The Status of Antarctic Fisheries Research

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INTRODUCTION

Until the Antarctic Treaty came into force in 1961, the International Whaling Commission was the only international body endeavouring to manage exploitation of marine species in the Southern Ocean. In 1964, the Antarctic Treaty Consultative Parties (ATCPs) adopted the Agreed Measures for the Conservation of Antarctic Fauna and Flora, but these only pertained to Antarctic organisms on land and shelf ice. Later, the Convention for the Conservation of Antarctic Seals (1972), which came into force in 1978, was negotiated as part of the Antarctic Treaty System. The last known sealing in the Antarctic occurred in the summer of 1986/87 by the USSR. For the remainder of the marine species, the Convention on the Conservation of Antarctic Marine Living Resources (1980) (CCAMLR) was negotiated by the ATCPs to ensure that the needs of the marine ecosystem were taken into account in managing, among others, the expanding krill fishery. This convention came into force in 1982.

CCAMLR was a major advance in the conservation and management of marine species in the Southern Ocean, not least because of the extension of the Antarctic Treaty area (south of 60°S) to encompass the whole of the Southern Ocean south of the Antarctic Convergence (Antarctic Polar Front) (Everson 1977). CCAMLR was considered, and remains by comparison to other international instruments, an innovative convention (Hofman, 1984), the first to take an ecosystem approach to managing fisheries and be recognised for its development of a precautionary approach (Constable et al. 2000).

Exploitation of marine species in the Antarctic has been a progression of over-harvesting of seals, whales and finfish (Chittleborough, 1984; Kock, 1986). In the 1970s, the introduction and potentially rapid expansion of a fishery for Antarctic krill (Nicol & Endo, 1997) threatened the demise of the Antarctic ecosystem should the krill fishery follow the same path as the exploitation of seals and whales. Everson (1977) characterised the nature of possible future exploitation of Antarctic marine species.

With the backdrop of over-exploitation, fisheries research developed along two main themes – (1) methods for assessing harvest limits and managing the
exploitation of Antarctic marine species and (2) understanding the Antarctic marine ecosystem in order to forecast the potential effects of fishing on prey species, such as Antarctic krill. These two themes were initially developed independently through, respectively, the International Whaling Commission (IWC) and its management of whaling and the Antarctic Treaty System (ATS) for the management of all other marine living resources in the region. The IWC was a pre-eminent forum for evaluating many conventional methods for assessing the status and yield of exploited populations and for developing overall management procedures (see Cooke, 1999 for review). The work undertaken in this forum, particularly in the late 1970s and early 1980s, was a major precursor for approaches developed in CCAMLR. Nevertheless, the Antarctic Treaty System developed the various research programs to underpin the institutional arrangements being established in the 1970s to manage the exploitation of Antarctic marine living resources.

This paper provides an overview of the steps in developing Antarctic fisheries research in the Antarctic Treaty System. In so doing, the paper highlights the future directions required for maintaining a precautionary approach to managing fisheries and for successfully achieving the ecosystem approach to management, for which the Antarctic Treaty System has become a leading exponent.

FISHERIES RESEARCH

Fisheries research can be divided into areas relevant to the objectives of CCAMLR (the Convention) encapsulated in Article II. The first primary objective for target species is to ensure stocks are maintained close to levels that ensure greatest potential recruitment (birth and survival) of young fish to the population (shortened to be termed ‘recruitment’). This was based on conventional fisheries assessment practices that held that the stock could be reduced to about 50% of its pre-exploitation abundance while maintaining high levels of productivity, through recruitment and growth. The catch that would keep the stock at this level was known as the maximum sustainable yield (MSY). In the early years of CCAMLR, the derivative methods from the MSY approach were applied. Although MSY is no longer the specific goal of stock assessments in CCAMLR, the models being developed in CCAMLR rely on similar kinds of information, including knowledge of the dynamics of populations (birth [recruitment] and death [mortality] rates), productivity of individuals, including growth and reproduction, and the interaction between the fishery and the population, ie. the ages or sizes of fish being exploited. This approach does not take into account whether harvested species are predators or prey of other species.
The second primary objective is for conservation of the marine ecosystem. In this respect, the direct effects of fishing on by-catch species are important, including, among others, benthos, finfish and seabirds. Research is largely focussed on the same elements as for target species but also requires research into measures to mitigate incidental mortality of these species, such as that discussed by the Scientific Committee (SC-CAMLR) *ad hoc* group on Incidental Mortality Arising from Longline Fishing (see Conservation Measure 29/XIX, CCAMLR, 2000).

