 5). Since 1996/97, longlining for Patagonian toothfish has expanded rapidly into the slope waters of previously unfished islands, banks and seamounts in the Indian and Pacific Ocean sectors of the Southern Ocean. In spite of conservation measures implemented by CCAMLR, there is a considerable amount of unregulated and illegal fishing. In the 1996/97 season, estimated catches from unregulated and illegal fishing exceeded those from regulated fishing by a factor of at least five.

Antarctic toothfish (*Dissostichus mawsoni*)

Distribution
The geographical distribution of Antarctic toothfish is confined to the waters around the Antarctic continent with a northern limit at about 60°S. There are occasional records of this species from as far north as 57°S in the Atlantic and Indian Ocean sectors. Its bathymetric range extends to about 800 m.

Size and Age
The maximum size and weight observed are, respectively, 180 cm and about 75 kg. Individuals of 140 to 165 cm in length have been estimated to be from 22 to 30 years old.

Biology
Antarctic toothfish feed on a variety of other fish, octopods, squid and crustaceans. They are likely to become sexually mature at a similar length to Patagonian toothfish and probably spawn

over the continental slope in August–September. The species' fecundity ranges from 470 000 to more than 1.3 million eggs, depending on the length of the fish.

Exploitation
Since 1996/97 Antarctic toothfish have become the target of a number of new and exploratory fisheries.

Status
The fishery is regulated by precautionary TACs imposed by CCAMLR for new and exploratory fisheries.

Patagonian rockcod (*Patagonotothen guntheri*)

Distribution
This species is found on the southern Argentine Patagonian shelf, and off the Falkland/Malvinas Islands and Shag Rocks. Single specimens have been found at South Georgia. It is most abundant in waters shallower than 250 m, but has been found at 350 m depth.

Size and age
The species attains a total length of 23 cm. The maximum age recorded is 6 years.

Biology
Patagonian rockcod is apparently benthopelagic, leaving the bottom to feed in the water column. At Shag Rocks this species generally preys on krill and, to a much lesser extent, the hyperiid amphipod *Themisto gaudichaudii*. It attains sexual maturity when 12 to 16 cm long. The egg size is 1.4 mm in diameter. Fecundity ranges from 6 000 to 23 000 eggs. In the Shag Rocks area, they spawn from September to October.

Exploitation
This species was exploited in the Shag Rocks area from 1978/79 to 1989/90. Because of the small size of the species, catches were mostly reduced to fish meal. The fishery was closed by CCAMLR after it became apparent that the stock was depleted.

Status
The current status of the stock is unknown. CCAMLR has prohibited directed fishing for this species.

Sub-Antarctic lanternfish (*Electrona carlsbergi*)

Distribution
This species has a circumpolar distribution between the Subtropical Convergence and the waters just south of the Antarctic Polar Front. Dense aggregations have been found around South Georgia and Shag Rocks. Sub-Antarctic lanternfish are found mostly in the upper 200 m of the water column, but at greater depths towards the Subtropical Convergence.

Size and Age
The maximum size and weight rarely exceed 10 cm and 14 g respectively. Fish live four to five years.

Biology
The main components of the diet are copepods, pelagic amphipods and euphausiids. Fish attain sexual maturity at 75 to 78 mm. Spawning is likely to take place between the sub-Antarctic and

the Subtropical Frontal Zone in the austral summer–autumn. Egg diameter is from 0.7 to 0.8 mm. This species spawns several batches of eggs over the season. It is not known when the larvae hatch.

Exploitation
The Soviet Union began a trawl fishery for lanternfish (reported indiscriminately as *E. carlsbergi*) in the Antarctic Polar Front in the 1980s, with annual catches initially varying between 500 and 2 500 tonnes. Catches increased from 1987/88 by 14 000 to 23 000–29 000 tonnes in the two subsequent seasons, and peaked in 1990/91 (78 000 tonnes) and 1991/92 (51 000 tonnes) (Figure 2). The fishery lapsed in the 1992/93 season, as it was no longer considered to be economically viable.

Status
The status of the stock(s) is unknown. A TAC has been imposed by CCAMLR on the fishery in the South Georgia region (Statistical Subarea 48.3).

Humped rockcod (*Gobionotothen gibberifrons*)

Distribution
The geographic distribution of this species is confined to the Atlantic Ocean sector (northern part of the Antarctic Peninsula, islands of the Scotia Arc). Humped rockcod has been found down to 750 m, but is most abundant between 100 and 400 m depth.

