

**REPORT OF THE WORKING GROUP ON  
ECOSYSTEM MONITORING AND MANAGEMENT**  
(Siena, Italy, 12 to 23 July 2004)

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### INTRODUCTION

#### Opening of the meeting

1.1 The tenth meeting of WG-EMM was held at the University of Siena, Siena, Italy, from 12 to 23 July 2004. The meeting was convened by Dr R. Hewitt (USA).

1.2 Prof. P. Tosi (Chancellor of the University of Siena), Ambassador L. Cortese (Ministry of Foreign Affairs and CCAMLR Commissioner), Prof. C. Ricci (Chair of the Italian Scientific Committee for Antarctic Research), Prof. S. Focardi (Dean of the Faculty of Science, University of Siena) and Dr Hewitt welcomed the participants.

1.3 Dr Hewitt and Dr D. Miller, Executive Secretary, thanked the University of Siena and Prof. Focardi for hosting the tenth meeting of WG-EMM and recalled that the University had also hosted the first and very successful meeting of the Working Group in 1995.

1.4 Dr Hewitt outlined the program for the meeting. This was the fourth meeting with a mixed agenda consisting of plenary and subgroup sessions to discuss core topics, and a workshop (Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management – section 2). Much of this work was started in Siena during the 1995 meeting.

#### Adoption of the Agenda and organisation of the meeting

1.5 The Provisional Agenda was discussed and the Working Group agreed to expand Item 5.4 to 'Consideration of models and analytical and assessment methods'. With this change, the agenda was adopted (Appendix A).

1.6 The list of participants is included in this report as Appendix B and the List of Documents submitted to the meeting as Appendix C.

1.7 The report was prepared by Drs D. Agnew (UK), A. Constable (Australia), Prof. J. Croxall (UK), Drs D. Demer (USA), M. Goebel (USA), S. Kawaguchi (Australia), G. Kirkwood (UK), P. Penhale (USA), D. Ramm (Secretariat), K. Reid (UK), E. Sabourenkov (Secretariat), H.-C. Shin (Republic of Korea), V. Siegel (Germany), W. Trivelpiece (USA), P. Trathan (UK) and G. Watters (USA).

## WORKSHOP ON PLAUSIBLE ECOSYSTEM MODELS FOR TESTING APPROACHES TO KRILL MANAGEMENT

2.1 The Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management, which was established in the program of work for WG-EMM in 2001, was held at the University of Siena, Siena, Italy, from 12 to 16 July 2004. The meeting was convened by Dr Constable. The report is attached as Appendix D.

2.2 The terms of reference for the workshop were agreed in 2003 (SC-CAMLR-XXII, Annex 4, paragraph 6.17). The Working Group agreed that excellent progress was made by the workshop on the first two terms of reference for the development of plausible models, including intersessional work by the workshop's steering committee in 2003/04 (SC-CAMLR-XXII, paragraphs 3.45 to 3.49; Appendix D, paragraph 1.2), and endorsed the report of the workshop. This work provides the foundation for technical implementation of ecosystem models under the third term of reference.

2.3 Dr B. Fulton (CSIRO, Australia) was invited for her expertise in developing models for the evaluation of management procedures (strategies). A second expert was invited but was unable to attend the workshop due to unexpected circumstances. Dr Fulton made a very valuable contribution to the workshop, including her guidance during the discussions.

2.4 The workshop had agreed that a primary aim of the workshop was to develop the specifications that will be used by programmers to produce the modelling framework in which plausible models of the Antarctic marine ecosystem can be simulated. Also, the workshop considered ecosystem and other scenarios that would need to be explored to help evaluate the potential for biases in our monitoring and in the assessment process, and whether those biases could lead to incorrect decisions that would cause the Commission to fail to meet one or more of its objectives.

2.5 In undertaking its work, the workshop noted that the discussions were to draw together information and concepts to provide a common framework for developing one or more ecosystem models for testing approaches to krill management. The workshop noted that some tables, figures or text may not be complete in their consideration or presentation of the issues. Nevertheless, the workshop agreed that the format of the workshop provided the foundation for further development and implementation of ecosystem models for the work of WG-EMM.

2.6 The workshop reported on the outcomes of intersessional activities, which included:

- (i) seeking the contribution and participation from experts (Appendix D, paragraphs 1.5 to 1.7);
- (ii) a review of relevant literature on ecosystem models, primarily in the Southern Ocean (Appendix D, paragraphs 2.3 to 2.5);
- (iii) compilation of a catalogue of available software and other simulation environments for ecosystem modelling (Appendix D, paragraphs 2.6 and 2.7);
- (iv) preliminary consideration of the requirements for datasets, estimates of parameters and other aspects related to the second term of reference (Appendix D, paragraphs 2.8 to 2.10);

- (v) preliminary outline of the aims and specifications for ecosystem modelling as it relates to the development of management procedures for krill (Appendix D, paragraphs 2.11 to 2.13).

2.7 Dr Fulton presented illustrations of her use of models in CSIRO in evaluating management strategies for the marine environment. She provided background on management strategy evaluation, steps for developing ecosystem models and summary details of two models that she uses, Atlantis and InVitro. Her presentations are summarised in Appendix D, paragraphs 2.15 to 2.25.

2.8 The workshop summarised desirable attributes of ecosystem models. A review of existing models is provided in Appendix D, paragraphs 3.1 to 3.15. The general attributes of models for evaluation of management procedures and their implementation were discussed and agreed by the workshop in Appendix D, paragraphs 3.16 and 3.17.

2.9 The workshop developed conceptual representations of the ecosystem with the following points in mind (Appendix D, paragraphs 4.1 to 4.3):

- (i) the aim of developing conceptual models is to provide a flexible framework for considering how each taxon might be influenced by the rest of the ecosystem, thereby providing the means to explicitly decide how best that taxon should be represented in the model to evaluate krill management procedures;
- (ii) some taxa will need to be represented in some detail in order to simulate field monitoring and the local-scale effects of fishing;
- (iii) other taxa might be simulated in a very general way in order to save simulation time while ensuring that ecosystem responses are realistic;
- (iv) the approach is intended to provide a means for explicitly determining how to take account of structural uncertainties given the paucity of data on many aspects of the ecosystem. The approach is also designed to allow an assessment of the sensitivity of model outcomes to assumptions about the relationships between taxa;
- (v) the basic elements of the model will be the lowest, indivisible quantity in the food-web model and could be a species, guild, ecological group, population, local population or life stage (not necessarily age-structured);
- (vi) some consideration will need to be given to distributions of each element in space and depth, as well as the time steps required to satisfactorily model each element;
- (vii) the conceptual models will require consideration of the characteristics of elements, even though each characteristic may not be explicitly incorporated as a separate part of a model.

2.10 In the first instance, the workshop agreed to undertake the following work in developing conceptual representations of key components:

- (i) develop pictorial representation, as appropriate, of key population processes, primary locations of individuals relative to features in the physical environment and spatial foraging patterns;
- (ii) identify key parameters and processes that will need to be considered in the representation of each element in the ecosystem model, including population dynamics, foraging behaviours and spatial and temporal distributions;
- (iii) undertake initial consideration of:
  - (a) the interactions between taxa and between taxa and the environment;
  - (b) the representation of space, time, and depth in ecosystem models;
  - (c) the requirements for modelling field observations, which will be undertaken in the evaluation process.

2.11 The workshop noted that the major considerations for the development of operating models are with respect to:

- physical environment
- primary production
- pelagic herbivores and invertebrate carnivores
- target species
- mesopelagic species
- marine mammals and birds.

2.12 Other taxa may need to be considered in future, such as demersal and bathypelagic species, including *Dissostichus* spp., *Macrourus* spp., skates and rays. It was noted that the current framework was sufficient for initiating work on evaluating approaches to krill management.

2.13 The Working Group endorsed the body of the workshop report describing the results of discussions on conceptual representation of these components (Appendix D, paragraphs 4.9 to 4.100).

2.14 The workshop considered the types of scenarios that need to be considered in evaluating the robustness of krill management procedures to structural uncertainties of the model. This discussion focused on two broad topics. The first was concerned with the plausibility of the model (Appendix D, paragraphs 5.2 to 5.4) and the second was concerned with questions of ecosystem dynamics that could be explored with the model (Appendix D, paragraph 5.4).

2.15 After some discussion, the workshop concluded that the following scenarios should be accorded the highest priority:

- (i) behaviour of the model system in response to artificial (i.e. known) forcing functions in order to better understand the properties of the model;
- (ii) effects of alternative formulations of krill transport on ecosystem dynamics;
- (iii) effects of climate change on primary production and/or ocean circulation.

2.16 The Working Group requested guidance from the Scientific Committee with regard to the priorities for exploring realistic scenarios and future work.

2.17 The workshop discussed a number of items that relate to the formulation and specification of ecosystem models in general (Appendix D, paragraphs 6.2 to 6.4) and to Antarctic ecosystems in particular (Appendix D, paragraphs 6.5 to 6.25).

2.18 The workshop agreed that it would be desirable to develop an ecosystem model as a set of connected modules rather than a single large piece of software. Individual modules might be used to model various oceanographic processes (e.g. separate modules for ocean currents and the seasonal development of sea-ice) and the population dynamics of individual taxonomic groups (e.g. separate modules for Antarctic krill and fur seals). The Working Group endorsed the discussion on developing these modules provided in Appendix D, paragraphs 6.2 to 6.4.

2.19 The Working Group noted that ecosystem models typically describe interactions between species and taxonomic groups in the context of predator–prey and competitive interactions (although many other types of interactions are possible), and the manner in which such interactions are characterised typically has profound effects on the behaviour of and predictions from ecosystem models. It endorsed the discussion on predator–prey interactions in Appendix D, paragraphs 6.6 to 6.20, noting that:

- (i) the figures of food-web interactions (Appendix D, Figures 30 to 34) are a useful foundation for conceptualising the food webs in the Antarctic marine ecosystem;
- (ii) sensitivity analyses should be done to explore how predictions from Antarctic ecosystem models change in response to different assumptions about predator–prey interactions (e.g. assuming a Type II or Type III functional response or assuming different decision criteria in individual-based foraging models) and to different ways of modelling these interactions (i.e. using functional response curves or individual (group) based foraging models);
- (iii) studies should be done to determine whether, and under what conditions, functional response curves can be satisfactory approximations of individual-based foraging models. Although the latter approach may be more realistic, the former approach is likely to be more efficient in a modelling context.

2.20 The Working Group endorsed the considerations of incorporating space, time and depth into ecosystem models (Appendix D, paragraphs 6.21 to 6.24).

2.21 The Working Group noted that some consideration will need to be given to peripheral processes and boundary conditions in the context of animals that move in and out of the spatial arena described by operating models (Appendix D, paragraph 6.25).

2.22 The Working Group agreed that the workshop had achieved the goal to provide a foundation for conceptual models of the physical environment and taxa of the Southern Ocean ecosystem and how to place these into a modelling framework. It recognised that future work will entail validating the work presented here and further developing conceptual models as

indicated in the body of Appendix D, sections 4, 5 and 6. As such, the Working Group recommended continued refinement of these conceptual models and encouraged their implementation in the modelling framework.

2.23 The Working Group noted that an important task is to collate the appropriate parameter values for implementing functions and model components derived from these conceptual models. In this respect it also noted that reviews of available information would be useful and that a common database of available parameters could be developed to facilitate a coordinated use of such parameters and information.

2.24 The Working Group requested WG-FSA review the details provided on fish, squid and fisheries in Appendix D, section 4, and provide component details for toothfish and demersal species and to address the issues in Appendix D, paragraph 7.2.

2.25 The Working Group noted that the development of complex models will take some time to complete (Appendix D, paragraph 7.5).

2.26 With respect to next year's Workshop Management Procedures (paragraphs 6.12 to 6.21), the Working Group noted that initial exploration of management options could be achieved using spatially structured krill population models that allow exploration of the interaction between

- the krill population
- spatial catch limits and the fishery
- krill predators
- transport of krill.

2.27 The Working Group agreed that this may be feasible next year with the further development of existing models and new basic models taking account of outcomes of this workshop. This was further discussed in preparation for next year's workshop.

2.28 The Working Group agreed that further development of the framework and the implementation of one or more ecosystem models will require coordinated work. It recommended that a steering committee be established to coordinate this work and noted the points for consideration raised by the workshop (Appendix D, paragraph 7.7).

2.29 The Working Group noted that a number of research groups of CCAMLR Members are developing ecosystem models for the Southern Ocean. It therefore agreed to establish the steering committee as quickly as possible (Appendix D, paragraph 7.8). Details for the steering committee are given in paragraph 5.62.

2.30 The Working Group noted that the development of models for next year's workshop is a different task from the longer-term work. Nevertheless, it was recommended that the conveners of next year's workshop coordinate the preparatory work for the workshop with the coordinator of the steering committee and, in the interim, with those scientists nominated in paragraph 5.63. This will help provide the opportunity for modelling work for next year to be developed in such a way that it might contribute to the longer-term modelling work.

2.31 The Working Group thanked the Convener and the steering committee of the workshop and the Secretariat for successfully facilitating a productive workshop.

## STATUS AND TRENDS IN THE KRILL FISHERY

### Fishing activity

3.1 In the 2002/03 season, five Member countries fished, with a total of nine vessels, only in Area 48 (WG-EMM-04/15). The total catch reported was 117 639 tonnes, a slight decrease from the previous fishing season. Japan caught approximately 60 000 tonnes, followed by the Republic of Korea and Ukraine each with approximately 20 000 tonnes, and the USA and Poland each with approximately 10 000 tonnes. Fifty-seven percent of the total catch was taken from Subarea 48.3. Within Subarea 48.1, most of the catch was taken within the Western Drake Passage SSMU; in Subarea 48.2, the western sector South Orkney SSMU; and in Subarea 48.3, the South Georgia Eastern SSMU.

3.2 In the 2003/04 season to July 2004, seven vessels from six Members had reported a catch of about 43 000 tonnes of krill, suggesting that the total catch for 2003/04 would be below 100 000 tonnes (WG-EMM-04/15).

3.3 Fishing had been undertaken by Japan, Republic of Korea, Poland, Ukraine, UK and the USA. In addition, one vessel flagged to Vanuatu had entered the fishery. However, no data had been submitted to CCAMLR to date. It was noted that Vanuatu, an Acceding State to the Convention, had notified CCAMLR of its intention to fish according to CCAMLR requirements. Dr Agnew confirmed that the Vanuatu vessel was currently fishing in Subarea 48.3. A UK observer had been deployed. The Working Group asked the Secretariat to confirm with Vanuatu that the data would be submitted to CCAMLR.

3.4 The Working Group expressed its thanks to fishing nations for the provision of notification information in Table 1 (WG-EMM-04/6). This is the first time that the Working Group had had this information. It was recognised that although the total catch in Table 1 appeared to be much higher than in previous years (226 000 tonnes) the actual catches may not meet the forecasts depending on economic and other factors. Forecasts are therefore more likely to be upper estimates of potential catch. For instance, Dr V. Bibik (Ukraine) informed the meeting that Ukrainian vessels are likely to take significantly less than notified in the table, 25 000 tonnes with two vessels. The number of vessels and potential products may provide a better indicator of trends in the fishery.

3.5 The information on the timing and areas of potential fishing is particularly useful for the work of EMM. Information on products is useful to determine trends within the market for krill that might have implications for future development. Any requests for additional data in the notifications would similarly be linked to specific questions required for the work of WG-EMM.

3.6 The Working Group emphasised that the reason for requiring these data was to satisfy the requirement of Conservation Measure 51-01. This states that once the total catch in Area 48 exceeds 620 000 tonnes, precautionary catch limits will need to be developed and applied to smaller management units. Adequate warning of the approach of this catch limit is required in order for the Working Group to recommend appropriate subdivision of the area-wide catch limit.

## Description of the fishery

3.7 WG-EMM-04/39 presented an analysis of CPUE data from the former USSR. Interannual variation in CPUE for the overall fishing ground in Area 48 was found to be insignificant, and the paper suggested that krill density of 170–200 g m<sup>-2</sup> is the average density within the fishing grounds of Area 48. The document concluded that the stable CPUE for Area 48 is due to krill transport between subareas. Dr P. Gasyukov (Russia) emphasised that these estimates of krill density were only relevant to the krill fishing grounds.

3.8 WG-EMM-04/52 presented CPUE and daily production analyses of haul-by-haul data from the Japanese krill fishery during the 1980–2003 seasons. Catch per searching time was used as a proxy of krill abundance in the fishing area. Searching time was defined as the sum of time between hauls within an entire continuous operational fishing period, itself defined as the period between steaming to/from fishing grounds or between non-fishing periods.

3.9 The paper was based on a working hypothesis that operational effort will be maximised as krill density increases, until a critical krill density beyond which effort will decrease as processing capacity becomes limiting. CPUE will increase linearly as krill abundance increases until the critical density is reached, at which time CPUE will be constant whilst production is maintained. The analysis was done by using linear mixed models.

3.10 In the Drake Passage and Elephant Island area, neither fishing effort, CPUE nor production showed any clear trend that could be attributed to the above hypotheses. In the South Orkney area, the production pattern behaved as hypothesised, but fishing effort appeared to increase, and CPUE to decrease, at high krill abundance. In the South Georgia area, the production pattern behaved as hypothesised, but CPUE showed an increasing trend until reaching critical abundance and thereafter decreased, whereas effort showed a decreasing pattern to some point and thereafter increased.

3.11 The observed pattern suggested that the South Orkney and South Georgia areas are both operating around the critical point which is just enough to maintain the best factory performance but they suffer low production in years of low krill density. The status of Subarea 48.1 was not clear.

3.12 The document suggested that daily production may be a suitable index for krill abundance at low krill densities. It further suggested the need to validate the use of catch per searching time as an index of krill abundance. To do so it will be necessary to undertake acoustic surveys by research vessels in the same time and areas that fishing operations are taking place. Alternatively, it may be possible to analyse quantitative echograms from the fishing vessels.

3.13 The Working Group recalled that it had asked for this sort of analysis to be undertaken in the past (SC-CAMLR-XXII, Annex 4), and therefore welcomed the paper (WG-EMM-04/52). It encouraged further research along the lines of that suggested in paragraph 3.12, and asked Members to investigate the possibility of acquiring quantitative recordings from echo sounders on fishing vessels.

3.14 The behaviour pattern of the Japanese krill fishery in Area 48 was analysed in WG-EMM-04/51, based on questionnaires sent out to skippers. More than 10 years of accumulated information showed Japanese krill fishing operations tend to utilise fishing

grounds close to the southern limit within the ice-free range. This document revealed the usefulness of questionnaires to understand the behaviour of fishing vessels. Fishing patterns may vary between nations, and the document suggested the necessity of performing the same kind of analysis for all other nations' vessels to understand overall fishing strategies of the krill fishery.

3.15 The Working Group recalled that last year two Members (Poland and the USA) submitted questionnaires on krill fishing strategies. The Working Group stressed the usefulness of questionnaires for understanding behaviour of krill fishing fleets, and encouraged other Members to submit questionnaires.

3.16 WG-EMM-04/44 presented an analysis of seasonal variation in towing depth and CPUE in relation to the photoperiod using Japanese fishery data from 1980 to 2003. CPUE was highest during the day and lowest at night. Diurnal changes in fishing depth were observed at the South Shetland and South Orkney Islands, but did not occur during winter around South Georgia. Mean trawling depth was found to be shallow during summer and early autumn (in the top 60 m of the water column) but became deeper in mid-autumn, reaching a maximum average depth of 144 to 187 m in mid-winter. These changes reflect distribution of krill in relation to feeding and spawning behaviour.

3.17 WG-EMM-04/62 described the 2002 and 2003 fishing seasons in Subarea 48.3. Fishing occurred exclusively in the eastern region of South Georgia in 2002, but in 2003 part of the effort shifted to the western region. The modal size of krill in 2002 was the same in the fishery and the fur seal diet, however, in 2003, the modal size in seal diet was smaller than the mode of fishery-caught krill. During the winter period when there was a reduction in the frequency of occurrence of krill in the diet of seals, the fishery appeared to operate at greater depths suggesting a possible depth change of krill during winter. An initial analysis of krill length sampling variance suggested that significant gains in CV are not made at sample sizes greater than 400 individuals. The paper recommended that observer tasks should be restructured accordingly, to allow, especially, more time to be devoted to sampling fish by-catch.

