Antarctic Science 9 (3): 235–242 (1997)

Review
The CCAMLR Ecosystem Monitoring Programme

DAVID J. AGNEW

Renewable Resources Assessment Group, Centre for Environmental Technology, Imperial College, 8 Princes Gardens, London SW7 1NA, UK

Abstract: The Convention on the Conservation of Antarctic Marine Living Resources states as part of its objective the maintenance of ecological relationships and the prevention of irreversible changes to the ecosystem. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has implemented an Ecosystem Monitoring Programme (CEMP) for the Antarctic marine environment to give effect to this requirement. The design phase of the programme took three years. The programme has been fully implemented since 1987 and involves monitoring selected predator, prey and environmental indicators of ecosystem performance. The central aim of the programme is the detection of changes in these indicators and the interpretation as to whether these changes are due to natural events or the harvesting of marine living resources. The core of the programme is the acquisition, centralised storage and analysis of standardised monitoring data combined with a strong emphasis on empirical and modelling based research. This both modifies the monitoring approach in line with changing requirements and creates a sound scientific background against which to test the effects of management options on components of the Antarctic ecosystem. The development of procedures for translating monitoring results into management advice is a critical part of the programme. Management takes the form of the regulation of fishing activities. Since 1987 CEMP has collected data on six bird and seal species at 15 sites around the Antarctic. Up to 14 parameters of predator performance and 10 parameters of prey and environmental performance are collected at each site. The data sets collected by CEMP form an extremely powerful tool for understanding and managing the Antarctic marine ecosystem.

Received 8 August 1996, accepted 13 May 1997

Key words: Antarctic fisheries, CCAMLR, CEMP, ecosystem management, ecosystem monitoring, krill, predator-fisheries interactions

Introduction

Commercial fisheries for krill (*Euphasia superba*) and fish in the Antarctic developed in the late 1960s and early 1970s. By the end of the 1970s a number of fish stocks had been over-exploited and the krill catch was rapidly rising to its peak in 1982 of 528 201 tonnes (Kock 1992, Nicol 1991). At the same time, it was known that krill was a key species in Antarctic ecosystems. There was therefore real concern that overfishing of krill might have serious consequences for the Antarctic (Nicol 1991). It was against this background, during 1979–80, that the Convention on the Conservation of Antarctic Marine Living Resources was negotiated (Edwards & Heap 1981). The Convention entered into force in 1982. Central to the Convention is Article II which states its objectives:

a) the prevention of decrease in harvested populations to levels below those which ensure stable recruitment;

b) the maintenance of ecological relationships between harvested, dependent and related populations;

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

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was established to give effect to the Convention. It has the responsibility of developing rules for managing Antarctic fisheries (called Conservation Measures) within the framework of Article II.

CCAMLR approached the first and last parts of Article II by applying standard fisheries management techniques to Antarctic problems, and it did this by setting up a working group on Fish Stock Assessment in 1984 and one on Krill in 1986 (Nicol 1991). The second part of Article II (the so-called 'ecosystem approach') was, however, entirely new to fisheries conventions. It required the development of novel techniques, and resulted in the establishment of the CCAMLR Ecosystem Monitoring Programme (CEMP).

There has been a considerable amount of recent international interest in monitoring large ecosystems (for example in Canada, Marshall *et al* 1993; on the Australian Great Barrier Reef, Poutinen 1994). This paper describes CCAMLR's experience as one of the first international initiatives to monitor a large marine ecosystem.

Development of the CCAMLR Ecosystem Monitoring Programme

A substantial amount of work was undertaken in the early 1980s summarizing the status of the Antarctic ecosystem and suggesting ways in which Article II could be implemented (Argentina 1984, Australia 1984a, Beddington & de la Mare 1984, Butterworth 1984, Sabourenkov 1984).

As early as 1979, while CCAMLR was being negotiated, Croxall & Prince (1979) had suggested monitoring top predators as a means of detecting changes in the abundance and distribution of Antarctic harvested prey stocks. A number of studies at that time were demonstrating that seabirds and mammals were reasonably good indicators of prey availability in certain environments (see the review by Bengtson 1984). For instance, Anderson *et al* (1980, in Bengtson 1984) demonstrated that brown pelican fledging rates were good indicators of Californian anchovy stocks. Studies off the South African coast indicated that various parameters of breeding success in a number of seabird species, including the African penguin *Spheniscus demersus*, were influenced by the abundance of fish stocks (Crawford & Shelton 1981, Crawford & Dyer 1995).