Size and Age
This species may grow to 55 cm in length and 1 800 to 2 000 g in weight. At South Georgia, fish may live from 15 to 20 years.

Biology
Humped rockcod eat primarily benthic prey, such as tube worms, brittle stars, sea urchins and molluscs. The fish becomes sexually mature at 34 to 36 cm at South Georgia and at a slightly smaller size on the more southerly grounds. Spawning occurs at the end of the austral winter, but with latitudinal differences between stocks. Fecundity ranges between 21 000 and 130 000 eggs. Egg diameter is 2.0 to 2.5 mm. The larvae hatch in spring and early summer. Juveniles change from pelagic to benthic life at the end of the austral summer.

Exploitation
The first catches of this species were reported in 1976/77. Together with some icefish species, humped rockcod has been primarily a by-catch of the bottom trawl fishery targeting mackerel icefish. Only in some years, such as in 1977/78 at South Georgia, was this species targeted by the fishery, taking annual catches of more than 5 000 to 10 000 tonnes. The directed fishery on this species was closed by CCAMLR in 1989.

Status
There is evidence that the stock around South Georgia has partly recovered from depletion. The status of the stock near the South Orkney Islands is unknown. The stock around Elephant Island appears to have been little affected by fishing.

Wilson’s icefish (*Chaenodraco wilsoni*)

Distribution
Wilson’s icefish has a circum-Antarctic distribution, with northernmost records coming from the South Orkney and the South Shetland Islands. It is found down to 800 m depth.

Size and Age
Maximum size and weight observed are, respectively, 43 cm and about 700 g. Ages have not been estimated.

Biology
Wilson's icefish feeds primarily on krill, and to a lesser extent on fish. It becomes sexually mature at 23 cm and spawns in October–November, but its spawning grounds are unknown. Fecundity is 300 to 2 000 eggs in individuals of 30 to 32 cm in length. Egg diameter is from 4.4 to 4.9 mm. The larvae are likely to hatch in the austral autumn–early winter.

Exploitation
Polish and former East German trawlers reported catches of 10 100 tonnes and 4 300 tonnes respectively from Statistical Subarea 48.1 in 1978/79 and 1979/80, when concentrations of Wilson's icefish were detected north and northeast of Joinville Island at the tip of the Antarctic Peninsula (Figure 4). In the 1980s this species was taken regularly in an exploratory fishery of the Soviet Union off the coasts of the Antarctic continent. Depending on the ice conditions and the availability of fish aggregations, between 270 and 1 800 tonnes were caught each year. The fishery lapsed at the end of the 1980s when it was no longer considered to be economically viable.

Status
The status of the stock(s) is unknown.

Scotia Sea icefish (*Chaenocephalus aceratus*)

Distribution
The geographic distribution of this species is confined to the Atlantic Ocean sector (northern part of the Antarctic Peninsula, islands of the Scotia Arc, Bouvet Island). Scotia Sea icefish has been found down to 770 m, but is most abundant between 100 and 350 m depth.

Size and Age
Females attain 70 to 75 cm and up to 3 800 g, males attain 55 to 58 cm and 1 300 g. At South Georgia, they may live for 13 to 15 years.

Biology
Post-larvae and juveniles up to 30 cm in length feed primarily on pelagic and benthopelagic organisms, such as krill and mysids. Older juveniles and adult fish are bottom-dwelling and prey mostly on other fish. Males reach maturity at 35 to 45 cm and females at 45 to 55 cm. The species spawns from April to July in coastal waters. Fecundity ranges from 3 000 to 22 000 eggs. The diameter of ripe eggs is 4.4 to 4.7 mm. The larvae hatch between August and October.

Exploitation
Catches of the species have been reported since 1976/77. Scotia Sea icefish has primarily been a by-catch species in the bottom trawl fishery targeting mackerel icefish. Only occasionally, such as in 1977/78 at South Georgia, has the species been targeted by the fishery. Annual reported catches never exceeded a few thousand tonnes per statistical subarea. However, there is evidence that part of the by-catch in other fisheries was not reported. The fishery was closed by CCAMLR in 1989 when stock assessments indicated that some stocks had been depleted to below 50% of their sizes before exploitation.

Status
Research surveys suggest that the stocks around South Georgia and Elephant Island have largely recovered from depletion. The status of the stock near the South Orkney Islands is unknown.