3.18 The Working Group noted that seasonal depth changes in the distribution of krill aggregations were observed from fisheries data (WG-EMM-04/44), predator diet data (WG-EMM-04/62) and observer data (WG-EMM-04/10). All implied that krill depth distributions are shallowest during summer and autumn, deep in winter, and again shallow in spring.

3.19 WG-EMM-04/15 presented four measures of the degree of overlap between predator foraging, krill distribution and the krill fishery. The feasibility of calculating overlap indices for each of the SSMUs were investigated. It was recognised that estimated krill consumption and foraging areas for all known predator colonies are needed. This could be done by, for example, using data analysed in the SSMU Workshop.

3.20 WG-EMM-04/43 reported a relatively high rate of bacterial infection in krill in the catch. They were mainly infected in cephalothoracic segments. The infection rate was 1.93%, and the species of bacteria is yet to be determined.

3.21 WG-EMM-04/30 reviewed the USSR's fishery and scientific studies in the Atlantic sector of the Southern Ocean. Between 1961 and 1989, a total 55 scientific voyages was

undertaken, and these data are all stored in a newly created database. Whale surveys commenced in 1960, and the collected data includes statistical and biological data on embryo growth rate of several baleen and toothed whale species, including physiological structure of the females which could be used for stock evaluation and understanding population dynamics. Krill surveys started in 1961, and fish surveys in 1967, with the main aims of understanding ecology, stock and recruitment assessment and searching for new resources.

#### Scientific observation

3.22 There has now been a total of 14 international scientific observer cruises on krill vessels (WG-EMM-04/15). Three of these were in Subarea 48.1 in the 1999/2000 and 2000/01 fishing seasons (observers from the USA, Japan and Ukraine). Five were in Subarea 48.3 in the 2001/02 fishing season (four UK observers, one Ukraine observer) and six in Subarea 48.3 in the 2002/03 fishing season (all UK observers).

3.23 WG-EMM-04/31 reported incidental entanglements of seals in krill trawls in Subarea 48.3 recorded by UK observers in the 2002/03 fishing season. A total of 27 dead, 15 alive and 1 unknown seal entanglements were reported. Entanglements were noted only on vessels where the crews had no or limited previous experience in the krill fishery. Simple mitigation measures, involving the introduction of seal escape panels in the net, substantially reduced the problem. The observers reported that Antarctic fur seals were always present around the vessel during fishing operations.

3.24 The Working Group recalled the request of the Scientific Committee for information on this topic (SC-CAMLR-XXII, paragraphs 5.42 and 5.43). The Working Group regarded the issue of design of mitigation measures to avoid fur seal by-catch to be very important. All vessels should have some means of mitigation for fur seals and other affected species. The Working Group solicited the prompt submission to WG-IMAF of descriptions of mitigation measures and devices that have been developed in krill fisheries. This information may come from observers and the fishing industry. This will enable the development of advice on mitigation measures.

3.25 The Working Group agreed that when such advice has been developed, it would expect to recommend that mitigation devices be deployed on all krill vessels.

3.26 WG-EMM-04/10 reported the observations of the national observer on board a Ukrainian commercial krill vessel which fished from 25 March to 7 May 2003 in Subarea 48.2 and from 25 May to 23 June 2003 in Subarea 48.3. In Subarea 48.2, krill size ranged between 24 and 58 mm, comprising three size groups. Krill were slightly smaller than those observed in the previous season. Salps were not recorded. Only one small fish by-catch was recorded from this area. In Subarea 48.3, the krill size ranged between 32 and 60 mm, dominated by the 2000 and 1999 year classes. Juvenile icefish were recorded as by-catch in five samples. In Subarea 48.2, average sea-surface temperature at the fishing ground in April was abnormally low, possibly because of high abundance of icebergs in 2003. The Subarea 48.3 fishing ground also had below-normal sea-surface temperature in May and June. The average CPUE for the period was  $22.5 \text{ t.h}^{-1}$  and  $163.3 \text{ t.day}^{-1}$  for Subarea 48.2, and  $22.8 \text{ t.h}^{-1}$  and  $170.8 \text{ t.day}^{-1}$  for Subarea 48.3.

3.27 The Working Group drew the attention of WG-FSA to these records of juvenile icefish in catches from the krill fishery.

3.28 WG-EMM-04/42 reported the activities of a national observer on board the Japanese krill trawler *Chiyo Maru No. 5* from 4 August to 21 September 2003. The fishing area was around South Georgia, and 451 tows were performed during this observation. The average number of daily tows was 11.6 and the average duration was 27.5 minutes. By-catch sampling, biological measurements of krill, vessel sightings and marine mammal observations were reported. It was not possible to undertake conversion factor analysis from the meal plant since this would have required disruption of the operations. The observer suggested sampling from the conveyer belt is safer than working on deck, however, it is essential to ensure that sampling is not biased.

3.29 The Working Group recalled that there were a number of types of data that it required from the fishery: catch data, data on skipper behaviour, vessel decisions, biological properties of target species, information on fish by-catch and dependent and related species. Some of these types of data are best collected and reported by fishing vessels, and some are best collected by observers. The Working Group asked WG-FSA to consider if it is possible for WG-FSA-SAM to consider what observer coverage and sampling techniques would be appropriate to collect relevant data in the krill fishery.

3.30 In the meantime, the Working Group recommended that international scientific observers continue to be placed on as many krill vessels as possible. Some participants considered that a high level of observation would be required to acquire the information necessary to determine sampling protocols, and that this ought to apply equally to all krill fisheries.

#### Possible dialogue between fishing operators and WG-EMM

3.31 The Working Group recognised that information from the fisheries, particularly relating to the type, structure and density of aggregations which the fishing vessels target, may help increase the understanding of fishing operations and also greatly contribute to a better understanding of krill biology (e.g. overwintering biology) and the interactions between fisheries and predators.

3.32 The reason for the paucity in this kind of information is due to spatial and/or temporal mismatch between fishing operations and scientific surveys. This is largely because fishing operations occur throughout the year, whereas surveys are mostly limited to snapshots during summer months.

3.33 The Working Group identified a number of questions, for example, related to:

- (i) the commercial significance of different forms of fish and krill aggregations;
- (ii) properties of such aggregations and their significance to the fleet;
- (iii) catchability of different types of fishing gear;

- (iv) behaviours of fleets and individual fishing vessels in relation to the distribution of the fishable biomass;
- (v) how changes in the spatial distribution of krill may influence fishing behaviours.

3.34 The Working Group agreed to establish a dialogue with the fishing operators to obtain the necessary information, such as:

- (i) fisheries information, including:
  - haul-by-haul data
  - type of vessels and their technical characteristics
  - type of post-harvest processing;
- (ii) information on krill distribution patterns;
- (iii) visual information on predators;
- (iv) by-catch data;
- (v) biological data on krill and fish.

3.35 The Working Group noted that the information contained in paragraph 3.34(i), (iii), (iv) and (v) is available through the CCAMLR Scheme of International Scientific Observation if the forms are fully completed (paragraph 3.43(i)). The data which could not be obtained through scientific observation relate to information on the form of aggregation (paragraph 3.34(ii)).

3.36 Logging acoustic data voluntarily from a fishing vessel's echo sounder was suggested as a way to obtain information on the structure of aggregations at the fishing ground. The Working Group considered that this should involve minimum disruption to the fishing operation.

3.37 Several types of electronic interfaces are commercially available which allow logging of acoustic data from the ship's echo sounder.

3.38 The Working Group noted that there have been trials in the North Atlantic, which assessed the possibility of using echo sounders installed on fishing vessels to collect data on biomass (ICES-FAST report, 2004, [www.ices.dk](http://www.ices.dk)).

3.39 Another option considered by the Working Group was for fishing vessels to voluntarily undertake specific targeted and non-targeted tows at different times of the year at the fishing grounds to help understand the differences in krill population characteristics between those tows. This option may affect routine fishing to some extent, and these issues need to be carefully addressed.

3.40 Dr M. Naganobu (Japan) expressed his deep concern that collecting this information may violate the right to protect commercial confidentiality, and impose some unwanted, complicated duties.

3.41 The Working Group agreed to request further information on the acquisition of quantitative electronic echograms from fishing vessels, including on issues relating to equipment (and its installation) and data acquisition, access and analysis.

3.42 In the meantime, Members with an interest in collaborating on this topic were encouraged to develop appropriate proposals.

#### Recommendations for the attention of the Scientific Committee

3.43 The Working Group recommended the following:

- (i) The review of the *Scientific Observers Manual* should include:
  - (a) consideration of the number of samples that are required for estimation of krill biological properties and by-catch estimation on krill vessels;
  - (b) a requirement for vessel owners and skippers to give access to the factory decks for observers to undertake conversion factor analysis and to allow samples for the assessment of by-catch to be made before any sorting of the catch has taken place;
  - (c) consideration of the level of observer coverage (at vessel, season, haul and within-haul levels) required to acquire unbiased data required by WG-EMM.
- (ii) The review of the *Scientific Observers Manual* should be coordinated by the Secretariat (WG-EMM-04/21) and should include a meeting and/or correspondence involving practising observers and observer coordinators.
- (iii) In the interim, while considering the observer coverage required, WG-EMM recommended that international scientific observers continue to be placed on krill vessels where possible.
- (iv) Members be encouraged to submit fishery behaviour questionnaires in accordance with the *Scientific Observers Manual*.
- (v) Members investigate the possibility of acquiring quantitative electronic echograms from fishing vessels.
- (vi) WG-IMAF be requested to review seal mortality mitigation measures, noting that the Working Group would expect that mitigation devices would be deployed on all krill vessels, if necessary.

## STATUS AND TRENDS IN THE KRILL-CENTRIC ECOSYSTEM

### Status of predators, krill resource and environmental influences

#### Predators (pinnipeds)

4.1 WG-EMM-04/4 reported on male fur seal diet at Stranger Point, King George Island, from February to April 1996. Krill was the primary prey and occurred in 97% of scats, while myctophid fish occurred in 69% of scats (only 3% contained fish only) and cephalopods occurred in 12% of scats. Although there were no differences in proportions of prey between summer and autumn, the modal length class of myctophids increased over the time period sampled. The authors reported a decrease in the nototheniid fish *Pleuragramma antarcticum* compared to studies in 1992 and 1994.

4.2 WG-EMM-04/9 presented three tables of non-CEMP data registered with the Secretariat in response to the request from this Working Group (SC-CAMLR-XXII, Annex 4, Appendix D, paragraph 96). Tables 1 and 2 listed biological and environmental datasets, most of which were submitted as part of the 2003 CEMP Review Workshop. Table 3 listed other data of potential utility to CEMP.

4.3 In WG-EMM-04/33, labelled water methods were used to measure energy expenditure during lactation and energy gain during the post-breeding/pre-moult foraging trips for southern elephant seals. Total energy expenditure and energy gain were similar to measures made on animals breeding at South Georgia, however, because of shorter trip duration, the rate of energy gain in South Shetland females was greater. The authors attributed this to a potentially shorter transit time to primary foraging areas than seals making trips from South Georgia. Because information on diet in elephant seals is so limited and confined primarily to a few onshore lavaging studies, the authors used a range of squid and fish proportions to calculate an estimate of the total biomass consumed. In spite of assumptions about at-sea metabolic rates and diet, this is a valuable contribution and has potential for use in ecosystem models of squid- and fish-centric food webs.

4.4 WG-EMM-04/49 tested the hypothesis that there is no difference in krill length frequencies between predators and nets using net data collected only in fur seal foraging habitat and scat samples collected concurrently on land. As with studies at South Georgia (Reid et al., 1999) there was broad coherence with overall krill demographic trends from year to year. Significant differences in krill length frequencies occurred between predator diet and scientific net samples when the entire dataset for the west area of the US AMLR survey grid is used. However, when only net samples collected at survey stations in the area used by fur seals foraging from the scat-collection areas, no differences in krill length-frequency distributions for the two datasets resulted.

4.5 The Working Group asked whether fur seals foraging from Cape Shirreff bypass large krill occurring over the continental shelf to forage in the slope region northwest of the cape. If so, does the spatial distribution of krill inshore versus offshore differ in some way such that offshore krill aggregations were easier for fur seals to exploit?

4.6 Dr Goebel pointed out that data on the diet and foraging locations of penguins would suggest that larger krill are indeed exploited by penguins foraging much closer to Cape

Shirreff. He also pointed out that throughout a period of changing krill demographics (1999–2004, which includes two years of substantial recruitment) fur seals consistently foraged in the continental slope region northwest of Cape Shirreff.

4.7 WG-EMM-04/67 reported on the ecological implications of body composition and thermal capabilities in young Antarctic fur seals. Juvenile survival is important for sustaining predator populations and is the least understood phase of predator life cycles. This paper uses measures of body composition and metabolic rates for moulted pups and yearling fur seals to model post-weaning metabolic rates and thermoregulation to provide evidence that foraging habitat near natal rookeries may be important for post-weaning survival. It suggested that there is potential overlap between fishing areas and recently weaned foraging fur seals.

#### Predators (seabirds)

4.8 WG-EMM-04/5 reported on the 2004 breeding season at Cape Shirreff, Livingston Island. The chinstrap penguin population continued to decline as it has over the past four seasons; however, results for all other breeding and foraging indices found 2004 to be an average year for the chinstrap and gentoo penguins at this site. For the first time in seven years of study the size of krill taken by chinstrap penguins was significantly smaller than for gentoo penguins during their concurrently sampled chick-rearing periods.

4.9 WG-EMM-04/29 provided updates to a series of papers presented to the Working Group meeting last year by Dr R. Crawford (South Africa). Populations of gentoo, macaroni and eastern rockhopper penguins and Crozet shags continued to decrease at Marion Island in 2003/04. The decreases are thought to be due to a reduced availability of prey to birds foraging near the island. Populations of three albatross species (wandering, grey-headed and light-mantled sooty), two tern species (Antarctic and Kerguelen) and northern giant petrels appear stable at Marion Island, albeit with large annual fluctuations in breeding numbers. Numbers of dark-mantled sooty albatrosses, southern giant petrels and kelp gulls have shown a long-term decrease, although the count for dark-mantled sooty albatrosses was higher in 2003/04 than for several seasons.

4.10 WG-EMM-04/36 presented a list of publications for information only. It comprised a set of papers that were produced by two BAS core-funded science programs. The bibliography was tabled to ensure that Members are aware of the ongoing research programs that have relevance to the work of WG-EMM, but are not directly related to the current agenda.

4.11 WG-EMM-04/38 presented the results of diet sampling of Adélie penguins at two colonies in the Ross Sea, at Edmonson Point during five seasons (1995–1997, 1999 and 2001) and at Inexpressible Island in 2001. Mean diet composition varied from year to year and between the two locations in 2001. Results show the relative importance of krill and fish as principal resources in the summer diet of this species in the Ross Sea. *Euphausia crystallorophias* and *E. superba* varied from year to year, with the latter particularly abundant in 2001 at both colonies. These differences in the diet composition between two colonies in close proximity suggest that several factors, including environmental factors, colony location and colony size, should be considered before reaching conclusions on prey availability from diet data.

4.12 WG-EMM-04/57 described temporal changes in foraging range throughout the breeding season of Adélie penguins nesting at Béchervaise Island in Eastern Antarctica. Penguins ranged furthest north during incubation and used a recurrent polynya to forage in the early season. They made their shortest trips during the guard stage of chick rearing and penguins foraged most intensively at the continental shelf break and over submarine canyons, particularly whilst feeding chicks. Birds foraging prior to their annual moult travelled hundreds of kilometres to both the west and east of their breeding sites. Foraging ranges increased as the chick-rearing period progressed, consistent with hypotheses of prey depletion and intra-specific competition. Projection of the foraging ranges derived from this study onto other Adélie penguin colonies in the Prydz Bay region indicated varying degrees of overlap depending on the stage of the breeding season and the distance between populations. On the basis of the foraging areas described in the paper, two management units could be defined between longitudes 51°–71°E and 71°–81°E and extending as far north as 65°S.

### Krill

4.13 WG-EMM-04/39 highlighted that, due to the scarcity of comparable scientific long-term data, the nature of interannual fluctuations of krill biomass for the entire Scotia Sea is uncertain. The authors noted that the extensive dataset collected from the former Soviet krill fishery might fill this gap, because long haul duration across krill patches may be considered as an appropriate sampling strategy. This would allow the use of CPUE indices for direct monitoring of 10-day, monthly and longer-term fluctuations in krill biomass. Haul-by-haul data were used for the period from 1977 to 1991 and CPUE indices were calculated for all vessel types.

4.14 For the period from 1986 to 1991 the average CPUE was 6.3 t.h<sup>-1</sup> for all vessel types, ranging between 5.6 t.h<sup>-1</sup> and 6.4 t.h<sup>-1</sup> depending on the vessel type. Interannually, CPUEs in Area 48 varied from 4.9 to 6.4 t.h<sup>-1</sup> for all vessel types. In Subarea 48.1, the average CPUE was 5.2 t.h<sup>-1</sup>, in Subarea 48.2 it was 7.3 t.h<sup>-1</sup>, and in Subarea 48.3 it was 6.0 t.h<sup>-1</sup>. Interannual CPUE variations were rather small for Area 48 as a whole. The average CPUE values for the period from 1978 to 1986 were 6.1 t.h<sup>-1</sup> for the whole of Area 48 and for all vessel types.

4.15 The authors of WG-EMM-04/39 concluded that despite the variable interannual biomass estimates from acoustic surveys in subareas, the average annual CPUE values did not vary significantly for the whole of Area 48 as well as for Subareas 48.1, 48.2 and 48.3. The authors suggested that a mean biomass density of about 170–200 g m<sup>-2</sup> may be considered as an average characteristic value for fishing grounds in Area 48 (see paragraph 3.7).

4.16 The Working Group emphasised that analyses of krill stock stability/fluctuations from fishery CPUE data should consider the kind of krill aggregations from which these data were derived. It was further noted that CPUE data should be standardised. In particular, changes in variances should be considered in addition to the means to facilitate consideration by the Working Group (such as those described in WG-EMM-04/39) that would allow inferences to be drawn on whether the krill population was variable or stable.

4.17 WG-EMM-04/27 described results from two net sampling surveys across the Scotia Sea in the summers of 1984 and 1988. Three size groups of krill were identified: a large group of 48–50 mm modal size was associated with the southern branch of the ACC, while

medium- and small-sized krill (40–44 and 30–35 mm respectively) were linked to the Weddell Sea water mass. An additional bimodal size group was observed in the summer of 1988.

4.18 The authors noted that in the study area the considerable variability in the distribution of these size groups, and the boundaries between them, was dependent on the high interannual dynamics of the water masses in the area, reflecting the relative influence of water from the west as well as from the Weddell Sea. The authors suggested that in 1988 the water dynamic conditions were close to the climatic norm with Weddell Sea water transport to the eastern shelf of South Georgia and cold-water intrusion to the far north. Comparing their results with those obtained during the CCAMLR-2000 Survey, the authors suggested a high degree of similarity in krill stock distribution and composition between the two years. The situation in 1984 was thought to be anomalous; during a warm period the transport of the cold Weddell Sea waters into the eastern part of the Scotia Sea decreased due to ACC intensification. This scenario might provide an explanation as to why during this type of hydrological regime the small krill group was not transported to South Georgia, though it did occur further south in the Drake Passage.

4.19 The authors summarised that the observed regular occurrence of the three basic size groups, their spatial distribution and the association with water mass dynamics justifies the conclusion that the general structure of the krill population in the southwestern Atlantic sector has not changed during the past 20 years. The observed dynamics of the spatial distribution of krill size groups, and the variability in the structure and source of krill stocks at individual fishing grounds, is determined by interannual peculiarities of the hydrological regime.