These studies of seabird – harvested prey interactions were not being used to 'monitor' fisheries as part of a management process. In the late 1970s environmental impact analysis (EIA) was being developed as a management tool by many countries (Wathern 1988), primarily to assess the environmental effects of industrial or similar projects. In an EIA, a baseline study is conducted to predict the effects of a project and monitoring after the project is in place is used to assess the actual effects (Beanlands 1988). CCAMLR used the idea that predators were good indicators of the availability of harvested prey to develop a framework similar to an EIA where the ecosystem was monitored as part of a fisheries management system. CCAMLR also saw the implementation of a coordinated effort to monitor the Antarctic marine ecosystem as a logical extension of the BIOMASS programme (see El Sayed 1994) which finished in 1991 (SC-CAMLR 1984).

The objectives of a monitoring programme were developed by Bengtson (1984) and Green-Hammond *et al.* (1984). It became clear that any monitoring programme would have to address both the harvested species and their predators. Monitoring all species, or the whole ecosystem, was clearly impractical (Bengtson 1984) and CCAMLR therefore adopted the concept of *indicator species*. These were conceived as dependent or related species that were likely to reflect changes in the availability of harvested species, especially krill, and therefore 'indicate' the state of those parts of the ecosystem which were most impacted by fishing activities (SC-CAMLR 1984).

CCAMLR set up its CCAMLR Ecosystem Monitoring Programme (CEMP) in 1985, with the following aims (SC-CAMLR 1985, paragraph 7.2):

a) to detect and record significant changes in critical components of the ecosystem, to serve as a basis for the Conservation of Antarctic Marine Living Resources;

b) to distinguish between changes due to the harvesting of commercial species and changes due to environmental variability, both physical and biological.

The CEMP is administered by a specialist working group, which designs and co-ordinates the programme. Initially this was the Working Group on the CCAMLR Ecosystem Monitoring Programme (WG-CEMP), which operated from 1985 to 1994. It was succeeded by the Working Group on Ecosystem Monitoring and Management (WG-EMM) in 1995.

Design of the CCAMLR Ecosystem Monitoring Programme

Figure 1 illustrates the CEMP scheme. The design phase involved assimilation of much of the research described above and resulted in a suite of monitored species, sites and parameters which are described below. It also considered the destination of monitoring results though the interpretive and management parts of the programme (Fig. 1). Although it is difficult to predict how a programme will develop over time, other monitoring initiatives have confirmed that prior consideration of goals is important for such large-scale monitoring programmes (Abbott & Benninghof 1990, Kellerman *et al* 1994). The programme is reviewed periodically (SC-CAMLR 1996, Annex 4).

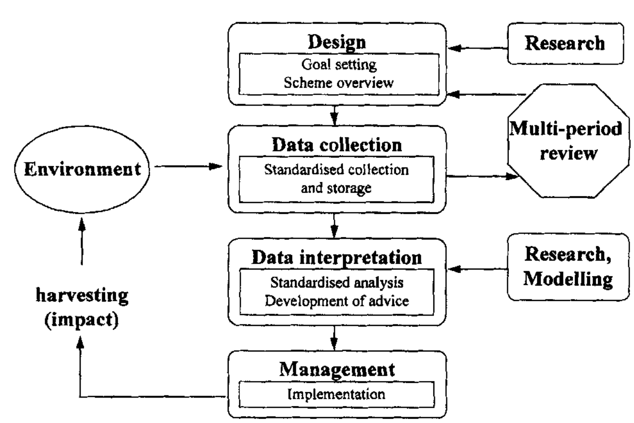

Fig. 1. The CCAMLR Ecosystem Monitoring Programme scheme. Major activities are in the centre of the diagram, and are complemented by research and review activities on the right. The environment is impacted by harvesting over which management exerts its control. This forms a feedback loop to the monitoring programme.

https://doi.org/10.1017/S095410209700031X Published online by Cambridge University Press

Species

The programme identified key prey species, whose potential harvest would have a major effect on other components of the ecosystem. These were two species of Euphasid, *Euphausia superba* (krill) and *E. crystallorophias*, the Antarctic silverfish (*Pleuragramma antarcticum*) and early life stages of fish. Krill is the primary food for many higher predators (fish, squid, birds and mammals) and has been the focus of CEMP to date. It is the only one of the key prey species which is currently harvested. Even though its annual catch of about 100 000 tonnes is less than 0.5% of estimated biomass (SC-CAMLR 1994, 1996) the potential for both global and local overfishing of krill remains of concern to CCAMLR.