South Georgia icefish (*Pseudochaenichthys georgianus*)

Distribution
South Georgia icefish is found off islands of the Scotia Arc and the northern part of the Antarctic Peninsula down to 475 m.

Size and Age
The species attains a length of 55 to 60 cm and a weight of 2 000 to 2 500 g. Specimens up to 15 years of age have been reported; however, age determinations differ widely between researchers.

Biology
South Georgia icefish feed almost exclusively on krill and fish. At South Georgia, they spawn in the austral autumn (March to May). Fecundity ranges from 5 000 to 11 000 eggs; the eggs are up to 4.8 mm in diameter. The larvae hatch between August and October.

Exploitation
The first catches were reported in 1976/77. The species has been a regular by-catch in the bottom trawl fishery, but has been targeted only in some years, such as 1977/78 at South Georgia and in 1979/80 in the South Orkney Islands. Annual reported catches exceeded a few thousand tonnes per statistical subarea in 1977/78. However, there is evidence that part of the by-catch in other fisheries was not reported. The fishery for this species was closed in 1989 after it became evident that the stocks at South Georgia and off the South Orkney Islands were depleted.

Status
The stock at South Georgia appears to have partly recovered from exploitation in the late 1970s–early 1980s. The status of the stock around the South Orkney Islands is unknown.

Stone crabs (*Paralomis spinosissima, P. formosa*)

Distribution
These species have been found at the South Orkney Islands, but appear to be most abundant in the South Georgia–Shag Rocks area. They are found at depths between about 100 m to more than 1 000 m.

Size and Age
Maximum carapace length is 122 mm in males and 112 mm in females of *P. spinosissima* and 102 mm in males of *P. formosa* at South Georgia. No age estimates have yet been made.

Biology
Information on the biology of the two species is limited to estimates of length at sexual maturity. Female *P. spinosissima* mature at 62 mm carapace length, male *P. spinosissima* at 66 mm (Shag Rocks) and 75 mm (South Georgia), and male *P. formosa* at 80 mm carapace length (South Georgia).

Exploitation
P. spinosissima was the main species in the experimental crab fishery in the Shag Rocks–South Georgia area between 1992/93 and 1995/96. The fishery used crab pots; all other bottom gear was prohibited. It was limited to sexually mature male crabs. A TAC of 1 600 tonnes per annum was imposed on the fishery. The one US fishing vessel that entered the fishery removed a total of 835 tonnes of crabs over three seasons (see section 1.2). The fishery was discontinued after the 1995/96 season because it was not viable.

Status
The impact fishing has had on the stocks is unknown.

Martialia hyadesi

Distribution
The squid *Martialiahyadesi* is a circum-Antarctic species whose distribution is linked to the Antarctic Polar Front. It appears to be particularly abundant in the southwest Atlantic Ocean sector, but is also found near the Kerguelen Islands and Macquarie Island.

Size and Age
The species attains a maximum mantle length of 50 cm. Its life span is probably two years.

Biology
M. hyadesi feed largely on mesopelagic fish, such as lanternfish. The species reproduces once during its lifetime. Its spawning areas are not known, but the catch of a few small juvenile specimens on the edge of the Patagonian shelf suggests there is some spawning there. This species is a large part of the squid diet of toothfish, southern elephant seals, grey-headed and black-browed albatrosses, and white-chinned petrels.

Exploitation
M. hyadesi are regularly caught in small quantities on the extreme eastern edge of the Patagonian shelf in the fishery for the squid *Illex argentinus*. In some years, when oceanographic conditions are favourable, it is present in much larger quantities in this fishery. About 26 000 tonnes were caught in 1995 on the Patagonian shelf edge to the northeast of the Falkland/Malvinas Islands. There is currently an exploratory fishery for *M. hyadesi* in Statistical Subarea 48.3 (South Georgia), where about 80 tonnes were caught in 1996/97.

Status
The status of the stock(s) is unknown.

Annex II

A Brief Description of Species Monitored by the CCAMLR Ecosystem Monitoring Program

Antarctic fur seal (*Arctocephalus gazella*)

<u>Distribution</u>
Antarctic fur seals breed on most sub-Antarctic islands in the Atlantic and Indian Ocean sectors from South Georgia to Macquarie Island, but ~95% of the world's population is found at South Georgia. They also breed in small numbers at the South Sandwich, South Orkney and South Shetland Islands and at a few sites on the northern Antarctic Peninsula. The total population at South Georgia is approaching 3 million individuals. Although males generally move south from South Georgia towards the ice edge after breeding, some are present at South Georgia all winter. Females disperse after breeding but their distribution at sea is unknown.