In terms of indirect effects, the Convention requires the conservation of “dependent and related species”, which implies that food webs should remain largely unaltered as a result of fishing. Thus, research on the potential for competition to arise between fisheries and Antarctic predators is an important element of this program (Constable, 2001).

Lastly, the objectives of the Convention include rational use of marine living resources in the region, the need to allow the recovery of depleted species, such as seals and whales, and the need to avoid irreversible changes, ie. changes that cannot be reversed within two to three decades.

The overlaying of single species models with ecosystem and food web models potentially make the ecosystem approach difficult to put into practice (Constable, 2001). Although not explicit, the Commission has now recognised that methods to take account of uncertainty in the assessment process need to be developed.

**IMPETUS FOR RESEARCH – THE KRILL FISHERY**

Apart from whales, marine research in the Antarctic was focussed primarily on estimating the abundance and dynamics of Antarctic krill (*Euphausia superba*) combined with understanding the importance of krill to consumers such as birds and marine mammals. In this regard, estimates of abundance were extrapolated from estimated consumption of predators, notably seals, whales and birds (Laws, 1984). Combined with other estimates of production (Mackintosh, 1972, 1973; Everson, 1977), the abundance of krill in the Southern Ocean was estimated to be between 240 million tonnes and one billion tonnes, but these were not considered very reliable (Kock, 1986).

Dedicated research on the Southern Ocean marine ecosystem was initiated in 1974 as a joint initiative of the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR). This initiative resulted in the marine science program, Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) (El Sayed, 1994). It was developed with the aim to “gain a deeper understanding of the structure and dynamic functioning of the Antarctic marine ecosystem as a basis for future management” of living resources. Although the program was to be focussed on
the biology, ecology and abundance of Antarctic krill, there were many studies on other components of the ecosystem, such as finfish, birds, marine mammals, and biological and physical oceanography (El Sayed, 1994).

Two major research efforts were undertaken in this program – the First and Second International BIOMASS Experiments, FIBEX in 1980-1981 and SIBEX over the period 1983-1985. They represented a major undertaking in coordination of research effort (El Sayed, 1994) and provided the first estimates of abundance of krill based on the newly developing acoustic methodologies (see Miller & Hampton 1989 for review). The results of this program were used to set precautionary catch limits on krill in Area 48 in the Atlantic sector (CCAMLR 1991) and in Division 58.4.2 in the Indian sector (CCAMLR, 1992).

The work of BIOMASS has recently ended with much of the work on krill now taken up by the scientific working groups of CCAMLR.

Recent initiatives associated with CCAMLR include long-term national studies in CCAMLR integrated study regions (Hewitt and Demer, 1994) and large scale krill biomass surveys in the Indian (Nicol, 2000) and Atlantic (CCAMLR, 2000) sectors. These surveys supplant the use of the BIOMASS estimates of krill because they use better standardised acoustic technologies, survey designs and analytical techniques. These new results were used to establish new precautionary catch limits for krill in Division 58.4.1 (CCAMLR, 1996) and to update the catch limits in Area 48 (CCAMLR, 2000).

Other long-term or large-scale research in the Antarctic Peninsula region has included the Palmer Long Term Ecological Research (LTER) Program (Smith et al., 1995), the Research on Antarctic Coastal Ecosystem Rates (RACER) Program (Huntley et al., 1991), the Southern Ocean GLOBEC (Global Ocean Ecosystem Dynamics) winter study (GLOBEC, 1999) and the Joint Global Ocean Flux Study (JGOFS) (Smith et al., 2000a).

The current estimates of abundance of krill in the Southern Ocean are based on acoustic surveys and historical information on the distribution of Antarctic krill aggregations and fall between 60 and 155 million tonnes (Nicol et al. 2000). The reasons for the differences between this result and those from estimates of predator consumption are yet to be resolved (see Nicol et al. 2000 for discussion).