A number of predators were selected according to their potential as indicators of changes in prey availability, with the criteria that they should be specialist predators on the prey items identified; have a wide geographical distribution; be important ecosystem components; be easy to study; and that sufficient be known of their biology and sufficient baseline data exist to construct a scientific monitoring programme (SC-CAMLR 1985, Annex 7). The present list consists of Crabeater seals (*Lobodon carcinophagus*), Antarctic fur seals (*Arctocephalus gazella*), Adélie penguins (*Pygoscelis adeliae*), chinstrap penguins (*P. antarctica*), gentoo penguins (*P. papua*), macaroni penguins (*Eudyptes chrysolophus*), Antarctic petrels (*Fulmaris glaciodes*), cape petrels (*Daption capensis*) and black browed albatross (*Diomedea melanophris*). Minke whales (*Balaenoptera acutorostrata*) were originally included, but dropped in 1991 because no suggestions had been forthcoming about how one might monitor them.

Sites

Sites for the monitoring programme were chosen so as to maximize the possibility of separating effects due to harvesting from those due to natural variability. Three Integrated Study Regions (ISRs) were chosen for the intensive study of predators, prey and environmental interactions (Fig. 2). ISRs were chosen in areas where there was significant fishing activity and where scientific programmes were already established, hence there was background information on all ecosystem components. Of the five major krill fishing areas in the Antarctic – the South Shetland Islands, South Georgia, the Prydz Bay area, the South Orkney Islands and between Prydz Bay and the Ross Sea — the first three were chosen as ISRs (SC-CAMLR 1985, Annex 7). Within the Integrated Study Regions, monitoring sites were chosen so that distinctions between large scale and local scale changes and changes occurring in fished areas versus non-fished areas could be detected. Their position was also limited by practical considerations and the presence of established research stations. A wide network of additional sites was proposed to complement the monitoring and research within

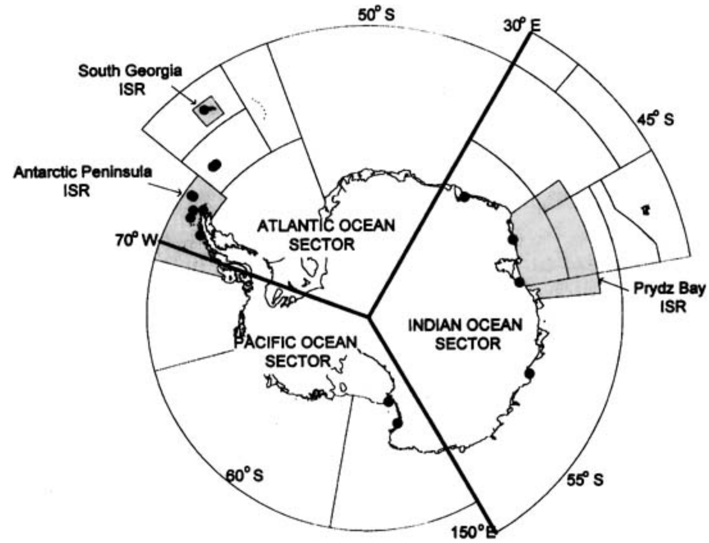

Fig. 2. Position of sites currently being monitored and submitting data to CEMP (●). Integrated Study Regions are shaded. The outer line is the northern limit of the CCAMLR Convention Area. CCAMLR management areas are defined, and separated into the three major oceanographic sectors.

the ISRs (Fig. 2).

Although the Antarctic is rather fortunate in being relatively free from major anthropogenic impact, significant numbers of tourists and scientists visit some areas. A major concern of CCAMLR has been to limit access to CEMP sites for any purpose other than monitoring them. Accordingly, in 1990 CCAMLR agreed Conservation Measure 18 which allows for the development of management plans for CEMP sites which restrict entry into and activities within a site.

Monitored parameters

Predator parameters were chosen for their potential to respond to changes in prey availability or environmental factors. They fall into four groups: parameters of reproduction; growth and condition; feeding ecology and behaviour; and abundance and distribution (SC-CAMLR 1985, Annex 7).

In order to facilitate statistical comparisons between monitoring studies, a set of Standard Methods for monitoring predator parameters were agreed by the Scientific Committee in 1987. They are published as the *CCAMLR Ecosystem Monitoring Programme: Standard Methods for Monitoring Studies* (CCAMLR 1995). Standard Methods for monitoring environmental parameters were agreed in 1990 (Agnew 1990, SC-CAMLR 1990). In addition to local conditions, regional sea ice distribution and sea surface temperature are monitored. These are likely to be important to both harvested and dependent species (Croxall *et al.* 1988, Siegel & Loeb 1995).

There are as yet no Standard Methods for monitoring prey parameters. However, two parameters relating to prey availability and fisheries-predator interaction are monitored routinely by the CCAMLR Secretariat. These are the catch of krill per hour (a measure of swarm density) from areas surrounding CEMP sites and the potential overlap between krill fishing and predator foraging areas (Agnew & Phegan 1995). Other parameters such as krill density and distribution can only be derived from research survey data. Methods for these are currently being investigated.