<u>Size and age</u>
Adult males are up to 2 m long, weigh from 120 to 220 kg, and live for up to 15 years. Sexual maturity is reached at around age 4, but males normally do not breed until 6 to 7 years old. Adult females are up to 1.5 m long, weigh from 25 to 60 kg, and live for up to 20 years. They mature from 2 to 4 years of age and produce a single pup in most years.

<u>Biology</u>
In the Atlantic Ocean sector, Antarctic fur seals feed on krill (*E. superba*), but also take fish, such as mackerel icefish and lanternfish (Myctophidae). In the Indian Ocean sector, lanternfish are their main prey. They give birth between late November and early January, when dominant males hold territories in the breeding colonies. Females mate again five to seven days after parturition and thereafter make regular four- to six-day trips to sea to find food. Lactation lasts four months and pups are weaned in early April.

<u>Exploitation</u>
The species was nearly exterminated by sealing in the 19th and early 20th centuries. By 1920 the species was considered extinct, but during the 1920s sightings were reported from South Georgia. By 1957 a colony had become established. During the 1960s the population growth rate was close to the biological maximum (18% per annum); by the 1980s it had declined to 10% per annum.

<u>Status</u>
Antarctic fur seal numbers are increasing throughout the Southern Ocean. Their increase in some locations may be driven by emigration from South Georgia. Entanglement in marine debris is thought to be the only current threat to this species.

Crabeater seal (*Lobodon carcinophagus*)

<u>Distribution</u>
Although this species is distributed circum-Antarctic and within the pack-ice zone, it is especially abundant towards the marginal-ice zone. Individuals have been shown to move over many thousands of kilometres and evidence suggests that crabeater seals in the Antarctic belong to a single population, with little or no segregation between residual pack-ice zones. These seals are most commonly solitary, but are sometimes found in groups of 50 to 100 swimming close together.

Size and age
Crabeater seals reach 2.6 m in length, weigh up to 200–300 kg and may live for over 40 years. Sexual maturity of both males and females is at 4 to 6 years of age.

Biology
The main prey is krill with a small proportion of fish, such as Antarctic silverfish (*Pleuragramma antarcticum*). Their diving behaviour is consistent with feeding on krill in the top 50 to 60 m. The pups are born during September and October. Lactation lasts 15 to 20 days and, towards weaning, mothers mate with an attending male.

Exploitation
In the past, small numbers of crabeater seals have been exploited as food for sledge dogs and, occasionally, as part of a limited commercial harvest. There is no current exploitation.

Status
Estimates of the number of crabeater seals vary from 7 to 30 million. A figure of 10 to 12 million is most likely, but a more precise estimate is required to discern trends in the size of the population. There are no known threats to crabeater seals at present.

Adélie penguin (*Pygoscelis adeliae*)

Distribution
This species' breeding distribution is circum-Antarctic, with concentrations in the Ross Sea, the Antarctic Peninsula and associated island groups, as far north as the South Sandwich Islands. Outside the breeding season this penguin is mainly confined to the pack-ice and marginal-ice zones. The lowest estimate of the total breeding population is about 2.5 million pairs.

Size
Overall length 70 cm, weight about 4 to 5 kg.

Biology
The breeding season starts in October and ends in February. The eggs are incubated for 35 days (two long shifts by each parent) and the chicks reared for 50 to 60 days. The birds usually moult on the sea-ice before dispersing into the pack-ice and marginal-ice zones for winter. On average, breeding starts at age 5 (female) to 6 (male), and can continue for the next 8 to 10 seasons. They have high fidelity to nest site, colony and place of birth. Juveniles usually first return to their birth site at 2 years old.

The penguin's diet mainly consists of crustaceans (krill) but fish, especially Antarctic silverfish, may be important at colonies on the Antarctic continent. Of crustaceans, *E. superba* dominates the diet of birds breeding in the Peninsula region. In the Ross Sea, *E. crystallorophias* is dominant; at other continental sites both *Euphausia* species are taken, proportions varying substantially within and between years.

Status
In the Ross Sea, colonies declined until 1970, remained stable in the 1970s and increased significantly in the 1980s, but are currently decreasing. At other continental sites more limited data suggest stability or slight increase from the 1950s to the 1980s, with some evidence of local increases in the 1990s. In the Peninsula region, colonies increased steadily from the 1940s to the 1970s, remaining stable (with considerable fluctuation) during the 1980s, but most have decreased in the 1990s.