**CCAMLR’S INHERITED FISHERIES - FINFISH**

At its second meeting in 1983, the Scientific Committee of CCAMLR (SC-CAMLR) recognised the need to review the status of fish stocks in the CCAMLR area because of the substantial exploitation already undertaken since 1969 on the Antarctic marbled cod, *Notothenia rossii*, and the mackerel icefish, *Champsocephalus gunnari* (Kock et al. 1985). At this time, SC-CAMLR did
not have any working groups to facilitate its work and made a request to the SCAR Group of Specialists on Southern Ocean Ecosystems and Their Living Resources to review the status of Antarctic fish stocks and krill. The latter review (Miller & Hampton 1989) is discussed above. The review on fish stocks was undertaken by the BIOMASS Working Party on Fish Ecology and was published in 1985 (Kock et al. 1985). It used as much of the available data as was available, primarily from the fisheries. This work was the precursor to the formation of the SC-CAMLR Working Group on Fish Stock Assessment in 1984. This review concluded that Antarctic fish were susceptible to overfishing owing to their life history characteristics, but had insufficient data to undertake full stock assessments (Koch et al., 1985; Koch, 1992).

Most finfishing has occurred in the South Atlantic, particularly around South Georgia Island, and around Kerguelen Island in the Indian Ocean (Koch, 1992). It began in the mid-1960s with the expansion into the region of fishing operations of the Soviet and other eastern-bloc nations. In two years from 1969, the bottom-dwelling marbled rockcod had almost disappeared from around South Georgia Island and stocks around other islands followed a similar fate soon after. By the end of 1980, this species was depleted throughout the Antarctic along with other species caught in bottom trawls (Koch, 1992).

Two species are currently exploited - the Patagonian toothfish (*Dissostichus eleginoides*) and the mackerel icefish (*Champsocephalus gunnari*).

The Patagonian toothfish is a large (1.5-2 m), long-lived (35-50 years), deep-water species. The species was originally caught as part of the mixed bottom-trawl fishery around South Georgia Island and Shag Rocks. The introduction of longlining in 1987 saw exploitation of larger, mature older fish from areas inaccessible to trawlers. Longlining is now the principal method of exploitation, although trawling still occurs around Heard, Kerguelen and Crozet Islands. Substantial catches of fish currently taken by IUU (illegal, unreported or unregulated) longline fishing threaten the sustainability of this species.

The mackerel icefish is a shallow-water (100 - 350 m), short-lived (< 6 years) species with separate stocks supporting fisheries around South Georgia, Kerguelen and Heard Islands. The history of these fisheries has been similar to that of notothenid fisheries. Mackerel icefish became a target of the Soviet fleets when abundance of marbled rockcod had declined by the mid-1970s. The considerable variation in recruitment led to large fluctuations in catches around South Georgia and around Kerguelen Island where most of these fisheries were undertaken. However, the mean annual catch declined over the first 20 years (Koch, 1992). The fisheries for mackerel icefish are the only viable finfish fisheries to remain from those fisheries undertaken prior to CCAMLR.
In the early years, the assessments of fish stocks depended on conventional methods based on catch per unit effort information and resulted in considerable conflict over the appropriateness of specific estimates of yield arising from different statistical methods. The implementation of catch limits arising from these debates usually lagged behind the science by one or two years (see Constable et al. 2000 for discussion). These difficulties increasingly raised the question ‘How should the Commission deal with uncertainty in assessments and advice from the Scientific Committee?’ Uncertainties arose from natural variation in stock abundance and statistical errors in stock assessment, uncertainty in estimates of model parameters, incomplete historical catch records and imprecise submission of recent data. They also arose in the decision-making process generally because of the assessment methodologies available at the time.

Constable et al. (2000) discuss how the problem manifested itself when the Commissioners, most of whom lack scientific training, had to choose between different assessments and their consequences, without detailed knowledge of why the differences arose. Within the Commission, the implementation of catch limits, as with any conservation measures, required consensus and often resulted in majority advice from the Scientific Committee for lower catch limits being ignored. The inability of the Commission to take account of the uncertainties in management advice from the Scientific Committee, combined with frustration arising from inadequate assessment methods resulted in CCAMLR scientists making a strong statement in 1990 on the inability of science to provide unequivocal advice on catch limits (SC-CAMLR, 1990, Appendix D, Annex 5). This statement paralleled disquiet amongst scientists concerned with management of living resources elsewhere (Ludwig et al., 1993). The statement on uncertainty was endorsed by the Commission in 1990 and signalled a change towards a precautionary approach by the Commission.