A full list of monitored parameters is presented in Table I. The temporal and spatial scales relevant to these parameters are shown in Fig. 3. A detailed review of many of them, and their sensitivity to changes in the marine environment, has been made with reference to penguins, albatross and seals by Croxall *et al* (1988).

Data management

There are a number of options for data handling for large international projects such as CEMP. These range from a distributed system storing mainly unstandardised data to a centralized system storing only standardized data (Kellerman *et al* 1994, Anon 1996). CCAMLR chose a centralized, standardized system as being the most accessible, efficient and responsive, with the consequence that the data management system is now widely recognised as one of the strengths of the programme.

Table I. Parameters identified by the CCAMLR Ecosystem Monitoring Programme. * indicates parameters for which a monitoring protocol is under development.

Label	Parameter
A1	Penguin adult weight on arrival at breeding colony
A2	Penguin incubation shift duration
A3	Penguin breeding population size
A4	*Penguin age specific annual survival and recruitment
A5	Penguin duration of foraging trips
A6	Penguin breeding success
A7	Penguin chick weight at fledging
A8	Penguin chick diet
A9	Penguin breeding chronology
B1	Black browed albatross breeding population size
B2	Black browed albatross breeding success
B3	Black browed albatross age specific annual survival and recruitment
C1	Fur seal cow duration of foraging/attendance cycles
C2	Fur seal pup growth
F1	Sea-ice cover - local
F2	Sea-ice cover within the ISR
F3	*Local weather
F4	Snow cover in the colony
F5	Sea surface temperature
H1	Local krill catch per unit effort
H2	Local krill catch
H3	Potential overlap between fishing areas and predator foraging areas
	*Local krill density
	*Krill distribution

Field work and data acquisition for the predator monitoring programme are carried out voluntarily by CCAMLR member states (referred to as Members). Currently nine out of the 23 Members collect predator data, from a variety of sites (Table II). Data collected during the Antarctic summer field season are submitted to the CCAMLR Secretariat by the end of the June which immediately follows it. For those parameters still under development such as penguin annual survival and recruitment, Members are encouraged to collect and archive data themselves.

Data from Antarctic fisheries must be submitted to CCAMLR within three months of the end of the statistical year (which runs from 1 July–30 June). These data are used by the Secretariat to calculate some of the prey parameters listed in Table I. Some environmental parameters, such as sea ice cover and sea surface temperature, are derived from public environmental datasets acquired from satellite sources. Thus data on predator, environmental and prey parameters are available for analysis in the six months immediately following the Antarctic summer and before CCAMLR's annual meetings in October.

CCAMLR now holds data covering about 80 combinations of site, species and monitored parameter for predator species, and approximately 30 combinations of site and parameter for prey and environmental variables (Table II). Some parameters were being monitored according to the protocols set out in the Standards Methods before CEMP came into being – as early as the 1970s for some species, and 1958 for macaroni penguins at Bird Island. However, most of the parameters listed in the table have been monitored only since the

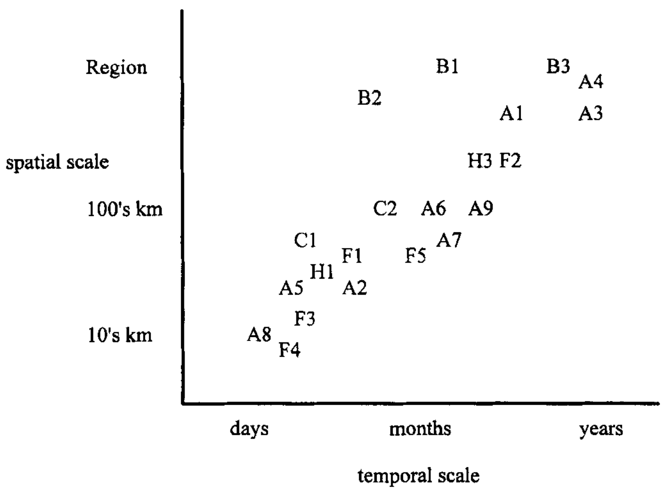

Fig. 3. Temporal and spatial scales for CEMP parameters. Refer to Table I for an explanation of the parameter labels. For example, penguin chick diet (A8) would be expected to reflect local krill availability over the days that an adult penguin is away on a foraging trip; whereas penguin adult weight on arrival at a breeding colony (A1) would be expected to reflect krill abundance and availability in the ISR for several months prior to breeding. H2 has identical characteristics to H1.

https://doi.org/10.1017/S095410209700031X Published online by Cambridge University Press

Table II. Number of CEMP predator parameters monitored at various sites (compiled from SC-CAMLR 1993, 1994, 1996). Only those data sets collected according to the protocols laid out in the CEMP Standard Methods and submitted to the CCAMLR Secretariat are presented. The first occurrence of data submitted to CCAMLR is given, but not all parameters may have been collected from the start of monitoring at a particular site. Environmental and prey parameters (principally F1, F2, F5, H1 and H3 in Table I) are also compiled for most of these sites. Sector refers to the oceanographic sector shown in Fig. 2.