Chinstrap penguin (*P. antarctica*)

<u>Distribution</u>
Breeding is virtually confined to the northern Antarctic Peninsula and associated island groups (particularly the South Sandwich Islands), with the northern limit at South Georgia. The only other breeding sites are Peter I, Balleny and Heard Islands; their current status is unclear. The world's breeding population is estimated at 7.5 million pairs – but this assumes 5 million pairs at the South Sandwich Islands, which have not been adequately surveyed.

<u>Size</u>
Their overall length is 70 cm, and weight about 4 kg.

<u>Biology</u>
The duration and chronology of the breeding cycle are similar to those of the Adélie penguin, but are shifted one month later, i.e. late October–early November to late February–early March. After breeding, chinstrap penguins moult (usually on land, often near breeding sites) and then disperse, mainly to open-water areas at the edge of the marginal-ice zone. Age of breeding, site fidelity and survival rates have not been recorded, but are probably similar to the Adélie penguins'. In the breeding season they eat krill almost exclusively.

<u>Status</u>
Peninsula populations increased rapidly from the 1940s to the 1970s; up to 1990 there were substantial fluctuations, but the populations were basically stable. However, there is evidence of recent population declines at many sites.

Gentoo penguin (*P. papua*)

<u>Distribution</u>
Widespread as a breeding species at sub-Antarctic islands in the South Atlantic and South Indian Oceans and at Macquarie Island, the gentoo penguin is also widespread on the Peninsula (and associated island groups) south to 64°S. The total world breeding population is about 317 000 pairs (33% at South Georgia, 21% at the Falkland/Malvinas Islands, 12% at Kerguelen).

<u>Size</u>
This species' overall length is 75 cm, and weight 5 to 7 kg.

<u>Biology</u>
At most sites most of the population probably remains near the breeding site year-round. The start of breeding is very variable between years and sites, being earliest (June) and longest at Indian Ocean sites; it more typically starts later (October) and is more synchronised, for example, at South Georgia and the South Shetland Islands. Incubation lasts 35 days (in shifts of only one to three days) and chick-rearing lasts from 80 to 120 days. After breeding they moult ashore, often near the breeding colony. Breeding can start as early as 2 years (mean 3 years) of age, with 8 to 10 further breeding seasons on average. Site and mate fidelity are strong but colonies are prone to shift location periodically. In the Atlantic Ocean sector the diet mainly comprises *E. superba*, less often also substantial quantities of fish, particularly mackerel icefish (*C. gunnari*) and nototheniids. In the Indian Ocean, fish (especially myctophids and nototheniids) dominate, with *E. vallentinii* (and *Nauticaris marionensis* at Marion Island) the main crustaceans.

<u>Status</u>
At the Falkland/Malvinas Islands and South Georgia, numbers have decreased by 20 to 40% over the last 20 years. Some Peninsula populations have increased by similar percentages over the last 10 to 15 years. Populations, especially in the Indian Ocean, are very susceptible to disturbance by humans.

Macaroni penguin (*Eudyptes chrysolophus*)

Distribution
This species is a widespread breeder, usually in very large colonies, at sub-Antarctic and similar islands in the Atlantic and Indian Oceans from Chile to Heard Island; its southern limit is effectively in the Elephant Island group (South Shetland Islands). The world breeding population is estimated at about 9 million pairs, but reliable recent data are lacking for many sites. Its strongholds, in descending order, are South Georgia and Crozet, Kerguelen, Heard and McDonald Islands. Outside the breeding season, its distribution is virtually unknown.

Size
The macaroni penguin has an overall length of 70 cm, and weighs 3 to 4 kg. Markedly sexually dimorphic, males are about 10% larger than females.

Biology
This penguin returns to colonies in late October–early November. Incubation (35 days) and brooding (about 20 days) are done in three long shifts (with the middle one by the female). Chick-rearing takes from 55 to 70 days. The adults then spend from 15 to 30 days at sea before returning to the breeding colony for 20 days to moult and fast. On average, it first breeds at 8 years of age, showing high site and mate fidelity. Juveniles of all ages return to shore to moult, often to their natal colony. They eat mainly, sometimes exclusively, euphausiid crustaceans, typically *E. superba*, (sometimes with *Thysanoessa* spp.) or *E. vallentinii* in the Indian Ocean. Occasionally tiny fish (mainly myctophids), particularly towards the end of chick-rearing, and the amphipod *T. gaudichaudii* are taken in some quantity.