4.20 The Working Group noted the potentially important influence of the Weddell Sea stock for krill stock composition in the Scotia Sea and at South Georgia, which may vary considerably between years. The Working Group felt that the potentially critical role of the Weddell Sea warrants further detailed consideration. However, the Working Group could not agree on a common view about the long-term stability of the krill population in Area 48. Some members interpreted the results of WG-EMM-04/27 as an indication that the ecosystem of the Atlantic sector has been stable for the past 20 years. Other members felt that the results may be regarded as a signal, but results came from three years only and it is difficult to interpolate these points to draw inference over a longer time period, especially in the light of results obtained from several long-term mesoscale scientific surveys.

4.21 WG-EMM-04/66 Rev. 1 presented the results of acoustic surveys from the summer months of 2000 and 2002 around South Georgia and reported significant distinctions in krill aggregation structures in the northwestern and northeastern parts. The northwestern part, where foraging grounds for predators are, is not attractive to the krill fishery. Potential fishing grounds with krill density exceeding the threshold value of  $100 \text{ g m}^{-2}$  were observed in the northeastern part.

4.22 It was assumed that a dispersed aggregation (layers and irregular forms) is suitable for predators and dense swarms are more attractive to the fishery. The author of the paper concluded that investigations of the foraging tactics of predators and comparison of the availability of different structures of krill aggregations to fishing vessels and predators are important for understanding how the interaction between upper-trophic level predators and krill biomass might be used to manage levels of krill fishing.

4.23 Dr Reid noted that both of these areas are used by the krill fishery during the winter and this may indicate that there were changes in the characteristics of the krill distribution between summer and winter. Dr Trathan suggested that at South Georgia during the winter period, when fur seals are not constrained to return to their breeding beaches, their foraging areas include areas that are also utilised by krill fishing vessels. This is evident, given the incidental mortality of fur seals (paragraph 3.23).

4.24 WG-EMM-04/44 examined seasonal variation in CPUE data from Japanese trawling operations during different seasons and in different parts of Area 48. During summer and winter, average trawling depth showed a marked diurnal change around the South Shetland and South Orkney Islands, i.e. trawling operations were deepest during the day and shallowest at night. At South Georgia in winter, the average depth was deepest at dawn and shallowest at dusk. Trawling depth was relatively shallow in summer (20–60 m) and deepened gradually until autumn (40–160 m), attained the maximum depth in winter (100–300 m) and rapidly decreased again in early spring. The depth range over which trawling occurred increased from summer to winter. Diurnal changes also occurred in CPUE data. In summer largest catch rates were obtained at night, while in autumn and winter largest CPUE values were observed during the day. The authors concluded that the observed seasonal variation patterns in trawling depth and CPUE can be explained by diel vertical migration behaviour of Antarctic krill triggered by the light regime.

4.25 The Working Group noted that such patterns of seasonal changes in vertical distribution of krill were also observed in other areas (Lazarev Sea, WG-EMM-04/23), predator diet studies (WG-EMM-04/63) as well as in other CCAMLR fishing operations (WG-EMM-04/10). This indicated that the described seasonal vertical distribution pattern might be a more general pattern than just for the described area or years.

4.26 WG-EMM-04/62 presented an initial analysis of the characteristics of Antarctic krill taken by the fishery and fur seals during the winters of 2002 and 2003 at South Georgia. There was considerable overlap in the size composition of krill taken by the fishery and in the diet of fur seals. During winter, the occurrence of krill in the diet of fur seals was reduced and the fishery was apparently operating at greater depths. This may suggest a possible depth change of krill during winter.

4.27 Dr Constable indicated that it might be useful to ask krill fishing vessels to undertake research trawls at given times, depths and locations to further the understanding on the interactions between krill distribution and foraging behaviour of predators.

4.28 WG-EMM-04/63 described data on the population size composition of krill from the diet of predators at Bird Island, South Georgia, over the past decade. This analysis has provided a re-evaluation of population demographics of krill at South Georgia, and has provided evidence for a relationship between sea-surface temperature and the level of krill recruitment in Subarea 48.3. The Working Group noted that using predators as samplers of krill can help provide information on the life-history parameters of krill used in assessments.

4.29 WG-EMM-04/23 introduced results of krill net sampling surveys from Subareas 48.1 and 48.6 in the 2004 season. It was noted that the Lazarev Sea survey is located in the high-latitude part of the distribution range of *E. superba*. During April 2004 krill in the Lazarev Sea were distributed inside and outside the pack-ice zone. More than 90% of the day samples had zero or less than one krill per 1 000 m<sup>-3</sup>, whereas more than 90% of all night samples

were larger than one krill per 1 000 m<sup>-3</sup>. A possible explanation for day–night catch differences could be a different krill vertical migration behaviour during this late autumn period and/or in these high latitudes. Krill abundance estimates from night samples only were 31.1 krill per 1 000 m<sup>-3</sup>. This level of density is below the long-term average observed in the Antarctic Peninsula region. Mean abundance of krill larvae in the Lazarev Sea was low compared to the FIBEX 1981 survey and the CCAMLR-2000 Survey indicating that absolute recruitment and stock density will not greatly increase in the next year.

4.30 Krill length-frequency data from the Lazarev Sea survey showed recognisable size groupings with medium-sized immature krill dominating north of the pack-ice. A second group was characterised by bimodal length frequencies consisting of immature stages and large adults inside the pack-ice zone. Recruitment indices for the 2004 Lazarev Sea survey were low for the 2003 year class (R1 = 0.039) and very high for the 2002 year class (R2 = 0.762).

4.31 Krill numerical density indices in Subarea 48.1 for the Elephant Island survey were around 50 krill per 1 000 m<sup>-3</sup>. This was below the long-term average and a substantial drop since the high level of krill abundance in the 2001 and 2002 seasons. Recruitment indices for the Elephant Island survey showed a very poor recruitment success of the 2003 year class (R1 = 0.0001), while values from earlier years indicate good recruitment for the 2000 to 2002 year classes which caused the interim increase in density values after a long period since the mid-1980s with rather low stock abundance.

4.32 WG-EMM-04/72 presented results on krill demography and zooplankton composition in Subarea 48.1 during the summer of 2004. Mean krill densities in the Elephant Island area were similar during two consecutive surveys with values quite close to the 1992–2004 means (52.1 and 54.4 krill per 1 000 m<sup>-3</sup>). In January, lengths were distributed around 42 mm modal size with >75% of individuals over 35 mm in length; in February–March length distribution was polymodal around 33–35, 43–45 and 50 mm lengths.

4.33 The conclusion of the paper was that the overall krill length-frequency distributions from January to March 2004 (predominantly >35 mm individuals) reflected strong recruitment success of the 2000, 2001 and 2002 year classes and minimal representation from 2003. It is also concluded that the presence of relatively advanced furcilia larval stages in January indicated an extremely early initiation of spawning and that the combination of prolonged reproductive efforts and abundant larvae provide a basis for good recruitment success the following year, however, other factors such as advective regimes and overwintering conditions may also be critical determinants.

4.34 January 2004 was characterised by relatively sparse zooplankton catches. Total zooplankton abundance one month later was an order of magnitude greater. This was due to increases in copepods, chaetognaths and larval *Thysanoessa macrura*. After 1998, the dominance of salp and copepod and their relative abundance changed dramatically. This has been associated with a significant order of magnitude increase in mean copepod abundance. Other zooplankton taxa such as *E. frigida* and chaetognaths also demonstrated significant abundance increases. In the light of increases in certain zooplankton taxa and increased frequency of strong krill year classes, the author suggested that after the 1998 El Niño the Antarctic Peninsula region may have experienced the same regime shift that is affecting the entire Pacific Ocean basin. Most significant of these changes to CCAMLR is the build-up of krill stocks in Subarea 48.1 that had declined significantly during the past 20 years.

4.35 The Working Group realised that currently three quite different scenarios are suggested to describe the state of krill stocks in Area 48:

- stable population over the past 20 years (WG-EMM-04/27, 04/39)
- fluctuation with an eight-year cycle (Hewitt et al., 2003)
- regime shift since 1998 (WG-EMM-04/72).

The Working Group noted that the simulation models currently under development by WG-EMM may help address this question in future, taking into account the physical environment, and indicate which of the scenarios might be more realistic.

4.36 Dr Constable voiced his concern that the terms ‘oscillation’, ‘fluctuation’, ‘changes in state’ and ‘regime shift’ should be used carefully, and that there is a need for WG-EMM to discuss these terms and come to a common understanding and use of these terms.

4.37 Dr Kawaguchi noted that the distribution of krill larvae described in WG-EMM-04/23 may be a good indication of a southward movement of krill larvae in autumn. This would support the concept of the seasonal aspects of krill distribution summarised in WG-EMM-04/50 which will form part of the ecosystem modelling approach of WG-EMM.

4.38 Dr Naganobu highlighted the importance to investigate other zooplankton species such as *E. frigida*, because dynamics of their distribution might help to explain a southward shift or changes in the transport rate of the ACC.

4.39 WG-EMM-04/10 described the results of scientific observations on a krill fishing vessel around the South Orkneys and South Georgia in autumn (March to June) 2003, and comparison with data from previous seasons. The paper presented data on catch, biological state of krill, size groups of krill and analysis of weather and ice conditions. Sea-surface temperature around the South Orkneys from March to April was lower than in normal years, and ice was formed earlier, resulting in a fishing season 1.5 to 2.5 months shorter than usual. Hydrometeorological conditions around South Georgia were closer to the long-term average. Fishing conditions (in terms of CPUE) in Subarea 48.2 were generally favourable, and fishing conditions in Subarea 48.3 from May to September were very favourable.

4.40 WG-EMM-04/35 reported near-shore acoustic surveys for Antarctic krill that were conducted using a small vessel at South Georgia in January 2004. These surveys obtained estimates of krill biomass from areas where no such data have been available so far, but are important for foraging to some species of land-based predators (e.g. penguins). Mean krill densities were 5.9 to 7.1 g m<sup>-2</sup>, and this low density was not unexpected in line with cyclical patterns, but may have been exacerbated by the presence of large icebergs. The Working Group noted that this is a new attempt, and combination of data from small vessels operating near the shore with data collected over more extensive, offshore areas by large ocean-going research vessels would provide a more comprehensive understanding of the prey field available to krill predators.

4.41 WG-EMM-04/71 presented a preliminary result of the interdisciplinary survey conducted in the Ross Sea from December 2003 to January 2004. Two krill species (*E. superba* and *E. crystallophias*) moved with different spatial and temporal scales. Distribution centres of the two species were different – the centre of *E. superba* was further

north than that of *E. crystallophias*. The distribution centre of *E. superba* in this survey was found in the northernmost position (70°–69°S) and, as in previous surveys, this was where the greatest number of whales was observed.

### Physical environment in Subarea 48.3

4.42 WG-EMM-04/34 explored temporal variability in the physical environment at South Georgia. The paper showed how time-series analysis of sea-surface temperatures highlight the presence of high levels of autocorrelation, with periodicity evident in temperature anomalies at lag periods of approximately three to four years. The authors presented cross-correlation analyses of temperature series from South Georgia with temperature anomaly data for the El Niño 4 region in the Pacific; these analyses showed that variability at South Georgia reflects temperature fluctuations in the Pacific, with the Pacific leading South Georgia by approximately three years. The Working Group recalled that similar relationships had been presented previously at the Workshop on Area 48 (SC-CAMLR-XVII, Annex 4, Appendix D).

4.43 WG-EMM-04/34 also explored biological variability at South Georgia, with variability evident in data from a suite of top predators. The paper showed how periods of reduced predator breeding performance are strongly correlated with warm anomaly periods, but lagged by a number of months. For some predators the most critical periods appear to be prior to the breeding season during the summer and early autumn of the preceding year. The analyses showed that gentoo penguins exhibit a strong negative relationship between the number of chicks fledged and sea-surface temperature in the preceding February some 12 months earlier. Antarctic fur seals also show a similar negative relationship between the number of pups surviving at birth and the temperature 14 months earlier in the preceding November.

4.44 WG-EMM-04/34 suggested that the observed relationships most likely reflect prey (krill) availability. WG-EMM-04/63 explored this relationship further and showed a relationship between sea-surface temperature and the level of krill recruitment.

### Physical environment in the southwest Atlantic

4.45 WG-EMM-04/46 used spectral analysis to explore an updated Drake Passage Oscillation Index. These analyses showed periodicity at scales of approximately 20, 35 and 55 months. These scales are consistent with the periodicity in sea-surface temperature anomalies reported by WG-EMM-04/34.

4.46 WG-EMM-04/45 compared oceanographic structures in the southwest Atlantic during the 1981 FIBEX survey and the CCAMLR-2000 Survey. The paper suggested that the distribution of cold Antarctic Surface Water during the 1981 FIBEX survey was more extensive than during the CCAMLR-2000 Survey. The author suggested that this is consistent with the interannual variability. However, the author also suggested that this is consistent with environmental warming.

4.47 In contrast to this, WG-EMM-04/72 suggested that a regime shift (paragraph 4.36) affecting the entire Pacific Ocean basin has occurred following the 1998 El Niño and that this shift has resulted in dramatic ecological changes in the AMLR survey area around Elephant Island. The author suggested that these results now raise questions about the validity of previous conceptual models of how krill, salp and sea-ice dynamics operate in the Antarctic Peninsula region.

4.48 WG-EMM-04/72 also suggested that should this regime shift persist, it is likely that it will have profound effects on the Antarctic Peninsula ecosystem; the most significant of these changes is likely to be a build up of krill stocks in Subarea 48.1 following an increased frequency of years with successful krill recruitment and apparently increasing population size.

4.49 All these papers (WG-EMM-04/34, 04/45, 04/46, 04/63 and 04/72) suggested that large-scale climate variability has a potentially profound effect on the dynamics of the marine ecosystem in the southwest Atlantic. Consistent signals are reported by some of these papers (WG-EMM-04/34, 04/46 and 04/63); however, some effort is still required before it is possible to have a conceptual model that also includes the hypotheses outlined by others (WG-EMM-04/72). The Working Group therefore recognised that important challenges remain before large-scale climate signals, sea-ice dynamics, polynya formation and other physical processes influencing the Southern Ocean are fully understood.

#### CEMP parameters

4.50 Dr Ramm presented the annual report of trends and anomalies in CEMP indices in WG-EMM-04/14 provided by the Secretariat. The report included all data submitted up to the 18 June 2004 deadline and provided a summary of intersessional progress in data validation and checking.

4.51 WG-EMM-04/14 also included a new index of Antarctic fur seal pup growth rates (SC-CAMLR-XXII, Annex 4, paragraph 4.110). The Working Group noted that the new index was currently calculated for both sexes combined and asked that the index be calculated individually for male and female pups.

4.52 Following the recommendation of the Working Group last year (SC-CAMLR-XXII, Annex 4, paragraph 4.4) the Secretariat had investigated the feasibility of calculating predator–fishery overlap indices for each of the SSMUs. Whilst it may be relatively straightforward to allocate krill catch to SSMUs on the basis of STATLANT data, the calculation of overlap indices would require estimates of krill consumption and foraging areas for all known predator colonies within each SSMU. Currently this data only exists for penguins in Subarea 48.1, however, WG-EMM-04/14 suggested that the data prepared and analysed during the SSMU Workshop (SC-CAMLR-XXI, Annex 4, Appendix D) may be useful in developing this approach further.

4.53 WG-EMM-04/17 contained correspondence relating to the collection of CEMP data on gentoo penguins in a collaborative project involving Ukraine and Bulgaria. The Working Group thanked Ukraine and Bulgaria for providing the information that it had requested (SC-CAMLR-XXII, Annex 4, paragraph 7.14) and noted that the data arising from this research would be difficult to integrate into CEMP at this time.

4.54 WG-EMM-04/17 also contained details of the methods used by Norway when collecting CEMP data at Bouvetøya that highlighted the difficulties of working at this site. The Working Group asked that these details be archived by the Secretariat in order that they be available to advise future analyses of CEMP data.

4.55 WG-EMM-04/60 presented preliminary analyses of approaches which may be used to evaluate the sensitivities of CEMP indices to sampling procedure. The methods and presentation of CEMP parameters A1 (penguin arrival mass), A5 (penguin foraging trip duration) and A7 (penguin fledging mass) were evaluated using simulated time-series data.

4.56 Analysis of the effects of the intensity and timing of sampling during five-day periods for measures of arrival and fledging mass suggested that situations where sampling is distributed unevenly around the peak arrival/fledging date may introduce substantial bias in CEMP parameters A1 and A7.

4.57 The analysis of parameter A5 addressed the concern that the description of foraging trip duration using the mean arising from a bimodal distribution of trip durations from individual penguins may not provide a useful index of foraging performance. The analysis presented in WG-EMM-04/60 suggested that although the mean may provide a useful index, the use of the 90th percentile of the cumulative foraging effort may provide a more sensitive measure of variability arising from changes in foraging strategies of penguins.

4.58 The Working Group agreed that these preliminary analyses represented an important development in the understanding of the properties of CEMP indices and recognised that the continuation of such analyses would be an important part of the future work of the Working Group.

4.59 Following the advice of the Working Group in 2003 (SC-CAMLR-XXII, Annex 4, paragraphs 4.9 to 4.18), WG-EMM-04/61 suggested a potential alternative to the current approach to providing advice on the status of the krill-centric ecosystem which relies on the evaluation of statistical anomalies in the CEMP database. This approach uses an ordination of variables according to functional groupings to summarise the variability in CEMP parameters, following the outline in WG-EMM-03 (SC-CAMLR-XXII, Annex 4, paragraph 4.15) based on the methodology developed by WG-EMM to produce composite standardised indices (CSIs) from data matrices containing missing data. Examples of the approach were provided using data from Subarea 48.3 (see WG-EMM-03/43) together with a potential procedure for identifying anomalous years with respect to the rest of the time series.

4.60 Dr Constable noted that the analysis of CEMP data should identify when there is a significant departure from a normal situation and that it was important to evaluate: (i) the properties of the constituent parameters for inclusion in combined indices in order to identify appropriate functional groups for inclusion in such analyses; and (ii) the statistical properties of the indices themselves. He further noted that the use of ordination approaches to facilitate decision-making had received considerable attention in the environmental impact literature of the 1990s.

4.61 The Working Group agreed that the approach developed in WG-EMM-04/61 was useful and encouraged further exploration using data from other regions. The Working Group agreed that further work was required both to develop: (i) a quantitative mechanism by which to evaluate the properties of methods to summarise CEMP parameters; as well as (ii) a

process of decision-making based on those summaries. In so doing, it recalled its agreement in 2000, that further development of the interpretation of CEMP indices would need to include a consideration of the issues described in SC-CAMLR-XIX, Annex 4, paragraph 3.51.

#### Further approaches to ecosystem assessment and management

4.62 The Working Group considered two papers which raised issues potentially relevant to other aspects of CCAMLR's approaches to the management and conservation of marine systems, species and stocks.

4.63 WG-EMM-04/28 described approaches in South Africa to manage interactions between fishery target species and dependent species, arising from new South African legislation incorporating principles of sustainable use and precautionary and ecosystem approaches, giving effect to obligations under a variety of international agreements (e.g. FAO's Code of Conduct and Reykjavik Declaration on Responsible Fishing, World Summit on Sustainable Development's Implementation Plan).

4.64 In respect of providing protection for dependent species, WG-EMM-04/28 discussed the topic of setting target population levels, particularly for restoration of depleted populations, such as African penguins. The paper suggested that some of the criteria used in determining the conservation status of species in the IUCN system may be useful in this context. It noted some of the issues involved in converting estimates of extinction probability (and associated estimates of Minimum Viable Populations (MVP)) to population level targets which incorporate appropriate levels of precaution for rebuilding depleted populations. The paper also discussed possible management approaches in South Africa for restoring depleted populations of dependent species, potentially involving consideration of closed areas and prey-escapement levels based on predator-prey functional relationships, taking account of density-dependence considerations.