CCAMLR member	CEMP site	Sector	Year started	Species	number of parameters
Argentina	Esperanza Bay, Antarctic Peninsula	Atlantic	1994	Adélie penguin	6
	Laurie Island, South Orkneys	Atlantic	1988	Adélie penguin	3
	King George Island, South Shetlands	Atlantic	1988	Adélie penguin	3
Australia	Béchervaise Island, Mawson Station	Indian	1991	Adélie penguin	7
	Magnetic Island, Davis Station	Indian	1994	Adélie penguin	4
	Shirley Island, Casey Station	Indian	1996	Adélie penguin	6
Brazil	Elephant Island	Atlantic	1990	macaroni & chinstrap penguin	8
Chile	Cape Shirreff, South Shetlands	Atlantic	1994	fur seal	1
UK	Bird Island, South Georgia	Atlantic	1958	fur seal, albatross, macaroni & gentoo penguin	13
	Signy Island, South Orkneys	Atlantic	1990	Adélie, chinstrap & gentoo penguin	6
Italy	Terra Nova, Ross Sea	Pacific	1995	Adélie penguin	7
Japan	Syowa Station	Indian	1982	Adélie penguin	1
New Zealand	Ross Island, Ross Sea	Pacific	1989	Adélie penguin	1
USA	Anvers Island, Antarctic Peninsula	Atlantic	1990	Adélie penguin	6
	Seal Island, South Shetlands	Atlantic	1988	fur seal, macaroni & chinstrap penguin	9

specification of the Standard Methods in 1987.

The combined database of predator, environmental and harvested species parameters forms an extremely powerful tool for the development of CCAMLR's management advice. However, the potential for scientists within the CCAMLR community to publish analyses using another investigator's data could lead to reluctance from some scientists to submit data to the Secretariat. In response to this problem CCAMLR has arrived at a strict set of rules for access to data (CCAMLR 1989, paragraph 64). This is accompanied by a code of understanding to govern the practical implementation of the rules (SC-CAMLR 1994, Annex 10).

All data are freely available to Members for the analysis and preparation of papers for the use of CCAMLR, although requests for access to data must be submitted by nominated Member representatives. Owner/originators are informed of the destination of data supplied in response to such a request. Where data are required for analyses or publication not directed at CCAMLR, permission from the owner/originator must be sought before data can be used. This applies equally to data held by CCAMLR and working papers submitted to CCAMLR. The code elaborates on this, emphasizing that any scientist wishing to make use of the data in the CCAMLR database other than his/her own should communicate with the owner/originator of the data prior to commencing analysis. This system appears to work well at the moment, but its adherence will become increasingly important as the size and consequent value of the CCAMLR database increases.

One of the objectives of the programme has been to generate datasets which can be compared across species, sites and years. Long time series of data are required for such multivariate comparisons, and a substantial commitment to continue monitoring activities has been necessary to ensure that datasets are as complete as possible. Even so, there are a number of sites where continuity of observation has not been possible, whether from funding or operational reasons. Time series which cease are of much reduced value, somewhat negating the substantial effort required to monitor them in the first place.

Interpreting monitoring results

CCAMLR has conducted an annual review of predator status based on its monitoring results since 1992 (SC-CAMLR 1992, Annex 7). The review now undertaken by WG-EMM proceeds in two parts: identification of trends and anomalies in the time series, and an assessment of the implications of those trends or anomalies.

Data are held in the CCAMLR database in a variety of formats, depending on the parameter of interest. In order to compare data across species and parameters, a single 'index' of a parameter for a unique site, species and year is calculated according to Agnew (1992). 'Anomalous' values of the index are identified using the mean and variance of the series (or a transformed series if the original is not normally distributed) (SC-CAMLR 1996, Annex 4, Appendix H). A total of 108 series were generated in this way from predator, prey and environmental parameters in 1996. Analysing the raw data of such a large data set at a working group meeting would be very difficult, but tabulation of the standardized series has enabled WG-EMM to visualise the data easily and make rapid cross-series comparisons (SC-CAMLR 1996, Annex 4, table 4). Multivariate analyses of the data series have not so far been possible, because most series only run for nine or fewer years, but undoubtedly will be developed in the future.