Status
Few data exist. Numbers increased in the Kerguelen Islands from 1962 to 1985; there is no subsequent information. At South Georgia, numbers probably increased between the 1950s and the 1970s; since 1977 there has been a substantial decline, perhaps by up to 50%.

Black-browed albatross (*Diomedea melanophrys*)

Distribution
The black-browed albatross breeds at South Georgia, Crozet, Kerguelen, Heard, Macquarie and Antipodes Islands; also in the Falkland/Malvinas Islands and South America. The world population numbers about 680 000 pairs, 86% in the Falkland/Malvinas Islands, 10% at South Georgia. In the breeding season, the birds are mainly associated with continental shelves and adjacent frontal zones. Non-breeders and immatures are widely distributed between 40 and 65°S. Breeding birds migrate north in winter, especially to coastal waters around South America, South Africa and Australia.

Size
This albatross stands about 50 cm tall (overall length about 90 cm), with a wing span up to 250 cm. It weighs about 4 kg.

Biology
In September–October, the adults return to their colonies and lay in mid–late October. The eggs are incubated for 68 days and the chicks fledge in April–May after another 115 days. Adults show very high site and mate fidelity; juveniles show high fidelity to their birth site. This bird breeds first, on average, at about 10 years of age. Its diet is a varied mixture of crustaceans, fish and cephalopods. At South Georgia, fish (usually *P. guntheri*, *P. georgianus* and *C. gunnari*); squid (mainly ommastrephids *M. hyadesi*); and crustaceans (chiefly *E. superba*). In the Indian Ocean, krill are absent, crustaceans rare and fish predominant, with ommastrephid squid also important.

Status
The Falkland/Malvinas Islands population increased rapidly during the 1980s (in concert with a major offal-producing fishery), but is now virtually stable. The population at Bird Island, South Georgia, fluctuated but was fairly stable until the late-1980s; since 1989 it has decreased by about 7% a year, with reductions in adult survival and, especially, juvenile recruitment. Interactions in the non-breeding season with longline fisheries, especially those for toothfish around South Georgia and elsewhere, are believed to be the most likely cause. The Kerguelen population is also decreasing, and at-sea abundance in the Prydz Bay region decreased significantly between 1981 and 1993.

Antarctic petrel (*Thalassoica antarctica*)

Distribution
Breeding is confined to the Antarctic continent, all but one of the 35 known colonies being in eastern Antarctica. Colonies are often very large, and many are on mountain tops well inland. The birds feed mainly in open-water areas near ice. Outside the breeding season they are mainly associated with polynyas in pack-ice and with the marginal-ice zone. The world population is unknown, but rough estimates are of several million birds.

Size
Its overall length is 45 cm, wing span 100 cm, and weight about 700 g.

Biology
Birds arrive at the colony in early October and lay in mid-November. The chicks fledge in early March after incubation and chick-rearing periods of about 45 days each. Demography is largely unknown. In the breeding season the birds eat mainly krill, but substantial amounts of squid and fish (especially *Pleuragramma*) have also been recorded.

Status
No data available.

Cape petrel (*Daption capense*)

Distribution
The cape petrel breeds at all sub-Antarctic islands (north to the Chatham Islands and New Zealand), around the Antarctic continent (mainly in the Indian Ocean sector) and is widespread in the northern Antarctic Peninsula and associated island groups. Breeding birds are mainly found on shelf waters during the breeding season, and there are few records north of 50°S. In March, they make a northward migration, with a substantial proportion of the population wintering north to 20°S off the coasts of South America, South Africa and Australia. The world population is unknown, but undoubtedly numbers several million birds.

Size
The adult birds have an overall length of 40 cm, a wing span of 85 cm, and weigh about 450 g.

Biology
Birds return to the breeding colony in September–October and lay in November–December. Their chicks fledge in March after 45 days' incubation and about 50 days of rearing. The cape petrel first breeds on average at 6 years of age. Its diet in the breeding season is mainly euphausiids – *E. superba* in the Atlantic Ocean sector, usually mixed with *E. vallentini* and often smaller amounts of fish, typically *P. antarcticum* in the Indo-Australian sector.

Status
In the Atlantic Ocean sector, numbers increased markedly during and after the whaling era; they may have colonised South Georgia early in this period. Populations are probably stable nowadays.

Annex III

Further Reading

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