4.65 The Working Group welcomed this information and noted some similarities with management approaches developed within CCAMLR. It was observed, however, that target population levels for recovery of depleted populations would be very different from population target levels associated with fisheries, including those currently assessed by CCAMLR. Even in respect of restoring populations of krill-dependent species (even those within the same IUCN category of threat) within the Convention Area, target levels would need to reflect the different trajectories of populations and species. Thus, for instance: (i) Antarctic fur seals are increasing in most areas, and possibly exceeding pre-exploitation levels in some of these – in other areas populations are still recovering to former (historical) levels; (ii) populations of many species of baleen whales (several in IUCN globally threatened categories) may be increasing but are still in need of substantial restoration; (iii) some macaroni penguin (IUCN Vulnerable category) populations have been declining for 20 to 30 years.

4.66 It was recommended that WG-FSA be consulted to determine if any models or methods relating to the estimation of target population levels could be evaluated by WG-FSA-SAM.

4.67 Management measures to achieve desired population levels would have to take account, at least in the case of krill, of the need to manage simultaneously different targets associated with krill-dependent species with different population trends and functional relationships. Some of the modelling initiatives, particularly multispecies predator–prey interactions involving krill considered by the Workshop on Plausible Ecosystem Modelling, may assist with investigating the feasibility of this.

4.68 In reviewing WG-EMM-04/20, concerning the marine ecosystem in the Ross Sea, it was noted that this paper was a development of ideas and concerns last considered by the Working Group in WG-EMM-02/60.

4.69 In WG-EMM-04/20, the author argued that the Ross Sea Shelf Ecosystem (RSShelfE) is:

- (i) of the world’s ‘Large Marine Ecosystems’ (LME), the one least affected by direct anthropogenic alteration;
- (ii) a highly distinct ecosystem within the Antarctic by virtue of its physical and biological characteristics;
- (iii) the subject of the Antarctic’s most intensive programs of long-term multidisciplinary scientific research, involving notable multinational collaboration and cooperation;
- (iv) through its unique attributes and the intensive research, providing some of the clearest evidence of climate forcing and top-down controls – and that there are few, if any, other marine ecosystems where both processes are important, still extant and accessible for study.

4.70 The paper discussed the potential for top-down control of ecosystem processes with examples from current research on Adélie penguin and minke whales (key consumers of *P. antarcticum* and *E. crystallophias*), and on orcas (killer whales) and Weddell seals in relation to interactions with *Dissostichus mawsoni*.

4.71 The paper also noted that CEMP is relatively undeveloped in the RSShelfE (and focused exclusively on Adélie penguins) and that CCAMLR may receive little information on, for instance, the increasing knowledge of the key role that toothfish may play in respect of dependent species such as seals and whales.

4.72 WG-EMM-04/20 concluded by suggesting that the recent initiation and rapid expansion of the fishery for *D. mawsoni* and the continuing removal of large numbers (in terms of potential ecosystem effects) of minke whales may have the potential for:

- (i) prejudicing the scientific research programs directed at studying fundamental processes (including relevance to regional and global climate change) in this system;
- (ii) creating unforeseen (and currently unmonitored) effects for dependent species, including their potentially critical role in ecosystem processes.

It noted that reviewing the effects of current levels of exploitation in the RSShelfE would require collaboration between CCAMLR and the IWC.

4.73 In relation to some of the points raised by WG-EMM-04/20, Dr K. Shust (Russia) observed that:

- (i) the paper did not provide a full understanding of the functioning of the RSShelfE. In particular, it did not accurately reflect the development of the fishery, including the conservation measures implemented to ensure that any expansion remained consistent with CCAMLR's principles of precautionary management for new and exploratory fisheries;
- (ii) the area has complicated topography, especially in relation to benthic habitats, which might warrant consideration of the most appropriate types of fishing gear to be used, including for longline fisheries;
- (iii) he had concerns about the apparent presumption, in the absence of adequate scientific data, that conservation issues, including the use of marine protected areas, should be given greater emphasis than the maintenance of sustainable fisheries;
- (iv) there was considerable additional information, relevant to the high-latitude Pacific sector, including the RSShelfE, especially on climate change and physical forcing functions, in Maslennikov (2003).

4.74 Dr S. Olmastroni (Italy) believed that WG-EMM-04/20, taken in conjunction with the references cited therein, did provide an accurate appraisal of many aspects of current thinking on ecosystem interactions in the region. She noted that time series of data on many species and processes were very extensive and that the understanding of many of the predator-prey-environment links in this specialised system was at least as good as anywhere else in the Southern Ocean. She believed that, on the basis of the scientific data currently available, there was a good case for CCAMLR considering the direct and indirect effects of removals of whales and toothfish in relation to:

- (i) complicating existing multinational collaborative investigations into fundamental physical and biological processes in the region's systems;
- (ii) the nature of existing management by CCAMLR and the IWC of the magnitude and distribution of exploitation.

Several members supported this view.

4.75 Dr Shust noted that additional data, including appropriate models of relevant interaction processes involving components of the high-latitude ecosystems of the Pacific sector, including Subareas 88.1 and 88.2, would be essential in any such evaluations.

4.76 Dr Kirkwood cautioned against incautious acceptance of statements (e.g. WG-EMM-04/20, p. 12) concerning the reasons underlying decisions made by the IWC and patterns of whale harvesting in, or adjacent to, the RSShelfE.

4.77 Dr Constable welcomed the synthesis of information contained in WG-EMM-04/20 and recognised that it posed some important questions for CCAMLR. These included:

- (i) How can we provide advice, in the future, on natural ecosystem processes, if fisheries are occurring everywhere?
- (ii) Therefore, how can we ensure that the ability to predict/detect the impacts of fishing is not affected by the fishing process itself?
- (iii) How best to coordinate conservation and management initiatives between CCAMLR and other international instruments and organisations with responsibilities relevant to the RSShelfE and adjacent areas.
- (iv) The possible need for data on by-catch of benthos, especially fragile species and communities, in longline fisheries within the RSShelfE.

4.78 Dr Naganobu noted the particular importance of the RSShelfE for existing and projected scientific research, notably recent research on marine environmental variability. He indicated that the Japanese research vessel *Kaiyo Maru* would collect data simultaneously on environment–Antarctic krill–whale interactions in the Ross Sea and adjacent waters during a survey in 2004/05 (WG-EMM-04/47). Transects along 180°E, 175°E and 165°E will cover hot spots such as the Scott Seamounts, the Balleny Islands, the shelf off Victoria Land and the Bay of Whales where high concentrations of krill and whales are suggested to occur. The 175°E transect will be surveyed in particular detail from the surface to near the sea bottom in relation to physical, chemical and biological processes.

4.79 Dr Penhale indicated likely increased US interest in regional and global process studies involving data collected from the RSShelfE and that such projects were, like SO GLOBEC, increasingly likely to include data collection from all trophic levels. She noted that modern protected-area concepts were readily applicable to the Southern Ocean and that the RSShelfE, as well as other areas, might benefit from such approaches.

#### Other prey species

4.80 WG-EMM-04/22 reported a study of within- and between-year variation in foraging patterns in the Antarctic blue-eyed shag. It concluded that before such variation could be used in monitoring programs as indicators of fish prey availability, considerable additional research is needed to understand the influence of other associated behaviour patterns that have potentially confounding effects.

4.81 WG-EMM-04/68 reported analyses of the cephalopod diet of gentoo penguins and Antarctic fur seals at Laurie Island, South Orkney Islands, in the March–May periods of 1988 (fur seals) and 1993, 1995 and 1996 (gentoo penguins). The occurrence of squid, particularly *Psychroteuthis glacialis*, in penguin and fur seal diets at this time of year may be fairly typical (albeit that krill was still the dominant prey category), especially in years of low local krill availability (1995).

4.82 It was noted, however, that, relative to krill, squid tends to be over-represented in such studies of penguin diet, because squid beaks have long residence times in stomachs. In addition, sample sizes for Antarctic fur seals were very small (39 seal scats and 35 squid beaks).

4.83 Some publications reporting research on other prey species of potential general interest to CCAMLR are listed in WG-EMM-04/36. In addition, several papers tabled for the Workshop on Plausible Ecosystem Models contained, or summarised, considerable information on the role of squid and fish in Antarctic marine ecosystems.

4.84 The Working Group requested the Scientific Committee to reconsider how it wishes to treat matters relating to ecosystem interactions involving fish and squid.

## Methods

### Acoustics

4.85 WG-EMM-04/18 reported on progress on the development of an ‘event driven’ archive of acoustic surveys compiled by the Secretariat; the archive contains ek5, EV and csv files from the CCAMLR-2000 Survey. Further work is required to import to the CCAMLR database the CTD and plankton net data from CCAMLR-2000 Survey data, and the Working Group noted that this work is scheduled as low priority and will be completed as resources allow.

4.86 WG-EMM-04/35 provided an assessment of the krill biomass at South Georgia in January 2004 conducted on a small vessel in near-shore waters. In respect of the methods of this study, the discussion related to the platform from which the survey was conducted rather than the details of the acoustic methodology. The Working Group agreed that the ability to survey areas within the foraging range of predators, that are not readily accessible to large research vessels, may be important to identify small-scale distribution of krill and local-scale foraging interactions.

4.87 WG-EMM-04/40 presented evidence that animal shape is an important determinant of sound scatter from crustaceans. Therefore, crustaceans cannot be expected to have a single target strength (TS) versus animal length relationship. Thus, the Greene et al. (1991) TS versus animal length model, developed from measurements of a variety of crustaceans, may be inaccurate for Antarctic krill. Broad bandwidth measurements of sound scatter from both northern and Antarctic krill support the Stochastic Distorted Wave Born Approximation model (SDWBA) derived with the same krill shape (WG-EMM-02/49, 02/50 and 04/41). For that reason, acoustic measurements of northern krill and the SDWBA model versus animal size, shape and orientation can be used to improve the techniques for species delineation and TS estimation for surveys of Antarctic krill.

4.88 WG-EMM-04/41 demonstrated that use of the Greene et al. (1991) TS versus animal length model is inappropriate for *E. superba* because: (i) the empirical TS model is only valid in the geometric scattering regime (where the acoustic wavelength is small relative to the animal dimensions); (ii) it does not account for animal shape, and was over-simplistically derived from measurements of a variety of crustaceans, excluding Antarctic krill; and (iii) it incorrectly predicts that sound scatter from crustacean zooplankton is dependent on the

animal's volume (versus area for the SDWBA model; see WG-EMM-02/49, 02/50 and 04/40). A simplified version of the SDWBA model, derived with an appropriate distribution of krill orientations (the 'Demer and Conti distribution'), is provided for convenient use in acoustic survey analyses. As an example, a reanalysis of the acoustic data using the SDWBA TS model solved with appropriate distributions of krill lengths and orientations, and a mean krill shape, results in a minimum increase in the CCAMLR-2000 Survey estimate of  $B_0$  for Area 48 from 44.3 to 109.4 million tonnes. This analysis was requested by the Working Group (SC-CAMLR-XXI, Annex 4, paragraphs 3.108 to 3.110), and has been accepted for publication in the *ICES Journal of Marine Science*.

4.89 The Working Group agreed that there is a need for expert re-evaluation of the acoustic protocols used in the determination of target strength of *E. superba*. In particular how the use of methods that determine the target strength as a function of animal shape relates to the estimation of biomass. There was discussion of how the data presented in WG-EMM-04/40 and 04/41 could be incorporated into the work of the Working Group. Although there was a clear history of development of the SDWBA approach with papers presented to this Working Group over the last two to three years, the Working Group noted that there was insufficient expertise present at the meeting and recommended the work be reviewed in the upcoming intersessional period by a group of experts (paragraph 4.92).

4.90 The Working Group noted the parallel work on acoustic delineation of *E. superba* and *Chamsocephalus gunnari* and suggested that it might be beneficial to coordinate the work of WG-EMM and WG-FSA in order to review these issues common to both working groups.

4.91 The Working Group agreed that it is important to develop a process by which such data/methodological advances are incorporated into the work of this group and that this should not become a protracted process where there is inactivity in the absence of appropriate feedback. To this end the Working Group agreed that the approaches to determine target strength of krill outlined in WG-EMM-04/40 and 04/41 would be reviewed at its meeting next year, based on reviews and information received and the Working Group will provide advice to the Scientific Committee next year.

4.92 The Working Group recommended that a standing Subgroup on Acoustic Survey and Analysis Methods (SG-ASAM) be established to advise the Scientific Committee in a timely fashion on protocols in acoustic surveys and analyses. SG-ASAM should address issues related to acoustic surveys for both WG-FSA and WG-EMM.

4.93 To that end, the Working Group recommended that the Scientific Committee consider the following terms of reference:

- (i) to develop, review and update as necessary, protocols on:
  - (a) the conduct of acoustic surveys to estimate biomass of nominated species;
  - (b) the analysis of acoustic survey data to estimate the biomass of nominated species, including estimation of uncertainty (bias and variance) in those estimates.

4.94 Immediate issues to be addressed are acoustic protocols for assessing:

- *E. superba* in Area 48
- *C. gunnari* in Subarea 48.3.

4.95 The Working Group also recognised that acoustic assessment of other taxa (e.g. myctophid fishes), and the conduct of surveys in other areas (e.g. Ross Sea) could be considered by SG-ASAM.

4.96 The Working Group requested that WG-FSA consider this proposal and the implications for its work in time for consideration at the meeting of the Scientific Committee.

#### CEMP

4.97 At the meeting of WG-EMM in 2003, including the CEMP Review Workshop, several areas of intersessional work that related to the analysis and interpretation of CEMP data were identified (SC-CAMLR-XXII, Annex 4, paragraphs 4.1 to 4.18, Table 3, and Appendix D, Table 9).

4.98 In order to make progress with this work an informal workshop attended by Drs J. Clarke, L. Emmerson and C. Southwell (Australian Antarctic Division), and Drs Ramm, Reid and Watters was held at the CCAMLR Secretariat from 18 to 27 February 2004. The aims of the workshop were to:

- (i) examine the performance of the CEMP standard methods in delivering the data to the CEMP database;
- (ii) examine the sources of variance, including the statistical and logistical implications of different sampling methodologies;
- (iii) consider different approaches to the presentation of CEMP data to WG-EMM.

4.99 A decision was taken by the participants to contribute papers arising from the informal workshop to the meeting of WG-EMM in 2004 (WG-EMM 04/60, 04/61 and 04/70) rather than a report of the workshop.

4.100 The Working Group thanked the participants of the informal workshop and recognised the considerable amount of intersessional work presented in the three papers.

4.101 WG-EMM-04/70 contained recommendations for actions and analyses aimed at refining and improving the CEMP standard methods and their delivery to the CEMP database. It also contained a number of recommendations that relate to changes in CEMP methods that are presented in Table 2 (Table 7 of WG-EMM-04/70) and the responses of the Working Group are outlined below.

#### Collection of CEMP parameter A2

4.102 The current methods for the collection of CEMP parameter A2 (incubation shift) meant that it was difficult to interpret prey availability as this index refers to two distinct time periods (pre-breeding versus breeding season). Therefore the Working Group agreed that any new entrants to CEMP would be advised that the collection of this parameter was no longer a requirement.

4.103 Dr Trivelpiece outlined work in progress to investigate sources of variance and the interpretation of this parameter based on data from the South Shetland Islands.

#### Collection of environment indices by the Secretariat

4.104 The Working Group agreed that the Secretariat should no longer produce environmental indices (F1 to F4) as there had been no requests for these data by Members, despite several papers that have been presented to the Working Group that used indices of the physical environment from a range of data sources. This reflects a substantial increase in the ease of availability of time series of physical data at a range of spatial scales since the collection of these indices by the Secretariat was initiated.

#### Collection of data on population size

4.105 The Working Group agreed that it would be useful to provide an operational definition of a colony for the purposes of reporting an index of changes in population size. This should include an assessment of existing counts from sub-colonies within a site to examine representativeness and consistency. In addition, consideration should be given to amending the CEMP standard methods for counting numbers of birds in a colony such that there is no feedback between observers until repeat counts are completed.

4.106 In order to progress this work further it was agreed that these issues might be best considered by the correspondence group on land-based predator surveys led by Dr Southwell.

#### Data analysis

4.107 The Working Group agreed that the examination of the distributional and variance characteristics of raw data for CEMP parameters, including a review of requirements for sample sizes to detect change, is an important component of future work. Such work would be guided by the definition of the statistical power required to detect changes in CEMP parameters.

4.108 Further analysis of the serial dependence and summary statistics for penguin foraging trip duration that was initiated in WG-EMM-04/60 should be undertaken by Members collecting these data.

#### CEMP methods

4.109 There was a clarification that the presence of an occupied nest was appropriate for the measurement of population size and for observations of chronology as the requirement to determine the presence of an egg had the potential to introduce an unwarranted level of disturbance.

4.110 The Working Group asked Australia to provide details of the cloacal examination techniques for sexing Adélie penguins that may provide a more suitable alternative to the existing method of the discrimination using detailed biometrics (*CEMP Standard Methods*, Part IV, Section I).

4.111 The Working Group encouraged Members to provide reviews of the implications of the use of fixed chronological reference points as an alternative to five-day periods with respect to the breeding chronology of penguins.

#### Future surveys

4.112 WG-EMM-04/37 contained a proposal for an Australian acoustic survey of the krill biomass in Division 58.4.2, the southwest Indian Ocean, from January to March 2006. The goal is a new estimate of  $B_0$  to support a revised CCAMLR precautionary catch limit for this division. The plan for a single-ship survey includes 15 parallel transects between 30°E and 80°E, and similar data collection and analysis methods to those of the CCAMLR-2000 Survey. Throughout the next year, Australia will consider constructive criticisms to the proposed survey design and analysis methods.

4.113 Australia extended an invitation to experts from WG-EMM to participate in the survey. Also, as Australia intends to define an ecological-based harvesting unit, they are soliciting additional ship resources to expand the proposed ecosystem investigation. The final survey plan is to be presented at WG-EMM-05.

4.114 WG-EMM-04/47 contained a proposal for a Japanese survey of the Ross Sea and adjacent waters from December 2004 to February 2005 to characterise the influences of long-term changes in the environment on krill and whales. The RV *Kaiyo Maru* will be used to sample the physical, chemical and biological oceanographic conditions in areas expected to have high krill and whale concentrations. These data will provide the environmental context to a concurrent JARPA (Japanese Whale Research Program under special permit in the Antarctic) survey.

4.115 WG-EMM-04/40 and 04/41 were discussed as they relate to analyses of future acoustic surveys for estimating  $B_0$  of *E. superba*. WG-EMM-04/40 recommended that analyses of future acoustic surveys of *E. superba* should use the SDWBA TS model solved with appropriate distributions of krill lengths, shapes and orientations. A simplified version of the SDWBA model is provided in WG-EMM-04/41 for convenient use in future survey analyses. The Working Group recalled its recommendation to the Scientific Committee that SG-ASAM (see paragraphs 4.92 and 4.93) should consider whether the simplified SDWBA TS model should replace the Greene et al. (1991) TS model as the CCAMLR-endorsed standard and provide comments in time for consideration at the 2005 meeting of WG-EMM.

#### Key points for consideration by the Scientific Committee

4.116 Estimates of krill recruitment in Subarea 48.1 indicate good recruitment in both 2001 and 2002, that resulted in a substantial increase in the local krill population abundance, and poor recruitment in 2003 (paragraphs 4.31 and 4.32).

4.117 Data from the krill fishery and from the diet of krill-dependent predators suggest that krill are found at greater depths during winter than in summer. Asking krill fishing vessels to undertake appropriate research trawls would help understand krill distribution and its relationship with the foraging behaviour of predators (paragraphs 4.23 to 4.27).

4.118 The Working Group considered three quite different scenarios to describe the state of krill stocks in Area 48:

- (i) stable population over the past 20 years (WG-EMM-04/27, 04/39)
- (ii) fluctuation with an eight-year cycle (Hewitt et al., 2003)
- (iii) regime shift since 1998 (WG-EMM-04/72).

It noted that the operational models currently under development by WG-EMM would be useful to evaluate the implications of each of these scenarios in the work of the Working Group (paragraph 4.35).