Attempts to interpret ecosystem responses to krill harvesting have stimulated the production of a number of models of

https://doi.org/10.1017/S095410209700031X Published online by Cambridge University Press

interactions between components of the krill dominated ecosystem. Models of krill catch per unit effort (Butterworth 1988, Mangel 1988), krill yield (Butterworth *et al* 1994), krill recruitment (de la Mare 1994) and fishing vessel behaviour (Agnew & Marín 1994) attempt to model the interaction between the fishery and krill populations. Dependent species energetics models (Croxall *et al* 1985) incorporate interactions between predators and their prey. Finally, a model of the functional relationship between krill and its predators (Butterworth & Thomson 1995) considers the consequences to predator populations of harvesting krill.

Empirical validation of these models is essential if they are to be used, along with the monitoring data, to predict likely ecosystem responses to management actions. Different approaches are required by the various models. Indeed, many of them have already been validated using existing CEMP data. One powerful technique would be to conduct experimental fishing to force an ecosystem response which could be directly attributable to krill harvesting, for instance by intensively fishing krill in the vicinity of a CEMP site while monitoring krill and predator responses. Although experimental fishing has long been suggested (Australia 1984b) it has not yet been used by CCAMLR for this purpose.

From its inception, CEMP has encouraged parallel programmes of research and monitoring. This enables monitoring to be modified in line with changing requirements and creates a sound scientific background for the interpretation of monitoring results. An example of such collaborative work was the massive mortality of Adélie penguin chicks identified by the monitoring programme at Béchervaise Island in January 1995, which associated research demonstrated to be the result of krill scarcity only in the vicinity of Béchervaise (Kerry *et al* 1995). Since there has been no fishing in this area since 1990, this event was attributed to a local environmental anomaly. Investigation of predator, prey and environmental interactions remains a very active area of research within the CCAMLR scientific community.

Integration into the decision structure

CCAMLR has a well defined idea of what management entails – regulation of fishing activity through Conservation Measures. It has also incorporated the "ecosystem approach" into a number of its Conservation Measures. For instance, the catch limits calculated for krill incorporate an allowance for predator demands.

Feedback between the results of CEMP and regulatory conservation measures leading to management of fisheries (e.g. krill) has been harder to develop. There were some early attempts to explore this link (Croxall 1989, and the report of the Working Group on the Development of Approaches to Conservation, reported in CCAMLR 1989). Nevertheless, work on the harvested species and the predators remained separated primarily because there were two separate working groups – one on krill and one on CEMP. This was despite the fact that close liaison between the two groups was included in their terms of reference. Only after the two groups were merged into a single working group on Ecosystem Monitoring was significant progress made on an integrated approach to the incorporation of CEMP into management of krill.

Butterworth & Thompson's model of the effects of krill harvesting on predator populations is the most comprehensive attempt at this integration. It uses CEMP data to generate model inputs for predator survival, fecundity etc, and to assess the frequency of good and poor krill years. The model is still under development and is not used to set krill catch limits at the moment. Secondly Everson & de la Mare (1996) have suggested a method by which estimates of predator consumption, collected as part of CEMP, could be used to derive precautionary catch limits for krill. Neither of these approaches attempts to use CEMP as an annual 'monitor' of prey availability. However, discussions at WG-EMM meetings have recently started to focus on the analysis of CEMP data using multivariate techniques (SC-CAMLR 1996, Annex 4). This should enable the separation of changes due fishing and changes due to environmental variability and would be the first use of CEMP data in a truly 'monitoring' sense.

Conclusion

The CCAMLR Ecosystem Monitoring Programme is in its second decade of operation. It has succeeded in collecting data on a large number of key parameters of the Antarctic marine ecosystem from a diverse set of monitoring sites. The time series created by these data are approaching 10 years in length at most sites, and are much longer at others. The programme is beginning to prove its usefulness in guiding the development of management advice. However, there is still a long way to go in analysing and interpreting monitoring data before the programme can be used to provide direct input into the management of Antarctic fisheries.

Acknowledgements

I would like to acknowledge all those members of the Scientific Committee and Secretariat of CCAMLR who have worked long and hard to develop the CCAMLR Ecosystem Monitoring Programme. I am also indebted to K. Batts, J. Croxall, I. Everson, W. de la Mare and the reviewers, P. Penhale and M. Richardson, for their constructive comments on this paper.