THE PRECAUTIONARY APPROACH

The early years of CCAMLR were dominated by reactive management, where the Scientific Committee and Commission were continually attempting to update their knowledge and assessments in response to clear indications that a number of finfish stocks had been over-exploited (prior to the inception of CCAMLR). Part of this difficulty was that the objectives were not articulated in operational terms, ie. it was unknown how they could be interpreted and applied unambiguously. The development of the precautionary approach to managing the krill fishery was a major achievement for CCAMLR (see discussions in Nicol & de la Mare, 1993; de la Mare, 1996; Constable et al. 2000) and borrowed a number of principles from the approaches developed in the IWC in the early 1980s (de la Mare, 1996).
One of the most important features of the precautionary approach was the articulation of the objectives in measurable quantities as they relate to a single species assessment. This was done because of the paucity of information about the potential effects of fishing on the Antarctic food web generally. The objectives were converted into a three-part decision rule. The first part is to do with maintaining recruitment of the target species, such that a constant annual catch should have only a low probability of reducing the spawning population to less than 20% of the median (approximately average) level prior to exploitation. In this case, it is thought that reproduction and subsequent recruitment of young fish will become reduced if the population is too low. The second part is to ensure that the spawning stock is sufficiently large to maintain productivity as well as maintaining enough biomass for predators if the target species is an important prey species in the food web. For important prey species, this part specifies that the constant annual catch should be such that the median status of the spawning stock after the establishment of fishing (one generation time) should be no less than 75% of the median status prior to fishing (target species that are top predators would have a rule at 50%). The third part of the rule specifies that the lower of the two catches from the first two parts be accepted as the long term annual yield (de la Mare, 1996).

Computer simulations are used to determine these long-term annual yields and take account of uncertainties in the abundance of the stock and many population parameters. A number of techniques were developed including the simulation software (Butterworth et al. 1992) and assessment software for estimating krill recruitment (de la Mare, 1994a,b). This method was generalised for finfish stocks (Constable & de la Mare, 1996) and is now used for the assessment of yield for Patagonian toothfish. A modified method is used for assessing annual catch limits of mackerel icefish (see Constable et al. 2000 for discussion). These assessments rely on regular surveys of young fish. Much of the work on assessing fish stocks is now undertaken through the SC-CAMLR Working Group on Fish Stock Assessment with assessments of krill undertaken in WG-EMM.

THE ECOSYSTEM APPROACH
CCAMLR is widely known as the only international convention currently applying an ecosystem approach to managing fisheries. The CCAMLR Ecosystem Monitoring Program (CEMP) was initiated in 1986 to detect significant changes to the ecosystem, particularly in predators of krill, and to signal when such changes were the consequences of fishing (see Agnew, 1997 for a complete description of the program). In this way, the CEMP was intended to provide the necessary advice to the Commission on when fishing may be negatively impacting species dependent on the target species.
CEMP was deliberately restricted to monitoring a few selected predators in a few areas; the chosen predators feed predominantly on krill. A core set of sites was chosen from within three defined Integrated Study Regions – around South Georgia Island and the Antarctic Peninsula in the Atlantic sector and Prydz Bay/Mawson Coast in the Indian sector. Several parameters are monitored for each predator species to reflect short and long term changes in krill availability. Physical conditions, such as sea ice and sea state, are also monitored as they can affect the dynamics of krill (see Constable et al., in press, for review) as well as the reproductive success and winter survivorship of some predators. Field work and data acquisition are carried out voluntarily by members of CCAMLR. Data are submitted to the CCAMLR Secretariat and used in annual ecosystem assessments by the SC-CAMLR Working Group on Ecosystem Monitoring and Management (WG-EMM). The manner in which the data from CEMP will be utilised in the formulation of advice has yet to be resolved (Constable et al., 2000), although advances have been made in recent years on how this might be done (de la Mare and Constable, 2000).