4.119 The Working Group agreed that the ordination of variables according to functional groupings to summarise the variability in CEMP parameters was useful and encouraged further exploration using data from other regions. It agreed that further work was required both to develop a quantitative mechanism by which to evaluate the properties of methods to summarise CEMP parameters, as well as to the development of a process of decision making based on those summaries taking account of SC-CAMLR-XIX, Annex 4, paragraph 3.51 (paragraph 4.61).

4.120 The attention of the Scientific Committee was drawn to the discussion of the RSShelfE (paragraphs 4.68 to 4.79).

4.121 The Scientific Committee should reconsider how it wishes to treat matters relating to ecosystem interactions involving fish and squid (paragraph 4.84).

4.122 Reanalysis of the acoustic data from the CCAMLR-2000 Survey using the SDWBA TS model, that was requested by the Working Group in 2002 (SC-CAMLR-XXI, Annex 4, paragraph 3.105), suggested the estimate of  $B_0$  for Area 48 may increase substantially (paragraphs 4.88 and 5.76).

4.123 SG-ASAM should be formed to address the terms of reference in paragraph 4.93, including whether the simplified SDWBA TS model or alternative models should replace the Greene et al. (1991) TS model as the CCAMLR-endorsed standard and provide their comments in time for consideration at the 2005 meeting of WG-EMM (see paragraphs 4.92 and 4.93).

4.124 The Working Group agreed that in respect to the collection and analysis of CEMP parameters:

- (i) the Secretariat should no longer produce environmental indices (F1 to F4);
- (ii) any new entrants to CEMP would be advised that the collection of CEMP parameter A2 was no longer a requirement;

- (iii) the correspondence group on land-based predator surveys led by Dr Southwell be asked both to provide an operational definition of a colony for the purposes of reporting an index of changes in population size and to review the level of feedback between observers until repeat counts are completed;
- (iv) the number of occupied nests in penguin colonies is appropriate for the assessment of population size;
- (v) Australia should provide details of the cloacal examination techniques used in its program for sexing Adélie penguins.

## STATUS OF MANAGEMENT ADVICE

### Protected areas

5.1 Dr Penhale presented the report of the Advisory Subgroup on Protected Areas. Tasks that were assigned for the intersessional period included:

- (i) review of the membership, circulation of tasks and background information, and development of a page on the CCAMLR website;
- (ii) preparation of a draft revision of guidelines for the production of maps of protected areas;
- (iii) request for review by Brazil and the USA of the status of CEMP sites for which updated maps have not yet been submitted and to provide maps, if appropriate;
- (iv) review of the management plan for ASPA No. 145 (Port Foster, Deception Island, South Shetland Islands) which is concurrently undergoing review by the ATCM.

5.2 Additional agenda items for discussion during WG-EMM included:

- (i) review of the management plan for ASPA No. 149, Cape Shirreff and San Telmo Island, Livingston Island, South Shetlands Islands, which is concurrently undergoing review by the ATCM;
- (ii) discussion of a series of papers relating to the subgroup's term of reference (v) 'to provide advice on the implementation of marine protected areas that may be proposed in accordance with the provisions of Article IX.2(g) of the Convention, including the designation of the opening and closing of areas, regions or subregions for purposed of scientific study or conservation, including special areas for protection and scientific study.'

5.3 Dr Penhale noted that the development of the web page provided an excellent forum for conducting work during the intersessional period as it contained a list of members with contact information, a list of tasks, relevant documents, and correspondence amongst the subgroup. Subgroup members thanked Dr Sabourenkov and the Secretariat staff for producing this excellent web page.

5.4 Dr Penhale reported that outreach to the CCAMLR membership has resulted in an increase in membership and expertise of the subgroup. Membership presently includes 13 members from 11 countries.

5.5 Dr Penhale reported on the discussion of WG-EMM-04/19, which was a draft revision of Conservation Measure 91-01, Annex 91-01/A 'Information to be included in management plans for CEMP sites'. This measure had been updated with more detailed guidance for the production of maps, consistent with map guidelines produced by the CEP.

5.6 Subgroup members had agreed that this revised conservation measure provided excellent guidance for map production for CEMP sites and noted that in the future, additional guidance for map production could be required for marine protected areas to be considered under Article IX.2(g) of the Convention.

5.7 WG-EMM agreed to forward this revised conservation measure with a recommendation for approval by the Scientific Committee.

5.8 With regard to the status of maps, Dr E. Fanta related that Brazil no longer conducted CEMP research at Elephant Island; thus, there was no plan to produce a map of the site. Dr Penhale announced that since CEMP research had ceased at both Seal Island and Anvers Island, there was no plan to update maps of those sites. A map of the US CEMP research site at Admiralty Bay was currently being produced.

5.9 Dr Penhale asked subgroup members whether updated maps would be useful for sites where CEMP research had ceased, but for which data existed in the CCAMLR database. Prof. Croxall noted that maps that allowed the existing CEMP data to be associated with colony locations would be relevant to those who may utilise the data.

5.10 Dr Penhale reported on the discussion of the first of two protected area management plans containing marine areas which were submitted to the ATCM (WG-EMM-04/8). Each would thus require approval by CCAMLR. It was noted that the Cape Shirreff and San Telmo Island site is also protected as a CEMP site.

5.11 Subgroup members noted that due to the shallow nature and small size of marine area, the plan would not affect CCAMLR-related activities and thus recommended approval.

5.12 WG-EMM agreed to forward this revised management plan with a recommendation for approval by the Scientific Committee.

5.13 The second ATCM management plan included two small marine sites at Port Foster, located in the enclosed body of water within the caldera of Deception Island (SC-CAMLR-XXII/BG/14). Members noted that due to the shallow nature of the site and the location within the caldera, the plan would not affect CCAMLR-related activities and thus agreed that WG-EMM should recommend approval by the Scientific Committee.

5.14 Members noted that in terms of the management plan as a whole, there was insufficient scientific information to determine whether the site continues to require protection. Description of physical and biological features was minimal, with no rationale for the location and size of the two sites included in the plan. Also, there was no information on recent research being conducted in the area. While not central to the CCAMLR review, members wished to transmit these comments as advice for improvements to the plan.

5.15 WG-EMM agreed to forward this revised management plan with a recommendation for approval by the Scientific Committee. The additional review comments will be forwarded as advice to the originators of the plan.

5.16 Prof. Croxall introduced three papers, which the UK intended to submit to the Scientific Committee. These papers relate to the role of CCAMLR as an organisation with the attributes of a regional fishery organisation but with a wider conservation mandate, in the international discussion of marine protected areas as management tools for the world's oceans. He recognised that some of the content of these papers reflects and raises issues which require consideration of general principles by the Commission and/or the Scientific Committee. However, it was felt appropriate to solicit initial views and comments from WG-EMM and the Subgroup on Protected Areas.

5.17 WG-EMM-04/11 presented a table of protected areas that are partially or fully marine and are located within the Convention Area. The entries included areas that have been designated as, or proposed to be, protected under various instruments of the Antarctic Treaty or other appropriate regimes. Members found the document very useful in understanding the range and extent of various sites afforded protection.

5.18 Members suggested that additional information in the tables could prove useful; these included the application of the IUCN protected area classification system, information on which areas were most central to the interests of CCAMLR, which areas have already been approved by CCAMLR, and complete information on the size of the marine component of the plans. Prof. Croxall thanked members for this advice, which he will transmit to the authors. He would also welcome being informed of any errors in the paper.

5.19 Prof. Croxall introduced WG-EMM-04/32 which was a review of conservation instruments that have potential relevance to the topic of marine protected areas in the Antarctic Treaty System area. He noted that there is currently worldwide activity within bodies responsible for the management of the world's oceans to investigate how best to use marine protected areas as one of a suite of tools for the management of marine ecosystems within the areas of their jurisdiction and responsibilities.

5.20 Dr Shust noted that the Commission has had 22 years of experience in marine ecosystem management, using the conservation measure as the primary instrument for affording protection to species and sites. He felt that these means were sufficient for the purposes of CCAMLR and he noted that the tasks of the working groups and the Scientific Committee are strictly scientific and these groups must respond to the direction of the Commission. He cautioned against becoming involved in any political aspects of the topic. With regard to the information in WG-EMM-04/32, Dr Shust felt that the paper did not contain sufficient scientific data to justify further discussion by WG-EMM.

5.21 Dr Constable welcomed the overview paper and recommended that the inclusion of information from other conventions would be useful with respect to other conservation mandates that potentially have overlap with CCAMLR, such as CMS and CITES. He further noted that the Scientific Committee is regarded as having the most complete scientific expertise for providing management advice on the Southern Ocean. He felt that it was important for the Scientific Committee to establish the mechanisms for considering the global issues of marine ecosystem management in its future work.

5.22 Prof. Croxall called attention to subgroup term of reference (v) ‘to provide advice on the implementation of marine protected areas that may be proposed in accordance with the provisions of Article IX.2(g) of the Convention, including the designation of the opening and closing of areas, regions or subregions for the purpose of scientific study or conservation, including special areas for protection and study’. He believed that it would be useful and timely to consider the best way for CCAMLR to draw upon the scientific experience and expertise of its Members, including consideration of new developments within the international arena in relation to protection and management of marine habitats. Several members expressed agreement with this view.

5.23 In relation to the emerging worldwide issue of the negative impact of bottom trawling on benthic communities, Prof. Croxall introduced WG-EMM-04/12 which highlighted the importance and vulnerability of seamounts as a habitat for marine fish and benthic invertebrates.

5.24 Dr Shust noted that this overview paper did not present data relevant to CCAMLR and felt that further discussion should be based on scientific information from the Convention Area. He noted that there are examples of seabed protection already in place within the conservation measures. Prior to selecting seamounts as marine protected areas, detailed research including fishing methodology, is required.

5.25 Dr P. Wilson (New Zealand) informed the Working Group that New Zealand planned to submit a new management plan for protection within the Balleny Islands area and that the New Zealand committee responsible for producing the management plan will meet later this year. New Zealand welcomes information from and discussion with Members on how best to proceed with development of the plan for the archipelago to become an important contribution to the Antarctic system of marine protected areas in accordance with the provisions of Article IX.2(g) of the Convention.

5.26 It was suggested that as information on the scope and content of the new management plan became available, New Zealand might consider placing such material on the CCAMLR website in order to receive comments.

5.27 Dr Olmastroni informed the Working Group that Italy had submitted a management plan for a new protected area at Edmonson Point, Wood Bay, Ross Sea, to the ATCM in May 2004. Since it contains a marine area, it must be approved by CCAMLR. Due to bureaucratic reasons, Italy was not able to submit this plan in time for consideration at the 2004 meeting of WG-EMM. The plan, which has now been submitted to the Scientific Committee, is currently undergoing review in an ATCM intersessional group which will report to the June 2005 ATCM meeting.

5.28 Dr Olmastroni reported that the area includes an important CEMP research site, which is not protected through the CCAMLR system for CEMP sites. The marine component is a small area which extends approximately 200 m offshore, so there should be no issues related to harvesting in the Convention Area. Dr Olmastroni, on behalf of the Italian Antarctic Program, asked if there were a means for the subgroup to conduct its review intersessionally and provide a recommendation to be received by the Scientific Committee during its meeting in October 2004.

5.29 Dr Hewitt noted that it was unfortunate that the plan was not submitted to WG-EMM by the deadline, because the rules of procedure are that the subgroup reports directly to WG-EMM and not directly to the Scientific Committee. He asked the Chair of the subgroup whether it would even be possible for the subgroup to conduct a review prior to the meeting of the Scientific Committee.

5.30 Dr Penhale reported that with the increased efficiency afforded through the establishment of the subgroup web page, there would be time for the subgroup to make a recommendation on the management plan in time for discussion at the Scientific Committee.

5.31 Dr Constable indicated that the proposition for the subgroup to work intersessionally was a welcome means to provide the Scientific Committee with advice throughout the year. He also noted that consideration of such proposals might be expedited by developing a 'general rule' for proposals in coastal areas so that CCAMLR only focused on protected areas with marine components that are of central interest to CCAMLR, rather than addressing areas only metres offshore coastal sites. Such a rule would endeavour to identify the type of marine sites, such as coastal areas, for which there would be no conflict with CCAMLR activities.

5.32 Dr Holt, in his role as Chair of the Scientific Committee, stated that the current rules of procedure are that the subgroup reports to WG-EMM which reports to the Scientific Committee. He noted that any modification of established procedures would set a precedent that might present future difficulties.

5.33 Dr Wilson noted that there was a will among many members for the review and recommendation on the Edmonson Point management plan to go forward through intersessional review by the subgroup and subsequent discussion at the Scientific Committee. He noted that the rules do not allow the subgroup autonomy, but there should be some flexibility, due to the unique and overarching role of this subgroup, in terms of reporting pathways.

5.34 Prof. Croxall expressed sympathy with the dilemma posed by the situation. He noted that whether a recommendation from the subgroup subsequent to this meeting of WG-EMM could be considered by the Scientific Committee was entirely up to the Scientific Committee. He recommended that the subgroup continue its work intersessionally and make appropriate recommendations in time for the Scientific Committee to make a decision at its meeting in October 2004 as to whether it would review the proposed plan or refer it to the 2005 meeting of WG-EMM.

5.35 Dr Fanta suggested that the Scientific Committee consider reviewing the current procedures for the work of the Subgroup on Protected Areas, to allow more flexibility, possibly involving reporting via both WG-EMM and the Scientific Committee. This would take advantage of the possibility of interaction of all members of the group by correspondence, and of the access that Members have to the documents at the subgroup's web page. The Subgroup on Protected Areas needs to be particularly flexible because it not only gives advice, via WG-EMM to the Scientific Committee and Commission of CCAMLR, but is also involved in advice which relates to the procedures and timetables of meetings of the CEP and ATCP.

5.36 Dr Constable noted that an overarching issue is how CCAMLR could best conduct its business and provide advice in a timely manner. He felt that issues such as review of

management plans from the ATCM or issues arising from the Subgroup on Methods were ideally suited to intersessional work. He recommended that the Scientific Committee address the issue of how and when such advice could be delivered to the Scientific Committee.

5.37 Dr Hewitt summarised the consensus arising from the discussion by noting that the subgroup could continue to work intersessionally, although the Working Group would not be able to review its recommendations prior to the 2004 meeting of the Scientific Committee. Furthermore, the Scientific Committee would have to decide as to whether it will accept advice on the Edmonson Point management plan directly from the subgroup at its October meeting.

#### Harvesting units

5.38 Dr Naganobu informed the meeting that discussions between him and Dr S. Nicol (Australia) on the delineation of harvesting units were continuing and he indicated that it would be at least next year before any results of their considerations would be reported to WG-EMM.

#### Small-scale management units

5.39 Dr Trathan introduced the recent history relating to SSMUs for the krill fishery; this is outlined in paragraphs 5.40 to 5.43.

5.40 Three years ago at WG-EMM-01, the Working Group considered proposals for subdividing the Area 48 precautionary catch limit and establishing SSMUs, it elected to define 'predator units' based on consideration of land-based predator foraging ranges, krill distribution and the behaviour of krill fishing vessels. This approach was subsequently endorsed by the Scientific Committee and also by the Commission (SC-CAMLR-XX, paragraphs 6.15 to 6.19).

5.41 Two years ago at WG-EMM-02, the Working Group held a workshop with a view of defining SSMUs for Area 48. The recommendations made by that workshop were subsequently endorsed by the Scientific Committee (SC-CAMLR-XXI, paragraphs 3.16 and 3.17) and adopted by the Commission which then directed the Scientific Committee to provide advice on how the precautionary catch limit for krill in Area 48 should be subdivided among the agreed SSMUs (CCAMLR-XXI, paragraph 4.6). The Commission also adopted a requirement that krill catches should be reported at a scale of 10 by 10 n mile squares by 10-day periods at the end of the fishing season. In making this recommendation, the Scientific Committee noted that this requirement should be considered to be an interim measure and that haul-by-haul data by 10-day periods should be required when the precautionary catch limit was subdivided among SSMUs.

5.42 Last year at WG-EMM-03, a paper was presented (WG-EMM-03/36) that outlined various methods to subdivide the precautionary catch limit for krill among the SSMUs adopted by the Commission. The purpose of WG-EMM-03/36 was primarily to stimulate

discussion on general approaches rather than to advocate any specific proposal. During its discussions the Working Group requested that other alternative proposals for subdividing the precautionary catch limit should be submitted to WG-EMM-04.

5.43 WG-EMM-03/36 has now been extended and revised by the authors and accepted for publication in *CCAMLR Science* (Hewitt et al., 2004); the revised paper has also been tabled for information at this meeting. Hewitt et al. (2004) considers five options; the first four options may be considered to be static allocations of the precautionary catch limit, the fifth may be considered to be a dynamic allocation. Briefly these are:

- (i) subdividing the precautionary catch limit in terms proportional to the historical catch in each SSMU;
- (ii) subdividing the catch limit in terms proportional to the estimated predator demand in each SSMU;
- (iii) subdividing the catch limit in terms proportional to the estimated standing stock of krill in each SSMU;
- (iv) subdividing the catch limit in terms proportional to the standing stock less predator demand in each SSMU;
- (v) subdividing the catch limit using a dynamic allocation based on land-based predator monitoring conducted just prior to, or early in, the fishing season.

5.44 The Working Group noted that the Commission has also agreed that the krill fishery shall not expand above 620 000 tonnes per annum until the precautionary catch limit had been subdivided among SSMUs. It also noted that no additional papers describing potential methods for subdividing the precautionary catch limit had been tabled at this meeting.

5.45 In this context and in order to evaluate the five options, Dr Trathan suggested that the Working Group should examine closely some of the assumptions that underpin the different options described in Hewitt et al. (2004). Such assumptions include:

- (i) harvesting methods will remain the same as currently employed
- (ii) mitigation measures to reduce fishery by-catch are adequate
- (iii) the current seasonal and geographic pattern of catches remains the same
- (iv) transport of krill between SSMUs remains constant
- (v) climate-induced changes to the ecosystem are negligible.

5.46 In the ensuing discussion and in relation to allocating the precautionary catch limit of krill among SSMUs in the Scotia Sea, Dr V. Sushin (Russia) reiterated the objections he expressed at the WG-EMM-03 meeting (SC-CAMLR-XXII, Annex 4, paragraphs 5.22(ii) and 5.26). He noted that operational objectives and relevant biological reference points for krill predator populations have still not been developed. In this respect it is difficult to develop objective management advice that is connected with or includes krill predators.

5.47 It was noted that last year several Members had responded to Dr Sushin's concerns (SC-CAMLR-XXII, paragraphs 5.21 and 5.23 to 5.25).

5.48 In relation to biological reference points, Prof. Croxall noted the discussion this year on target population sizes (paragraphs 4.62 to 4.67), which indicates some of the problems associated with deriving these for krill-dependent species.

5.49 It was recognised that, while estimates of target population sizes could doubtless be derived using various methods and approaches, these were of limited use unless accompanied by suggestions for appropriate and feasible management measures. Such measures would need not only to address restoration of depleted populations but also to be applicable to simultaneous management of krill-dependent species with different population status, including those currently increasing.

5.50 Once appropriate measures could be evaluated by WG-EMM, it might then be feasible to consider their incorporation into the management of SSMUs. It would be inappropriate to delay managing SSMUs until measures to manage target population sizes of dependent species could be developed and agreed.

5.51 Dr Sushin then outlined specific remarks regarding the allocation options described in Hewitt et al. (2004); these were as follows:

- (i) Allocation of the precautionary catch limit on the basis of the standing stock (option (iii)) is not possible without consideration of oceanographic flux (both within and between SSMUs). Taking into account factors relating to oceanographic flux allows an assessment of the turnover of krill biomass within an SSMU and thus a more realistic evaluation of krill availability. For example, as a result of flux through the Antarctic Peninsula Drake Passage West SSMU and through the Antarctic Peninsula Drake Passage East SSMU (see Hewitt et al., 2004, Figure 1), the standing stock of krill could to be replaced 2.7 times during the December–March period (Hofmann et al., 1998; Ichii and Naganobu, 1996; Sushin, 1998; Sushin and Myskov, 1992). Consequently, the biomass of krill during that period (important for populations of dependent species) would be approximately 2.7 times higher than that indicated by the CCAMLR-2000 Survey. Dr Sushin considered that as a consequence of flux, krill could be replaced at a rate dependent on the water movement. Dr Sushin added that such considerations also affected other options described in Hewitt et al. (2004), specifically options (iv) and (v).
- (ii) Estimates for the subdivided catch limit within some of the SSMUs (calculated on the basis of options (iv) and (v)) are considerably lower than the historical krill catch levels within those SSMUs (e.g. South Georgia West and South Georgia East (see Hewitt et al., 2004, Figure 1) are approximately three to four times lower than the annual catch in the 1980–1991 period). As there are no signals that the former catches had a negative influence on predator populations or on the status of the pelagic ecosystem, such low catch allocations appear to be an unnecessarily strong restriction on the krill fishery.
- (iii) Bearing in mind the above remarks, it is not possible to conclude, at this stage of development, how the allocation of the precautionary catch limit of krill could be accomplished.