References

All publications of the Commission for the Conservation of Antarctic Marine Living Resources are available from the CCAMLR Secretariat, 23 Old Wharf, Hobart 7000, Tasmania, Australia, email ccamlr@ccamlr.org.

https://doi.org/10.1017/S095410209700031X Published online by Cambridge University Press

ABBOTT, S.B. & BENNINGHOFF, W.S. 1990. Orientation of environmental change studies to the conservation of Antarctic ecosystems. *In* KERRY, K.R. & HEMPEL G., *eds Antarctic ecosystems: ecological change and conservation.* Berlin: Springer-Verlag, 394-403.

AGNEW, D.J. 1990. *Investigations of required sampling regimes for environmental parameters.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1990, SC-CAMLR SSP/7. Hobart: CCAMLR, 561-573.

AGNEW, D.J. 1992. CEMP indices: their calculation and comparison by the Secretariat. *In CCAMLR Ecosystem Monitoring Programme: standard methods for monitoring studies.* Hobart: CCAMLR, Appendix 6.

AGNEW, D.J. & MARÍN, V.H. 1994. Preliminary model of krill fishery behaviour in Subarea 48.1. *CCAMLR Science*, **1**, 71-79.

AGNEW, D.J. & PHEGAN, G. 1995. Development of a fine scale model of land-based predator foraging demands in the Antarctic. *CCAMLR Science*, **2**, 99-110.

ANDERSON, D.W., GRESS, F., MAIS, K.F. & KELLY, P.R. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. *CalCOFI Report*, No. 21, 54-61.

ANON. 1996. *Environmental monitoring in Antarctica.* Report for the Scientific Committee on Antarctic Research (SCAR) and the Council of Managers of National Antarctic Programs (COMNAP). Cambridge:SCAR, 123 pp.

ARGENTINA. 1984. *Conservation and management strategy for the Antarctic marine ecosystem.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 203-218.

AUSTRALIA. 1984a. *An approach to a management strategy for the Antarctic marine ecosystem.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 1-13.

AUSTRALIA. 1984b. *Ecosystem management: proposal for undertaking a coordinated fishing and research experiment at selected sites around Antarctica.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 277-284.

BEANLANDS, G. 1988. Scoping methods and baseline studies in EIA. *In* WATHERN P., *ed. Environmental impact assessment: theory and practice.* London: Routledge, 33-46.

BEDDINGTON, J.R. & DE LA MARE, W.K. 1984. *Marine mammal fishery interactions: modelling and the Southern Ocean.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 155-178.

BENGTSON, J.L. 1984. *Monitoring indicators of possible ecological changes in the Antarctic marine ecosystem.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 43-153.

BUTTERWORTH, D.S. 1984. *Antarctic ecosystem management.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 15-41.

BUTTERWORTH, D.S. 1988. *Some aspects of the relation between Antarctic krill abundance and CPUE measures in the Japanese krill fishery.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1988, SC-CAMLR-SSP/5, Part I. Hobart: CCAMLR, 109-125.

BUTTERWORTH, D.S., GLUCKMAN, G.R., THOMSON, R.B., CHALIS, S., HIRAMATSU, K. & AGNEW, D.J. 1994. Further computations of the consequences of setting the annual krill catch limit to a fixed fraction of the estimate of krill biomass from a survey. *CCAMLR Science*, **1**, 81-106.

BUTTERWORTH, D.S. & THOMSON, R.B. 1995. Possible effects of different levels of krill fishing on predators - some initial modelling attempts. *CCAMLR Science*, **2**, 79-97.

CCAMLR 1989. *Report of the Eighth Meeting of the Commission* (CCAMLR-VIII). Hobart: CCAMLR, 133 pp.

CCAMLR 1995. *CCAMLR Ecosystem Monitoring Programme: Standard Methods for Monitoring Studies.* Hobart: CCAMLR, 192 pp.

CRAWFORD, R.J.M. & DYER, B.M. 1995. Responses by four seabird species to a fluctuating availability of Cape anchovy *Engraulis capensis* off South Africa. *Ibis*, **137**, 329-339.

CRAWFORD, R.J.M. & SHELTON, P.A. 1981. Population trends for some southern African seabirds related to fish availability. *In* COOPER J., *ed. Proceedings of a Symposium on Birds of the Sea and Shore.* Cape Town: African Seabird Group, 15-41.

CROXALL, J.P. 1989. *Use of indices of predator status and performance in CCAMLR fishery management.* Scientific Committee for the Conservation of Antarctic Marine Living Resource, Selected Scientific Papers 1989, SC-CAMLR-SSP/6. Hobart: CCAMLR, 353-365.

CROXALL, J.P., MCCANN, T.S., PRINCE, P.A. & ROTHERY, P. 1988. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: implications for southern ocean monitoring studies. *In* SAHRHAGE, D., *ed. Antarctic ocean and resources variability.* Berlin: Springer-Verlag, 261-285.