WG-EMM has discussed the need for work to estimate the relationships between predator reproduction and survivorship and krill abundance. It is intended that such information will help build dynamic models of the relationship between target species and predators and help interpret changes in the ecosystem observed in CEMP. Despite the apparent simplicity of the system, the effects of a krill fishery on krill predators may be difficult to detect because of spatial and temporal variability in the dynamics of the Antarctic marine ecosystem (Murphy et al., 1988), shifts in diet depending on availability of prey (eg. Agnew et al., 1998) and the relative effects of different levels of migration into some areas (see Constable et al., in press, for review). Quantitative predictions of indirect effects of krill harvesting are difficult to formulate at present with only a few models developed that address these issues (eg. Butterworth and Thomson, 1995; Mangel & Switzer, 1998; Murphy et al., 1998; Thomson et al., 2000).

Given the absence of well-developed models of the ecosystem, an important issue to resolve is how to manage for potential effects of fishing on predators when little information is available on predicting how predators may respond to different levels of harvesting. A recent approach has been considered by WG-EMM that potentially takes account of uncertainties in knowledge of the structure of ecosystems (Constable, 2001). This method uses estimates of predator production arising from the consumption of fished species. Depending on how well it can be developed into a field monitoring program, it potentially integrates across a range of “ecosystem” effects and can be related directly to the effects of fishing because it incorporates the relative influence of fished species on the estimates of predator production.
WG-EMM is yet to formulate a full management strategy for the krill fishery, although it now has a work program in place to develop such a strategy over the coming few years (SC-CAMLR, 2001). A number of issues are yet to be resolved before the ecosystem approach to management and the objectives of CCAMLR will be achieved. Apart from the general development of a management strategy, important work is required that elaborates plausible models of the interactions between krill, the physical environment, predators and the fishery, examines the utility of CEMP to a management strategy and identifies the spatial scales of interest to managers in terms of the conservation of krill predators. In particular, the development of operational objectives that relate to the ecosystem interactions will be an important step forward in the development of this approach.

CONCLUDING REMARKS

CCAMLR has successfully developed a precautionary approach to new and developing fisheries as well as established fisheries, such as those for krill, Patagonian toothfish and mackerel icefish (Constable et al. 2000). For krill, this approach takes into account the large-scale relationships between the target species, its predators and the fishery. However, it does not take specific account of the potential for localised effects on some land-based krill predators (Everson and de la Mare, 1996) or the need for recovery of some species. In addition, attention needs to be given to ensuring that CEMP will be able to provide the feedback information necessary to alter harvesting before irreversible changes occur in the Antarctic marine ecosystem.

Both of these requirements could be met in the early period of the fishery by concentrating fishing effort in some local areas where predators of krill are being monitored to determine if changes in predator populations can be detected. The maximum catch for these local areas could be prorated according to the catch per unit area that is allowed under the existing catch limits for, say, the whole of Area 48. Monitoring of predators in these areas and in other areas without fishing could provide an opportunity for testing whether the area-wide catch limit might have an effect on predators but with the outcome known well in advance of the area-wide catch limit being reached.

The greatest challenge for fisheries research in CCAMLR is to develop management strategies that take full account of uncertainties in knowledge and assessment methods (eg. de la Mare, 1986, 1987, 1996, 1998, Smith, 1993, Cooke, 1999, Mangel, 2000). Potential candidate strategies need to be developed prospectively in order to be confident they are likely to achieve their management objectives before being applied (de la Mare, 1996). This provides for testing whether the decision rules for altering harvesting activities will perform well in meeting the objectives despite uncertainties in the understanding
of stock dynamics, food web structure and elements in the assessment process. The most important task is to determine what combinations of monitoring, assessments and decision rules meet the required performance for different plausible formulations of the ecosystem.

CCAMLR faces a number of challenges in the near future, including the continued prevalence of illegal, unreported and unregulated fishing in the region, an expanding krill fishery and the need to provide ecologically sustainable development of new fisheries. All of these pressures are driven by the view that the Southern Ocean and the high seas generally are the last frontier for fisheries, following the decline of so many of the global fish resources. Directed and focussed research on ecologically sustainable practices and efficient, cost-effective management systems is now an urgent endeavour. If costs of the management system are not commensurate with the value of the fisheries then it is unlikely that compliance will ensue.

In conclusion, the ecosystem approach to management being developed by CCAMLR remains to face the real test. Is CCAMLR ready for the imminent expansion of the krill fishery?

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REFERENCES