5.52 Dr Naganobu indicated that he also shared the concerns of Dr Sushin and that it was difficult to formulate management advice at this moment.

5.53 With respect to Dr Sushin's specific comments, Dr Trathan suggested that understanding the relative level of in situ krill production and oceanographic transport was important and needed further evaluation; further that there were likely to be temporal and spatial differences in the way that such processes operated and that as a consequence, issues relating to flux should be explicitly considered when evaluating the different options (iii, iv and v). Dr Trathan also emphasised that part of the process to evaluate subdivision of the precautionary catch limit must be to examine the underlying assumptions; these should include modelling of production, flux and predation and the potential impacts on dependent species.

5.54 Drs Trathan and Constable emphasised that the Working Group already provides advice about uncertainty to the Scientific Committee and the Commission and that such concerns should form part of any evaluation of the different options for subdividing the precautionary catch limit. Further, that uncertainty about the level of the standing stock, the demand for krill from dependent species, the importance of oceanographic transport, and the need for appropriate monitoring studies (such as at CEMP sites), were each important components when considering the various options.

5.55 Dr Constable suggested that the modelling framework outlined in WG-EMM-04/73 provides opportunities to explore the consequences of different options for subdividing the precautionary catch limit. It may be advantageous to establish a subdivision, in the first instance, to obtain knowledge about how the ecosystem works and/or will respond to different levels of fishing at the scale of land-based predator colonies and the areas in which those predators forage. To that end, pulse fishing may be an option. Following the acquisition of new information, a revision to the subdivision may be in order. If a subdivision is established then it may be important to consider what monitoring may be required to establish that no problems arise with respect to predators in the future.

5.56 An ad hoc subgroup comprising Drs Trathan, Sushin and Naganobu met to further consider the ideas discussed by the Working Group. During their discussions the subgroup agreed that it was not possible at this time to select between the five different options laid out in Hewitt et al. (2004); this was because there was ecological (and therefore management) uncertainty associated with each of the options and that some of the assumptions underpinning the options were not fully evaluated.

5.57 The ad hoc subgroup agreed that modelling the various assumptions and options contained in Hewitt et al. (2004) would allow progress to be made. The subgroup therefore agreed that this should form the focus of future investigations and that use of a modelling framework, such as that described in WG-EMM-04/73, would allow the different options to be evaluated.

5.58 Dr Sushin considered that options (i) and (iii) (paragraph 5.43) would potentially enable progress to be made most rapidly. Both of these options contain just one component as the basis for calculating the subdivision of the catch limit (the historical catch or the standing stock) and as a consequence they potentially have a lower level of uncertainty than other options, for example options (iv) or (v).

5.59 However, other Members emphasised the importance of giving particular attention to those options that involved more direct consideration of the requirements of dependent species than options like (i) and (iii) which were based solely on utilising historical krill catch data and estimates of standing stock.

5.60 The Working Group recommended carrying forward the appropriate modelling work needed to support the subdivision of the precautionary catch limit amongst SSMUs through the proposed Workshop on Management Procedures in 2005 (paragraphs 6.12 to 6.21).

#### Consideration of models and analytical and assessment methods

5.61 The Working Group noted the outcomes of the Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management described in section 2.

5.62 In order to continue the development of plausible ecosystem models, the Working Group agreed to establish a Steering Committee on Antarctic Plausible Ecosystem Modelling Efforts (APEME) with the following terms of reference:

1. The Steering Committee should promote and coordinate the development of suitable models, analyses and publication of results, and the review of appropriate candidate models.
2. Specifically, the Steering Committee should:
  - (i) Science tasks –
    - (a) Ensure development of suitable frameworks to include the management and/or implementation of:
      - data, parameters, database availability
      - required code, platforms, components and protocols
      - validation process of the models.
    - (b) Ensure coordination and collaboration occurs including:
      - timetables for model development, analyses, estimation of input parameters, model verification and validation;
      - as far as possible, have all work coordinated prior to its commencement;
      - promote, coordinate and define workshop(s) to advance the work program;
      - coordinate analyses of data not undertaken at workshops;
      - identify and coordinate outputs and products.

- (c) Act as a two-way information conduit such that Steering Committee members are made aware of individual analyses being conducted by Members, and that individual scientists are made aware of this information.
- (ii) Publication –
  - (a) act as arbitrator/mediator in any conflict relating to authorship of publications;
  - (b) ensure that all manuscripts are brought to the attention of the Steering Committee prior to submission;
  - (c) maintain a register of all publications relating to the modelling task.
- (iii) Role of the Secretariat –
  - (a) ensure resources required from the Secretariat are clearly identified in advance.
- (iv) Maintain coordination with the conveners of WG-EMM workshops.

5.63 The Working Group requested that Members consider representation on the Steering Committee and that the structure of that committee, including its convener, be determined by the time of the meeting of the Scientific Committee. To that end, Dr Holt agreed to coordinate the process.

5.64 The Working Group agreed that it would be useful to progress the work of the Steering Committee, following the Workshop on Plausible Models and the need to provide input to the development of models for the workshop next year. Dr Constable offered to assist Dr Holt in ensuring that work is progressed amongst nominated members of the Steering Committee until such time as its organisation is completed.

5.65 Dr Constable presented a summary of the report of WG-FSA-SAM (WG-FSA-04/4). The key outcomes and points of discussion included:

- (i) methods to estimate recruitment of toothfish, including resolving issues arising at WG-FSA in 2003;
- (ii) the evaluation of the design of trawl surveys using simulation studies;
- (iii) developing assessments for exploratory fisheries;
- (iv) long-term management procedures for *C. gunnari*;
- (v) the combining of trawl and acoustic survey information in estimating the abundance of *C. gunnari*;
- (vi) methods for estimating mortality and total removals of skates and rays;

- (vii) development of assessment and estimation procedures, including survey design, parameter estimation, estimating IUU activities, and alternative assessment methods for *Dissostichus* spp.;
- (viii) plausible operating models for *Dissostichus* spp.;
- (ix) software;
- (x) assessment timetable for WG-FSA at its 2004 meeting.

5.66 The attention of the Working Group was drawn to the following issues:

- (i) Estimates of predator consumption of icefish need to be accompanied by the statistical error in those estimates, allowing better comparisons between different estimators (WG-FSA-04/4, paragraph 2.34).
- (ii) WG-FSA-SAM requested that WG-EMM consider the issues associated with discriminating between *C. gunnari* and krill in acoustic surveys in Subarea 48.3 and whether the estimates of density and abundance of krill in this area may need to be revised given the difficulty in discriminating krill from icefish using acoustics highlighted in WG-FSA-04/4, paragraph 2.36 (WG-FSA-04/4, paragraph 7.10(i)).
- (iii) A need to determine whether the diet of gentoo penguins in Subarea 48.3 is a consequence of diet selectivity or availability (WG-FSA-04/4, paragraph 2.37).
- (iv) WG-FSA-SAM agreed that a combination of bottom trawl and acoustic survey will provide the best information on the *C. gunnari* stock in Subarea 48.3 by estimating both the demersal and pelagic components and, to that end, the following areas need to be addressed (WG-FSA-04/4, paragraph 2.39):
  - (a) discrimination of *C. gunnari* from other acoustic scatterers
  - (b) further improvements in target strength estimates for *C. gunnari*
  - (c) age-specific patterns in daily vertical distribution of *C. gunnari*.
- (v) In addition, experimental and simulation studies will be useful in determining the appropriate design of trawl and acoustic surveys, including the use of target trawls, for use in assessments of biomass of *C. gunnari* (WG-FSA-04/4, paragraph 2.40).
- (vi) Like WG-EMM, WG-FSA has begun work programs to develop plausible ecological models and simulation operating models in order to provide the simulation framework for evaluating management methods and procedures (WG-FSA-04/4, section 3 and paragraph 4.7).
- (vii) The subgroup recalled its discussion last year on plausible models for toothfish and continued this discussion with an emphasis on the need to develop operating models to assist in the evaluation of assessment methods and management procedures (WG-FSA-04/4, paragraphs 3.34 to 3.53). It encouraged Members to further develop intersessionally the ideas developed during the meeting and to

submit papers elaborating on potential functional forms and/or components of plausible models to WG-FSA-04 and WG-FSA-SAM-05 (WG-FSA-04/4, paragraph 7.7(iii)).

- (viii) WG-FSA-SAM agreed that external reviews of CCAMLR software were important to provide transparency as well as a wider acceptance in the use of the software (WG-FSA-04/4, paragraph 4.5). However, such reviews would need to be clearly specified.
- (ix) WG-FSA-SAM (WG-FSA-04/4, paragraph 4.8) agreed that the term ‘Generalised Yield Model’ (GYM) now had two meanings, the first of which is in reference to the assessment method for *D. eleginoides*, while the second is in reference to the software used to implement the assessment method. It was noted that the GYM is the current tool to implement the toothfish, icefish and krill assessments. As such, it would be preferable to refer to the assessment of *D. eleginoides* by some other term, perhaps ‘recruitment-based long-term yield assessment’, which is used in the Standard Methods Descriptions (SC-CAMLR-XXI/BG/28). This would mean that the term ‘GYM’ refers to the implementation software for these assessments.
- (x) With respect to validation of the GYM software (WG-FSA-04/4, paragraphs 4.9 and 4.10) and to be confident that it correctly implements the assessments and is able to be used effectively and correctly by members of WG-FSA in its assessment work, a substantial amount of work had already be undertaken to validate the GYM computing code. The subgroup agreed that the primary task, in terms of the software, now would be in reference to its ‘user-friendliness’ and the degree to which users will be able to undertake the existing CCAMLR assessments using the GYM. It noted that the versatility of software may be evaluated through the use of questionnaires, surveys or small projects where ‘novice’ users, such as first-time users at WG-FSA or graduate students, may be asked to implement the software using available user manuals and operating instructions. This approach could be used to answer questions such as:
  - Is the manual explicit and well written?
  - Is the software easy and robust to use by novices?
  - Are the model runs reliable and are the results consistent on all platforms?
  - Are there sufficient diagnostic tools and features available to check that the assessments have worked as expected and is there sufficient detail provided to explain how to use the diagnostic tools?
- (xi) WG-FSA-SAM agreed that it would be helpful to obtain general information on the approaches used by other regional organisations such as RFMOs for adopting assessment software (WG-FSA-04/4, paragraph 4.11).
- (xii) WG-FSA-SAM discussed other software (WG-FSA-04/4, paragraphs 4.15 to 4.24), including AD Model Builder, Fish Heaven, CASAL, recommending that WG-FSA consider purchasing a single-user licence of AD Model Builder for use by the Data Manager and requested the Data Manager investigate whether it would be within the licence agreement for the software to be borrowed by

members of the subgroup for short, non-overlapping periods to enable familiarisation with the software and development of models (WG-FSA-04/4, paragraph 4.19).

- (xiii) WG-FSA-SAM requested that the Scientific Committee consider how papers from non-Members be received and utilised by its Working Groups (WG-FSA-04/4, paragraph 7.10(ii)).

5.67 The Working Group noted that the discrimination of krill from icefish and other taxa in the acoustic estimation of krill and icefish abundance is a general question worth considering in more detail by a group of acoustic experts (see paragraph 4.92). Although WG-FSA-SAM considered the problem in relation to the impact on estimates of icefish, the Working Group noted that the same question could be made with respect to the impact of mis-identification of the targets on estimates of krill. It was also noted that the problem will largely concern the discrimination of icefish of the same size as krill rather than for larger icefish.

5.68 Dr Trathan indicated that the UK was currently undertaking field trials with a new echo sounder that should be able to investigate some of the issues surrounding acoustic estimation using the equipment from the CCAMLR-2000 Survey. He also indicated that krill and young icefish might be spatially segregated, which would reduce the impact of mis-identification of young icefish and krill on acoustic estimates.

5.69 With respect to the consumption of icefish by predators, the Working Group noted the need to consider the variance in the estimates of consumption and requested Members to consider undertaking work in this regard.

5.70 The Working Group noted the overlap in consideration of methods under this item and under Item 4.4. It agreed that Item 4.4 was largely concerned with field methodologies. There was also an opportunity for introducing and discussing statistical methods more generally but these were usually those undertaken by individuals or research groups.

5.71 The Working Group agreed that a mechanism needs to be established to validate models and analytical and statistical methods, in a similar way to WG-FSA and its Subgroup on Assessment Methods, in order to agree to their general use in providing advice to the Scientific Committee from the Working Group. Prof. Croxall noted that this would involve developing linkages with other organisations and groups, e.g. in order to have information on the development of methods for modelling the population dynamics of vertebrate species, such as matrix population models.

5.72 The Working Group agreed that it needs to appropriately review within a reasonable timeframe the modelling, statistical and assessment methods underpinning advice to the Scientific Committee before the advice is given, such as through the establishment of subgroups, the initiation of expert review or other procedures considered appropriate. This process is illustrated by the steps agreed for the review of target strengths of krill and icefish (paragraphs 4.92 and 4.93).

## Existing conservation measures

5.73 Conservation Measure 51-01 sets precautionary catch limits for *E. superba* in Statistical Area 48 (4 000 000 tonnes), consisting of a limit of 1 008 000 tonnes in Subarea 48.1, 1 104 000 tonnes in Subarea 48.2, 1 056 000 tonnes in Subarea 48.3 and 832 000 tonnes in Subarea 48.4. The catch limits apply to all seasons until the total catch in any season exceeds 620 000 tonnes. In 2002, the Commission endorsed a Scientific Committee work plan that included development of advice on how the precautionary catch limit for krill in Area 48 could be subdivided among the established SSMUs (CCAMLR-XXI, paragraph 4.29).

5.74 The precautionary catch limits for Area 48 and its subareas were set based on analyses of the results of the CCAMLR-2000 Survey. WG-EMM-04/41 presented a reanalysis of the CCAMLR-2000 Survey data for the Scotia Sea, which suggested that the krill biomass in the Scotia Sea may be substantially higher than previously estimated and that therefore a revision of the precautionary catch level for krill in the Scotia Sea may be warranted.

5.75 This paper was considered by the Subgroup on Methods. In subsequent discussion by WG-EMM, it was concluded that there is a need to establish a standing subgroup on acoustics (SG-ASAM) to consider and review protocols in acoustic surveys and analysis. A series of tasks was identified for this group, including a review of the analysis in WG-EMM-04/41 (see paragraphs 4.92 and 4.93). The Working Group therefore does not propose any changes at this stage to Conservation Measure 51-01.

5.76 Several members noted that, following the deliberations of SG-ASAM, it was likely that the current estimate of  $B_0$  for Area 48 may change. This may, in turn, lead to a consequential revision of the precautionary catch limits for this area and its constituent subareas. The Working Group noted that at this stage of development of krill management procedures, it would be undesirable for there to be frequent alterations of the precautionary catch limits. It also noted that annual adjustments may be necessary in a feedback management procedure in the future.

5.77 Dr Constable recalled that it is some time since the current krill management procedure had been reviewed, particularly the input parameters, and that there were several issues that deserved further consideration. These included whether we have fully accounted for all the uncertainties and the extent to which the calculated catch limits are likely to be sufficiently precautionary given the types of biases in the acoustic methodologies. He noted that with the work of the Subgroup on Acoustics and the modelling initiatives proposed by the Working Group, including examination of alternative krill management strategies, it is likely in the next year or two that substantial progress could be made in reviewing the precautionary catch limits, including taking account of new information.

5.78 The possible subdivision of the precautionary catch limit for krill in Area 48 among SSMUs was discussed in paragraphs 5.39 to 5.60. A program of future work was recommended to study this issue further, and no new conservation measures are proposed at this stage for subdivision of the subarea catch limits.

5.79 It was noted that work on subdivision of catch limits among SSMUs should be considered regardless of parallel work on possible revision of the overall precautionary catch

limit. In this context, there would be merit in pursuing approaches that, where possible, may allow the subdivided catch limits to be calculated relative to the overall precautionary catch limit.

Key points for consideration by the Scientific Committee

5.80 Following consideration by the Subgroup on Protected Areas, WG-EMM recommended that the Scientific Committee (paragraphs 5.1 to 5.37):

- (i) approve revised Conservation Measure 91-01, Annex 91-01/A 'Information to be included in Management Plans for CEMP sites' (WG-EMM-04/19);
- (ii) approve the management plan for ASPA No. 149, Cape Shirreff and San Telmo Island, Livingston Island, South Shetlands Islands, which is currently undergoing review by the ATCM (WG-EMM-04/8);
- (iii) approve the management plan for ASPA No. 145, Port Foster, Deception Island, South Shetland Islands which is currently undergoing review by the ATCM (SC-CAMLR-XXII/BG/14).

5.81 The Scientific Committee should note the advice of the Working Group concerning:

- (i) the development of a proposed new management plan for the Balleny Islands (paragraphs 5.25 and 5.26);
- (ii) the status of the management plan for the new protected area at Edmonson Point (paragraphs 5.27 to 5.37).

5.82 Work is continuing on the delineation of harvest units, but it will be next year at least before the results are considered by WG-EMM (paragraph 5.38).

5.83 A program of further work was recommended to enable the subdivision of the precautionary catch limit in Area 48 amongst SSMUs through the proposed Workshop on Management Procedures (paragraph 5.60), taking account of the comments in paragraphs 5.58 and 5.59.

5.84 Key points of relevance to WG-EMM from the WG-FSA-SAM report and subsequent discussion are contained in paragraphs 5.65 to 5.69. In particular, the Working Group recommended the establishment of mechanisms to validate models and analytical and statistical methods relevant to the work of WG-EMM, in order to have an agreed basis for providing advice to the Scientific Committee (paragraphs 5.70 to 5.72).

5.85 Noting the outcomes of the Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management (see section 2) and the need to continue development of these models, the Working Group agreed to establish an APEME Steering Committee. Terms of reference for the Steering Committee are given in paragraph 5.62.

5.86 No change is proposed to Conservation Measure 51-01, pending a review of acoustic survey protocols and analyses, to be carried out by a Subgroup on Acoustics, and further modelling initiatives proposed by the Working Group, including examination of alternative krill management strategies (paragraphs 5.74 to 5.79).

## FUTURE WORK

### Predator surveys

6.1 A correspondence group was established in 2001 to consider the feasibility of broad-scale predator surveys. The group comprised Drs Southwell (coordinator), Trathan, Trivelpiece, Goebel and Wilson. Subsequent discussions by the correspondence group have focused on developing a framework for standardising surveys and on the usefulness of new technology such as satellite remote sensing and unmanned aircraft capable of carrying high-resolution photographic equipment (SC-CAMLR-XXII, Annex 4, paragraphs 6.1 to 6.12).

6.2 Four papers considering issues important to land-based predator surveys were received by the Working Group.

6.3 WG-EMM-04/54 modelled availability bias using existing time-series count data and developed the approach using an Adélie penguin case study. Preliminary modelling suggested that adjusting counts of adult Adélie penguins for availability bias to estimate the breeding population will have large associated uncertainty if counts are undertaken prior to late November or after early January. Modelling availability bias is constrained by limited time-series count data in the literature. The paper indicated that further modelling work could be facilitated by using any additional published or unpublished datasets to those used in this paper.