CROXALL, J.P. & PRINCE, P.A. 1979. Antarctic seabird and seal monitoring studies. *Polar Record*, **19**, 573-595.

CROXALL, J.P., PRINCE, P.A. & RICKETTS, C. 1985. Relationships between prey life-cycles and the extent, nature and timing of seal and seabird predation in the Scotia Sea. *In* SIEGFRIED, W.R., CONDY, P.R. & LAWS, R.M., *eds Antarctic nutrient cycles and food webs.* Berlin: Springer-Verlag, 516-533.

DE LA MARE, W.K. 1994. Modelling krill recruitment. *CCAMLR Science*, **1**, 49-54.

EDWARDS, D.M. & HEAP, J.A. 1981. Convention on the Conservation of Antarctic Marine Living Resources: a commentary. *Polar Record*, **20**, 353-362.

EL SAYED, Z.S. *ed.* 1994. *Southern ocean ecology: the BIOMASS perspective.* Cambridge University Press, 399pp.

EVERSON, I. & DE LA MARE, W.K. 1996. Some thoughts of precautionary measures for the krill fishery. *CCAMLR Science*, **3**, 1-11.

GREEN-HAMMOND, K.A., AINLEY, D.G., SINIFF, D.B. & SCOTT URQUHART, N. 1984. *Selection criteria and monitoring requirements for indirect indicators of changes in availability of Antarctic krill applied to some pinniped and seabird information.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 295-339.

KELLERMAN, A., LAURSEN, K., RIETHMULLER, R., SANDBECK, P., UYTERLINDE, R. & VAN DE WETTERING, B. 1994. Concepts for a trilateral integrated monitoring programme in the Wadden Sea. *Ophelia*, Suppl. 6, 57-68.

KERRY, K., CLARKE, J., GARDNER, H., MURPHY, R., HUME, F. & HODUM, P. 1995. Adélie penguin chick deaths investigated. *ANARE News*, No. 75, 18-20.

KOCK, K.-H. 1992. *Antarctic fish and fisheries.* Cambridge: Cambridge University Press, 359 pp.

MANGEL, M. 1988. *Analysis and modelling of the Soviet Southern Ocean krill fleet.* Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers, 1988, SC-CAMLR-SSP/5, Part I. Hobart: CCAMLR, 127-235.

MARSHALL, I.B., HIRVONEN, H. & WIKEN, E. 1993. National and regional scale measures of Canada's ecosystem health. *In* WOODLEY, S., KAY, J. & FRANCIS, G., *eds. Ecological integrity and the management of ecosystems.* Boca Raton: St-Lucie Press, 117-129.

NICOL, S. 1991. CCAMLR and its approaches to management of the krill fishery. *Polar Record*, **27**, 229-236.

POUTINEN, M.L. 1994. Designing effective baseline monitoring programs for the Great Barrier Reef Marine Park, Queensland, Australia. *Coastal Management*, **22**, 391-398.

SABOURENKOV, E.N. 1984. *Ecosystem monitoring and management - summary of papers presented at the Third Meeting of the Scientific*

Committee. Scientific Committee for the Conservation of Antarctic Marine Living Resources, Selected Scientific Papers 1982-1984, Part II. Hobart: CCAMLR, 264-276.

SC-CAMLR 1984. *Report of the Third Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-III). Hobart, CCAMLR, 238 pp.

SC-CAMLR 1985. *Report of the Fourth Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-IV). Hobart, CCAMLR, 275 pp.

SC-CAMLR 1990. *Report of the Ninth Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-IX). Hobart, CCAMLR, 345 pp.

SC-CAMLR 1992. *Report of the Eleventh Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-XI). Hobart, CCAMLR, 487 pp.

SC-CAMLR 1993. *Report of the Twelfth Meeting of the Scientific Committee of CCAMLR*(SC-CAMLR-XII). Hobart, CCAMLR. 431 pp.

SC-CAMLR 1994. *Report of the Thirteenth Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-XIII). Hobart, CCAMLR, 450 pp.

SC-CAMLR 1996. *Report of the Fifteenth Meeting of the Scientific Committee of CCAMLR* (SC-CAMLR-XV). Hobart, CCAMLR, 456 pp.

Siegel, V. & Loeb, V. 1995. Recruitment of Antarctic krill *Euphausia superba* and possible causes for its variability. *Marine Ecology Progress Series*, **123**, 45-56.

Wathern, P. 1988. An introductory guide to EIA. *In* Wathern P., *ed. Environmental impact assessment: theory and practice*. London: Routledge, 33-46.

https://doi.org/10.1017/S095410209700031X Published online by Cambridge University Press