6.4 WG-EMM-04/55 assessed the accuracy of Adélie penguin breeding abundance estimates at regional scales in Antarctica from existing count data as a case study for penguins generally. The paper concluded that there are likely regional differences in the accuracy of regional-scale estimates of Adélie penguin breeding populations, with estimates from the Antarctic Peninsula/Scotia Sea likely to be less precise than from the Ross Sea or East Antarctic regions. This is largely because the uncertainty in adjusting counts to a standard date, when only the breeding population is present has not been taken into account.

6.5 WG-EMM-04/56 developed and applied a general abundance estimator for Adélie penguins as a case study for developing such estimators for general use in land-based predator surveys. A general estimator of abundance is applied to a range of hypothetical logistic scenarios and related survey designs. It was recommended that the adoption of a general estimator would facilitate standardisation of any future surveys of land-based predators.

6.6 WG-EMM-04/64 reported on an evaluation of assumptions in shipboard line transect surveys of crabeater seal abundance in the pack-ice off East Antarctica. There were some minor violations to assumptions of line transect methods applied to pack-ice seals off East Antarctica as part of the APIS Program. Bias in abundance estimation resulting from assumption violation was minimised through analysis, in particular spatial modelling to address non-random transect placement.

6.7 Dr Trivelpiece welcomed these papers noting that Dr Southwell and his group have provided useful analyses to help progress the practical implementation of region-wide land-based predator surveys.

6.8 In addition to these papers, the Working Group also recalled the paper from 2002 (WG-EMM-02/45) on assessing the feasibility of regional surveys of land-based predator abundance in the Southern Ocean. That paper presented a framework for decision-making and planning of such surveys.

6.9 During the Working Group meeting, the correspondence group met briefly (with Dr Constable representing Dr Southwell). The group noted that there was a continued need to undertake a synoptic survey of land-based predators; it also highlighted the following important points:

- (i) the need for a continued consideration of broader issues relating to the planning of surveys, especially with respect to a standardised approach;
- (ii) the need to encourage Members to start considering the level and nature of logistic support required for future survey work;
- (iii) the necessity of a standardised or general framework (as opposed to standardised methods), e.g. different methods may be necessary for the same species in different locations, but these methods should be consistent with a general framework;
- (iv) a need to convene a short planning session in the near future (prior to WG-EMM-05 or in 2006) to progress the work of the group;
- (v) with respect to (iv), the correspondence group suggested that the proposed planning session should examine a variety of existing field data and existing analyses methods that would help contribute towards planning a synoptic survey;
- (vi) consider options for field methods, survey design and analyses, based on discussions last year (SC-CAMLR-XXII, Annex 4, paragraphs 6.43 to 6.45), papers submitted this year and any further work in the future, including work undertaken under existing or planned programs that Members may be undertaking;
- (vii) consider logistic arrangements for undertaking the work.

6.10 The Working Group noted the discussions from the correspondence group and agreed that:

- (i) it would be useful to establish a program of preparatory work, proposed field schedules and analyses as soon as is practicable and encouraged the correspondence group to help formulate this over the next year;
- (ii) in so doing, field work may not be feasible prior to the International Polar Year (IPY) and most field work would likely be undertaken following that time;

- (iii) there was a need to encourage Members to consider participating in these preparations, in particular to consider when they may be able to provide logistic support for this work.

6.11 The Working Group supported the suggestion to hold a planning session (principally for the correspondence group, though possibly with other interested experts) and encouraged the correspondence group to develop a suitable proposal (including terms of reference) in time for the next Scientific Committee meeting; this would then enable any budgetary implications to be considered. The Working Group recognised that it would be valuable to hold the meeting prior to the next meeting of WG-EMM.

#### Workshop on Management Procedures

6.12 The Working Group initiated its discussion on the Workshop on Management Procedures by recalling that:

- (i) the Commission has asked for advice on how the precautionary catch limit for krill in Statistical Area 48 might be subdivided among SSMUs (CCAMLR-XXI, paragraph 4.6);
- (ii) candidate management procedures for creating such a subdivision were discussed both at the 2003 meeting of WG-EMM (SC-CAMLR-XXII, Annex 4, paragraphs 5.13 to 5.30) and at this meeting (section 3);
- (iii) advice about these candidate procedures could not be provided to the Scientific Committee until the candidates were evaluated under a range of alternative hypotheses that characterise important sources of structural and functional uncertainty in the dynamics of the predator–prey–fishery system (section 3);
- (iv) such evaluations should occur in the near future, be model-based, and build on the work of the Workshop on Plausible Ecosystem Models (section 3).

6.13 The Working Group agreed that the objective of the 2005 Workshop on Management Procedures should be to evaluate candidate management procedures that subdivide the precautionary catch limit in Area 48. These procedures should include subdivisions developed according to:

- (i) the spatial distribution of catches by the krill fishery;
- (ii) the spatial distribution of predator demand;
- (iii) the spatial distribution of krill biomass;
- (iv) the spatial distribution of krill biomass minus predator demand;
- (v) spatially explicit indices of krill availability that may be monitored or estimated on a regular basis;
- (vi) pulse-fishing strategies in which catches are rotated within and between SSMUs.

6.14 The Working Group further agreed that these candidates should be evaluated by quantifying the degree to which they are robust or sensitive both to a range of assumptions about the structure and function of the predator–krill–fishery system and to the data or conditions that are used to initialise the candidate procedures. Robustness/sensitivity will be determined by measures of performance of important attributes of the krill–predator–fishery system, which could include factors such as catch rates and predator survival.

6.15 The Working Group recognised that each of the four items of work should be completed as far as is necessary in advance of the workshop:

- (i) Data that initialise the candidate procedures should be updated and provided to the workshop. Alternative conditions for initialising the candidate procedures might also be specified during this work. For example, catch data might be updated and data from different time periods might be used to initialise the procedure that evaluates a subdivision based on the spatial distribution of catches by the krill fishery.
- (ii) Alternative structural and functional assumptions about the dynamics of the predator–krill–fishery system should be considered and, where possible, specified. These alternatives should include assumptions related to the transport of krill through Area 48.
- (iii) Important measures of performance should be identified. These measures will be used to determine whether the candidate procedures are likely to produce results that are robust or sensitive both to the initialisation data and conditions, and to the alternative structural assumptions. Performance measures should be considered with respect to the different components of the predator–krill–fishery system.
- (iv) Models that explicitly consider the alternative structural assumptions and predict the important performance measures should be constructed and validated.

6.16 It was agreed that correspondence groups would be formed to advance the first three work items intersessionally. It was also agreed that the fourth work item will be addressed by Members as they see fit. It was, however, emphasised that there would be time to construct models at the workshop.

6.17 Three individuals agreed to organise correspondence groups related to krill (Dr Hewitt), the krill fishery (Dr Kawaguchi) and krill predators (Dr Trathan). Membership in the correspondence groups will be open to all interested parties, and participation in one group will not exclude interested parties from participating in the other groups.

6.18 All three correspondence groups will have similar terms of reference and will address the first three work items listed in paragraph 6.15. That is, each group will identify, and possibly provide, updated data that can be used to initialise the candidate procedures; specify some alternative structural and functional assumptions that can be addressed in the evaluations; and identify performance measures that would be useful to consider. Although each group will conduct this work with reference to their specific focus (i.e. to krill, the fishery or predators), it will be important for the work of all three groups to be coordinated. The workshop conveners will, therefore, coordinate communication between the groups.

6.19 The Secretariat was asked to further facilitate communication within and among the correspondence groups by developing and providing a correspondence web page. The Working Group agreed that such a web page should be placed in the secure 'Members Only' section of the CCAMLR website.

6.20 The Working Group agreed that the correspondence groups will advise the workshop conveners of the results from the intersessional work by the end of the 2004 meeting of the Scientific Committee. The advice will be distributed to WG-EMM soon after it is received from the correspondence groups, and will serve two functions. First, the advice will provide initial guidance to the conveners about those datasets, hypotheses and performance measures that WG-EMM would like to consider at the workshop. Second, it will inform those Members who are constructing models to advance work under the fourth item listed in paragraph 6.15.

6.21 Dr Kawaguchi pointed out that, given the time line identified in paragraph 6.20, it will be important to identify, as soon as possible, the kinds of data available to the fishery correspondence group and the analyses that can be done with these data. Dr Kawaguchi suggested that two informal meetings of the fishery correspondence group may, therefore, be useful. One meeting might occur some time during 2004 as appropriate after WG-FSA, and a second might occur just prior to the workshop. Discussion during the first meeting might focus on available datasets and analyses to be done during the intersessional period. Discussion during the second informal meeting might focus on synthesising results from intersessional analyses and finalising advice that is provided to the workshop.

6.22 The Working Group recognised that intersessional work to construct models for evaluating the candidate management procedures will be critical to the success of the workshop. Members undertaking such work were encouraged to:

- (i) utilise the data to address the hypotheses and the performance measures identified by the correspondence groups;
- (ii) build on the concepts developed during the Workshop on Plausible Ecosystem Models, paying particular attention to the interactions between the krill population, the krill fishery, krill predators and the transport of krill (see paragraph 2.27);
- (iii) develop their computer code in ways and on platforms that will facilitate its use by other Members;
- (iv) provide the conveners of the workshop with a report on the nature and status of their work by the end of April 2005.

6.23 The conveners will use the status reports identified in point (iv) of paragraph 6.22 to plan the work that will be conducted at the workshop. The status reports will also be distributed to WG-EMM so that work can be coordinated as far as possible.

6.24 The Working Group further recognised that it would be useful if the models developed for use in the workshop were generally compatible with the goals and objectives of the larger, long-term modelling effort to develop operating models of Antarctic ecosystems. Along these lines, those Members developing models for the workshop and the workshop conveners were advised to correspond with the APEME Steering Committee (see paragraphs 5.62 to 5.64).

#### Long-term work plan

6.25 The Working Group reviewed its long-term work plan and recognised that substantial progress is being made. Nevertheless, the work plan that was presented in the last report of WG-EMM (SC-CAMLR-XXII, Annex 4) does not adequately describe how that progress is being made.

6.26 The long-term work plan is an important communication tool. It provides the Scientific Committee an opportunity to understand and comment on how the Working Group envisions it can meet its obligation to provide useful advice.

6.27 It was agreed that the long-term work plan should be revised to more clearly reflect how progress is being made and take the following points into consideration:

- (i) The workshop planned for the next meeting of the Working Group (paragraphs 6.12 to 6.24) should be viewed as the first workshop to evaluate management procedures for the krill fishery.
- (ii) Plans for assessing predator demand are on schedule. Such assessments depend on the eventual conduct of regional-scale predator surveys; the development of such surveys is discussed in paragraphs 6.1 to 6.11.
- (iii) Discussions on the subdivision of large FAO statistical areas and the establishment of harvesting units should continue in 2005.
- (iv) Many aspects of work are converging, and, in the future, the Working Group will be conducting work that is more integrative.
- (v) Following from this attempt to integrate various work items, it may be useful to convene a workshop in 2006 that considers CEMP in the context of operating models of Antarctic ecosystems. Such a workshop could be used in a second evaluation of management procedures for the krill fishery.

A revised work plan for the Working Group is presented in Table 3.

6.28 The Working Group also discussed other strategic planning issues. It was agreed that advice should be sought from the Scientific Committee regarding mechanisms for:

- (i) consolidating work that overlaps with WG-FSA and WG-IMAF;
- (ii) reviewing broader biological and ecological information that is of interest to the Working Group but, due to time constraints at the annual meetings, receives limited consideration;

- (iii) making quantitative expertise available to the Working Group;
- (iv) responding to broader conservation issues that may be tangential to the topics identified in the Working Group's long-term work plan.

6.29 The Working Group noted proposals for various new subgroups and recommended that the Scientific Committee consider how best to coordinate and structure the work of its working groups and subgroups.

6.30 Similarly, noting the great deal of work being asked of the Secretariat, the Working Group recommended that the Scientific Committee, in consultation with the Secretariat, consider how the work of the Secretariat may best be coordinated across the work of the Scientific Committee, its working groups and subgroups.

6.31 Dr Hewitt also suggested that the Working Group consider discussing how it might develop its work beyond 2006. He envisioned that such a discussion might take one to two days and require participants to develop and table strategic planning documents that would provide useful talking points. Ultimately, such a discussion might develop a new work plan to replace that presented in Table 3.

6.32 In concluding the discussion on work planning, Dr Sabourenkov introduced document WG-EMM-04/13. This document was tabled to provide a historical perspective of the work that has been accomplished by the Working Group since the development of its five-year work plan in 2001. The Working Group thanked the Secretariat for preparing the document and agreed that it would be useful for a similar document to be tabled at its next meeting.

6.33 Tasks identified by the Working Group for the 2004/05 intersessional period are listed in Table 4.

#### Key points for consideration by the Scientific Committee

6.34 The Working Group agreed that plans for conducting synoptic surveys of land-based predators should continue (paragraphs 6.10 and 6.11). In particular, the planning will consider field methods, survey design, logistical requirements and methods of data analysis. For the moment, the Working Group recommended that this work should be done through intersessional correspondence and by informal meetings during the annual meeting of the WG-EMM (paragraphs 6.10 and 6.11).

6.35 The Working Group agreed to hold a workshop to evaluate candidate management procedures for subdividing the precautionary catch limit for krill among SSMUs in Area 48. The Workshop on Management Procedures will evaluate candidate procedures by quantifying the degrees to which they are robust or sensitive to key sources of uncertainty (paragraphs 6.13 and 6.14). To enable this:

- (i) three correspondence groups, organised by Drs Hewitt, Kawaguchi and Trathan will prepare background and scoping information. Their terms of reference and other operational details are in paragraphs 6.15 to 6.20;

- (ii) Members will be responsible, intersessionally, for constructing models that can be used to evaluate candidate management procedures at the workshop (paragraphs 6.16 and 6.20) taking account of the points presented in paragraphs 6.21 to 6.23.

6.36 The Working Group discussed its long-term work plan and determined that it did not adequately describe the ways in which progress was being made on its main work items (paragraphs 6.25 to 6.27). Therefore, the work plan was revised, and it is presented in Table 3.

6.37 The Working Group also discussed a number of strategic planning issues. It was agreed that advice should be sought from the Scientific Committee on the topics presented in paragraphs 6.28 to 6.30.

## OTHER BUSINESS

### Possible CCAMLR research activities during the IPY

7.1 During its meeting in 2003, the Commission encouraged the Scientific Committee and its working groups to consider plans for a research program during the IPY (2007/08). Such an initiative would serve the needs and objectives of CCAMLR and would at the same time provide an excellent opportunity for wider recognition of CCAMLR's role in research on the Antarctic marine ecosystem and the rational use of marine living resources.

7.2 The Working Group discussed the potential participation of CCAMLR during the IPY in 2007/08 and welcomed the willingness of Members to support this initiative. Currently some Members hope to contribute ship time for sea-going cruises or contribute scientific expertise in specialist research fields. The main research objectives were seen to be in the management context, recognising that process studies would also be valuable. Surveys similar to the CCAMLR-2000 Survey, as well as land-based predator studies, would be welcome.

7.3 At this stage, the Working Group sought guidance from the Scientific Committee, as to whether future planning of a CCAMLR program should centre around, e.g.:

- (i) a large-scale survey similar to the CCAMLR-2000 Survey in support of the development of krill management procedures including oceanography and shipboard observations of seabirds and marine mammals (and including phytoplankton and zooplankton studies and studies related to the evaluation of biodiversity or genetic diversity); or
- (ii) smaller-scale surveys around key marine areas that could be used as reference areas in the modelling initiative currently under development by CCAMLR (WG-EMM-04/73) to manage the Antarctic marine ecosystem; or
- (iii) the Census of Antarctic Marine Life, as presented and discussed at the Commission last year (CCAMLR-XXII, paragraphs 18.1 to 18.4) to assist in considering benthic habitat issues; or

- (iv) population estimation of Antarctic land-based predators (though the Working Group noted that it may not be feasible to undertake such a complex survey prior to the IPY (see also paragraphs 6.1 to 6.11)).

7.4 The Working Group considered that the planning phase for such a coordinated international exercise would take about three years. It therefore sought advice from the Scientific Committee and asked that it consider this item during its 2004 meeting; that it take into account proposals developed at the SCAR meeting in Bremen, Germany, held during July 2004, as well as any deliberations resulting from the next meeting of WG-FSA. Following discussion by the Scientific Committee, the Commission may then wish to establish an ad hoc planning group to develop and standardise sampling methodologies and protocols. This group should coordinate CCAMLR activities, but also establish contact with other groups such as the steering committee of CoML (Census of Marine Life) and CircAntCML (Circum-Antarctic Census of Antarctic Marine Life).

## SO GLOBEC

7.5 Dr Penhale reported that the US National Science Foundation is inviting grant applications for a special funding competition on SO GLOBEC synthesis and modelling in early 2005. The competition is also open to proposals using other Antarctic marine ecosystem datasets of relevance to SO GLOBEC. While funding is limited to scientists from US institutions, this competition provides an opportunity for collaborative work within the international scientific community.

## SCAR

7.6 Dr Fanta advised that SCAR will hold its Ninth International Antarctic Biology Symposium in Curitiba, Brazil. The theme will be 'Evolution and Biodiversity in Antarctica'. This theme was chosen because it encompasses all possible research approaches to Antarctic organisms, and because it establishes a link to global and local events, from the past to the present, and looking into the future. The theme includes all environments, plants and animals, from microbes to vertebrates, from biomolecular approaches to ecosystems, from pure to applied science. This is also the theme of a future umbrella program within SCAR, and will be discussed with the Antarctic Biology Community at a workshop during this symposium.

7.7 The symposium will be held from 25 to 29 July 2005 at Pontifícia Universidade Católica do Paraná. Meetings of SCAR groups (e.g. Seals, Birds, Evolanta, RiSCC) might be held between 20 and 23 July 2005.

## Research in the Ross Sea

7.8 Dr Wilson advised that an informal meeting had been held during WG-EMM-04 between various CCAMLR Members involved and interested in research in the Ross Sea.

The meeting was attended by Drs S. Corsolini, Olmastroni, M. Azzali, M. Vacchi and B. Catalano (Italy), M. Naganobu and K. Taki (Japan), Watters (USA), Fanta (Brazil), S. Hanchet and Wilson (New Zealand).

7.9 The aim of the meeting was to informally investigate how the various groups conducting research in the Ross Sea might collaborate further, with a particular focus on the further understanding of the Ross Sea ecosystem.

7.10 Dr Hanchet advised that New Zealand was planning to develop a preliminary ecosystem model of the Ross Sea in the coming year. The proposed work will proceed along similar lines to the CCAMLR modelling workshop with a view to evaluation of various models, identification of components and determination of parameter values. If time is available, a trial energy budget model will be assembled and data needs evaluated, identifying the focus for future research.

7.11 All attendees of the informal meeting were interested in providing data and collaborating on this work. They also considered the Ross Sea area as unique with respect to the importance of key components (e.g. *E. crystallorophias* and *P. antarcticum*). They also agreed that in the longer term it was important to include the Ross Sea within the larger CCAMLR ecosystem model currently under development under the auspices of the Steering Committee on APEME (paragraph 5.62).

#### Fourth World Fisheries Congress

7.12 The Working Group noted that Dr Hewitt had participated in the Fourth World Fisheries Congress and had chaired a session on 'Reconciling fisheries with conservation in polar seas'. Drs Hewitt, Everson and C. Jones (USA) had presented a paper entitled 'Reconciling fisheries with conservation: three examples from the Southern Ocean' (WG-EMM-04/48) which has been submitted for publication in the proceedings of the congress.

#### Living Planet Index

7.13 Dr Ramm advised on correspondence between the Secretariat and the UNEP World Conservation Monitoring Centre (UNEP-WCMC) arising from a query about the availability of time-series data on vertebrates from CEMP (WG-EMM-04/16). UNEP-WCMC was working on developing further the approach for measuring and communicating trends in biodiversity that was developed for the Living Planet Index ([www.panda.org/news\\_facts/publications/general/livingplanet/index.cfm](http://www.panda.org/news_facts/publications/general/livingplanet/index.cfm)). Initiated in 1998, this index combines data on population trends for a wide range of vertebrate species from many locations; the data are assembled from a wide variety of published and unpublished sources.

7.14 The Working Group noted that, despite the appropriate cautions expressed in the Data Manager's response to WCMC, the CEMP data contained time-series trend data of potential relevance to the Living Planet Index. It suggested that Members might wish to make these data available to WCMC, including via published papers where available. To avoid potential

duplication of effort, involving similar data that may be discussed during the SCAR meeting in Bremen, Germany, members of WG-EMM attending that meeting were asked to publicise and discuss the WCMC request.

#### Guidelines for the submission of papers to SC-CAMLR

7.15 In 2003 the Scientific Committee requested that its working groups review the existing guidelines for the submission of papers to SC-CAMLR (SC-CAMLR-XXII, paragraphs 12.31 to 12.34).

7.16 The Working Group noted SC-CAMLR-XXIII/5 prepared by the Secretariat. This was a matter for the Scientific Committee. However, the Working Group agreed that this paper, which would be considered by the Scientific Committee at its next meeting, may provide an opportunity to consider issues related to the submission of Working Group papers, and particularly:

- (i) whether the present deadline for the submission of papers (two weeks prior to the meetings) may be extended for certain types of papers which require specialised technical consideration;
- (ii) clarification regarding the consideration of unpublished papers from non-Members.

7.17 The Working Group proposed that the conveners of the working groups and other interested parties meet with the Chair of the Scientific Committee immediately prior to SC-CAMLR-XXIII to consider these matters and to develop a proposal for consideration by the Scientific Committee.

#### Implementation of the revised Rules for Access and Use of CCAMLR Data

7.18 The Working Group noted that the Commission had agreed to a revised set of Rules for Access and Use of CCAMLR Data (CCAMLR-XXII, paragraphs 12.1 to 12.6, see also [www.ccamlr.org/pu/e/e\\_pubs/bd/toc.htm](http://www.ccamlr.org/pu/e/e_pubs/bd/toc.htm)).

7.19 The Working Group discussed recent experiences with the rules. It was agreed that Members making data requests should clearly indicate the nature of their proposed work with respect to distinguishing between the work indicated in paragraphs 2(a) and 2(b) of the Rules of Access and Use of CCAMLR Data, including in the case of work endorsed by the Scientific Committee or the Commission, detailed reference to the relevant sections of their annual reports. This would assist the Secretariat in evaluating the nature of the proposed work and in determining the applicable process under the rules.

## Publication of results of the CCAMLR-2000 Survey

7.20 The Working Group noted that the special issue of *Deep-Sea Research II* reporting the results of the CCAMLR-2000 Survey was with the printer and proofs will be sent to authors very soon. CCAMLR will contribute A\$10 000 to the costs of publishing this special issue (CCAMLR-XX, paragraph 4.42).

7.21 The Working Group expressed its gratitude to the CCAMLR-2000 Survey steering committee and in particular to the guest editor of the special issue of *Deep-Sea Research II*, Dr J. Watkins (UK).

## ADOPTION OF THE REPORT AND CLOSE OF THE MEETING

8.1 The report of the tenth meeting of WG-EMM was adopted.

8.2 In closing the meeting, Dr Hewitt reflected on the Working Group's long-term plan and the work undertaken during the meeting. WG-EMM had made significant progress in developing operational models of the ecosystem, developing scenarios for subdividing the catch limit for krill in Area 48, and outlining further work on management procedures.

8.3 Although the work of WG-EMM has been, and remains, of great interest to Dr Hewitt, he advised that he would need to step down as Convener of the Working Group some time in 2005 due to his new job and a new set of work commitments. He asked that members of WG-EMM consider the convenership of the group over the next 12 months.

8.4 Dr Hewitt thanked all participants for contributing to the meeting and the workshop. He also thanked the Secretariat for their work in support of WG-EMM, both at the meeting and during the intersessional period.

8.5 Dr Holt, on behalf of the Working Group, thanked Dr Hewitt for his significant and dedicated contribution to the work of WG-EMM, and for leading another successful meeting.

8.6 Dr Holt joined Dr Hewitt in thanking Prof. Focardi and his team, particularly Drs Corsolini and Olmastroni and Ms Luanna Bonelli, for hosting the meeting at the University of Siena and for providing outstanding support. Their very generous hospitality has been greatly appreciated by all.

8.7 Dr Carrada, on behalf of Prof. Focardi, thanked the Working Group for meeting in Siena.

8.8 The meeting was closed.

## REFERENCES

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Table 1: Krill fishery plans notified for the 2004/05 fishing season.

Member	Date of notification	No. of vessels	Expected level of catch (tonnes)	Months during which fishing will proceed	Subareas where fishing will take place	Products to be derived from catch
Japan	8 June 2004	2	45 000	8 months	48.1, 48.2, 48.3	raw (crude) 42% boiled 9% peeled 5% krill meal 44%
Korea, Republic of	18 June 2004	2	30 000	6–8 months	48.1, 48.2, 48.3	processed 73% krill meal 27%
Poland	7 June 2004	1	10 500	Feb–Aug	48.1, 48.2, 48.3	frozen 48.5% krill meal 51.5%
Russia	19 June 2004	1	20 000	Mar–Nov	48.1, 48.2, 48.3	frozen 15% krill meal 85%
Ukraine	7 June 2004	4	84 000	Mar–Aug	48.2, 48.3	processed 20% krill meal 60% frozen 20%
UK	15 June 2004	1	1 500	Dec–Feb	48.3	frozen 100%
Uruguay	18 June 2004	1	10 000	to be advised	48.1, 48.2	krill meal
USA	18 June 2004	1	25 000	Feb–Oct	48.1, 48.2, 48.3, 48.4	processed 70% krill meal 30%
Total		13	226 000			

Table 2: Summary recommendations for actions and analyses aimed at refining and improving the CEMP standard methods and their delivery to the CEMP database arising from an informal workshop held at the CCAMLR Secretariat in February 2004 (WG-EMM-04/70).

General topic	Issue	Parameter	Recommendation for further work or action
Scales over which CEMP parameters integrate processes	Integration and measurement over a mixture of scales	A2	<ul style="list-style-type: none"> <li>Cease measurement of incubation shift durations unless continuation can be justified.</li> </ul>
		A3	<ul style="list-style-type: none"> <li>Analysis of the degree of concurrence of breeding population size trends within a range of scales and determination of the representativeness of population trends from single sites.</li> </ul>
		F2, F5	<ul style="list-style-type: none"> <li>Discontinue collation of sea-ice cover data by the Secretariat.</li> </ul>
Spatial extent of data	Regional differences in monitoring intensity	All parameters	<ul style="list-style-type: none"> <li>Consider regional differences in monitoring intensity in relation to management outcomes.</li> </ul>
Temporal extent of data	Missing data	All parameters	<ul style="list-style-type: none"> <li>Documentation of data gaps and analysis of the effects of missing data on calculation and interpretation of indices.</li> </ul>
Statistical properties and summaries of raw data	Distribution of raw data	All	<ul style="list-style-type: none"> <li>Examine the distributional form of raw data.</li> </ul>
	Independence of sampling units	A5	<ul style="list-style-type: none"> <li>Assess the extent of dependence between trips for a bird, between birds, or between pair members in penguin foraging trip duration data.</li> </ul>
		A3	<ul style="list-style-type: none"> <li>Examine submitted penguin breeding population size data for consistency in their interpretation and application of the colony as the sampling unit across programs, and correct any inconsistencies.</li> <li>Reconsider the definition of the colony as a sampling unit for penguin breeding population size.</li> </ul>
		A3, A6a, A6c	<ul style="list-style-type: none"> <li>Amend the standard method for penguin breeding population size such that observers are required not to communicate their counts to each other until repeat counts are completed.</li> </ul>
Sources and magnitude of variability	All	<ul style="list-style-type: none"> <li>Model the sources and magnitudes of variability in CEMP parameters from first principles using raw data.</li> </ul>	
Summary statistics		A5	<ul style="list-style-type: none"> <li>Undertake simulation studies to investigate the properties of alternative summary statistics for penguin foraging trip data that are non-normal in distribution at the trip level.</li> </ul>

(continued)

Table 2 (continued)

General topic	Issue	Parameter	Recommendation for further work or action
Covariates and qualifiers to summary statistics	Nest contents as a qualifier	A2, A5	<ul style="list-style-type: none"> <li>Determine the extent of compliance across all programs to the standard method's requirement for information on the presence/absence of eggs and chicks as a qualifier to calculation of summary statistics for penguin incubation shift and foraging trip duration.</li> </ul>
	Five-day periods and breeding chronology as covariates	A1, A5, A7  A9	<ul style="list-style-type: none"> <li>Undertake simulation studies to examine the effect of variable sample size over five-day periods for parameters using five-day periods as a covariate.</li> <li>Depending on the outcome of related work, assess whether alternative covariates or qualifiers to five-day periods may be appropriate (e.g. guard and crèche stages for foraging trip duration, or peak arrival and fledge for arrival and fledgling weights).</li> <li>Investigate the use of 'chronological anchor points' as an alternative to continued collection of breeding chronology data for programs still collecting breeding chronology data.</li> </ul>
	Spatial and temporal scale of environmental parameters	F2	<ul style="list-style-type: none"> <li>Discontinue collation of sea-ice cover data by the Secretariat.</li> <li>The Secretariat provides background information on the sources and forms of available environmental data to assist Members using those data for analyses.</li> </ul>
Sample size	Variability and sample size	All	<ul style="list-style-type: none"> <li>Sample size requirements are reassessed in the light of data now available. Such a reassessment should be undertaken in conjunction with previously recommended modelling of sources of variability.</li> </ul>
	Effect size	All	<ul style="list-style-type: none"> <li>Consider an appropriate effect size for detection of change in each parameter.</li> </ul>
	Compliance with recommended sample size	All	<ul style="list-style-type: none"> <li>The Secretariat determines the extent to which current sample size recommendations have been met.</li> </ul>
Representativeness and biased detection of change	Size criterion for selecting colonies, and the number of colonies monitored	A3	<ul style="list-style-type: none"> <li>Review the issues of a criterion for the size of colony to measure, and the scale at which inferences on population size are to be made.</li> </ul>

(continued)

Table 2 (continued)

General topic	Issue	Parameter	Recommendation for further work or action
Measurement error	Sex determination	A1	<ul style="list-style-type: none"> <li>Determine the optimal strategy with regard to the accuracy of available sex determination methods as a covariate to penguin arrival weight.</li> </ul>
	Occupied and incubating nest counts	A3	<ul style="list-style-type: none"> <li>Use occupied nest counts rather than incubating nest counts for breeding population and breeding success.</li> </ul>
	Drainage methods	A8	<ul style="list-style-type: none"> <li>Reconsider the recommendation on drainage methods made in Clarke (1995) as an amendment to the standard methods.</li> </ul>
Comparability of multiple procedures for a single parameter	Concurrence in time series	A1, A6, A7, C1, C2	<ul style="list-style-type: none"> <li>Examine time series data at sites where multiple procedures for the same parameter have been applied over several years for concurrence or otherwise. If possible, determine the cause of any non-concurrence.</li> </ul>
	Non-concurrence due to small sample size	A1, A7	<ul style="list-style-type: none"> <li>Examine non-concurrence due to variable sample size through simulation.</li> </ul>
New or alternative predator parameters	Reproductive output	A6, A7	<ul style="list-style-type: none"> <li>Investigate the properties of penguin reproductive output as a new parameter through simulation.</li> </ul>
Disturbance caused by monitoring activities		A9	<ul style="list-style-type: none"> <li>Assess the benefits of continuing nest observations against the possible cost of disturbance.</li> </ul>
		A2, A5	<ul style="list-style-type: none"> <li>The use of 'chronological reference points' is investigated as an alternative to continued collection of penguin breeding chronology data for programs still collecting breeding chronology data.</li> <li>Investigate whether presence/absence of nest contents can be inferred from the joint behaviour of pair members.</li> </ul>
Data processing by the Secretariat	Definition and measurement of 'change'	All parameters	<ul style="list-style-type: none"> <li>Reassess the process of identifying statistical differences between years and anomalous years in the light of improved knowledge of long-term variability.</li> </ul>

Table 3: Revised plan of work scheduled between 2003 and 2006.

Issue	2003	2004	2005	2006
<b>Revised Krill Management Procedure</b>				
Further development of predator–prey–fishery–environment models	Planning session	Workshop	Steering Committee	Steering Committee
Subdivide precautionary catch limit	Initial proposals	Additional proposals Recommendation	Initial advice based on workshop below	Further advice
Evaluation of management procedures including objectives, decision rules, performance measures	Discussion	Planning session	Workshop (1) to evaluate options for the subdivision of precautionary catch limit for Area 48	Workshop (2) CEMP properties and feedback management procedures
CEMP review	Workshop (SC-CAMLR-XXII, Annex 4, Appendix D)	Consideration of further analytical work (SC-CAMLR-XXII, Annex 4, Appendix D, Table 9)	Consideration of further analytical work	Consideration of further analytical work
Monitoring requirements from CEMP	Discussion		Initial specifications	Revised specifications based on workshop above
Reporting requirements from fishery	Interim requirements adopted by Commission	Consideration of revised requirements	Initial recommendation	Further recommendation
<b>Assessment of Predator Demand</b>				
Large-scale surveys of land-based predators	Discussion	Consideration of pilot studies	Consideration of pilot studies at a planning session	Preparation for surveys
<b>Subdivision of Large FAO Statistical Areas</b>				
Establishment of harvesting units	Discussion		Discussion	Proposals for Subareas 48.6, 88.1, 88.2, 88.3 and Divisions 58.4.1 and 58.4.2 Recommendation
<b>Strategic Planning</b>				
	Discussion	Discussion	Consideration of mechanisms to consider broader issues	Planning session for a workshop

Table 4: List of tasks identified by WG-EMM for the 2004/05 intersessional period. The paragraph numbers (Ref.) refer to this report unless stated otherwise.  
 √ – general request, √√ – high priority.

No.	Task	Ref.	Priority	Action required	
				Members	Secretariat
<b>Status and trends in krill fisheries</b>					
1.	Request Vanuatu to provide the required krill catch data for the 2004 season.	3.3	√√		Implement
2.	Encourage further analysis of krill fishery operational parameters.	3.13	√	Krill fishing Members	Remind
3.	Encourage submission of completed questionnaires on krill fishing strategies.	3.15	√	Krill fishing Members	Remind
4.	Solicit urgent submission to WG-IMAF of descriptions of mitigation measures and devices developed to avoid fur seal by-catch.	3.24	√	Krill fishing Members	Remind
5.	Consider what observer coverage and sampling techniques would be appropriate to collect the required krill fisheries data.	3.29	√	WG-FSA (Convener)	Provide support as required
6.	Implement, as required, recommendations for the revision of the <i>Scientific Observers Manual</i> .	3.43	√	National coordinators of scientific observation programs (Conveners of WG-EMM and WG-FSA)	Coordinate the work on the proposed revision
7.	Request further information on the acquisition of quantitative electronic echograms from fishing vessels, including on issues relating to equipment (and its installation) and data acquisition, access and analysis.	3.41	√	WG-EMM (Convener)	
<b>Status and trends in the krill-centric ecosystem</b>					
8.	Calculate the new index of Antarctic fur seal pup growth rates individually for male and female pups.	4.51	√		Implement
9.	Archive details of methods used by Norway when collecting CEMP data on Bouvetøya.	4.54	√		Implement
10.	Conduct further work on developing methods to summarise CEMP parameters.	4.61	√	Members involved in CEMP	Remind
11.	Consider how any models or methods relating to the estimation of target population levels could be evaluated.	4.66	√	WG-FSA	
12.	Establish a standing Subgroup on Acoustic Survey and Analysis Methods (SG-ASAM) and address issues related to acoustic surveys for both WG-FSA and WG-EMM.	4.89, 4.92–4.95, 4.115	√√	WG-FSA, subject to approval by SC-CAMLR	Provide support as required

(continued)

Table 4 (continued)

No.	Task	Ref.	Priority	Action required	
				Members	Secretariat
13.	Request WG-FSA to consider the establishment of SG-ASAM and its implication for the work of WG-FSA.	4.96	√√	Conveners of WG-EMM and WG-FSA	
14.	Advise new entrants to CEMP that the collection of incubation shift parameter A2 is no longer a requirement of CEMP.	4.102	√	Implement	Advise
15.	Discontinue production of environmental indices F1 to F4.	4.104	√		Implement
16.	Develop operational definition of a colony, amend CEMP standard methods for counting numbers of birds in a colony.	4.105, 4.106	√	Subgroup on Land-based Predator Surveys (Convener)	
17.	Undertake further analysis of the serial dependence and summary statistics for penguin foraging trip duration.	4.108	√	Implement (Members who collect these data)	Provide support as required
18.	Provide details of the cloacal examination techniques for sexing Adélie penguins.	4.110	√	Australia	
19.	Provide reviews on the implication of the use of chronological reference points with respect to the breeding chronology of penguins.	4.111	√	Implement (Members who collect these data)	Remind Members
<b>Status of management advice and future work</b>					
20.	Accomplish tasks for 2005 as agreed in the revised long-term work plan.	6.26, 6.27, Table 3	√	Implement (WG-EMM Convener, Members)	Participate, provide support as required
21.	Establish Steering Committee on Antarctic Plausible Ecosystem Modelling Effort (APEME) and accomplish the tasks assigned.	2.29, 5.62–5.64, 5.71, 5.73, 5.85	√√	Nominate participants (Dr Holt to coordinate), coordinate development of suitable models	Participate, provide support as required
22.	Conduct the 2005 Workshop on Management Procedures.	5.60, 5.83, 6.13, 6.14, 6.35	√√	Conveners to organise and conduct the workshop	Provide support as required
23.	Continue intersessional work on constructing models.	6.16, 6.21–6.23, 6.35	√√	Urged to implement (Members developing models)	
24.	Convene correspondence groups, accomplish the tasks assigned, report to the convener of the workshop by the end of the 2004 meeting of the Scientific Committee, inform Members who are involved in constructing models.	6.15–6.18, 6.20, 6.35	√√	Coordinator of correspondence groups	Participate, provide support as required

(continued)

Table 4 (continued)

No.	Task	Ref.	Priority	Action required	
				Members	Secretariat
25.	Establish a webpage on the CCAMLR website to assist the work of the correspondence group.	6.19	√√		Implement
26.	Establish a program of preparatory work to undertake a synoptic survey of land-based predators; consider conducting a planning session prior to the next meeting of WG-EMM.	6.10, 6.11	√√	Correspondence group (Coordinator, Dr Southwell)	Provide support as required
27.	Consider Edmonson Point Management Plan.	5.37	√	Coordinator ASPA	

**AGENDA**

Working Group on Ecosystem Monitoring and Management  
(Siena, Italy, 12 to 23 July 2004)

1. Introduction
  - 1.1 Opening of the meeting
  - 1.2 Adoption of the agenda and organisation of the meeting
2. Workshop on plausible ecosystem models for testing approaches to krill management
3. Status and trends in the krill fishery
  - 3.1 Fishing activity
  - 3.2 Description of the fishery
  - 3.3 Scientific Observation
  - 3.4 Regulatory issues
  - 3.5 Key points for consideration by the Scientific Committee
4. Status and trends in the krill-centric ecosystem
  - 4.1 Status of predators, krill resource and environmental influences
  - 4.2 Further approaches to ecosystem assessment and management
  - 4.3 Other prey species
  - 4.4 Methods
  - 4.5 Future surveys
  - 4.6 Key points for consideration by the Scientific Committee
5. Status of management advice
  - 5.1 Protected areas
  - 5.2 Harvesting units
  - 5.3 Small-scale management units
  - 5.4 Consideration of models and analytical and assessment methods
  - 5.5 Existing conservation measures
  - 5.6 Key points for consideration by the Scientific Committee
6. Future work
  - 6.1 Predator surveys
  - 6.2 Workshop on Management Procedures
  - 6.3 Long-term work plan
  - 6.4 Key points for consideration by the Scientific Committee
7. Other business
8. Adoption of report and close of meeting.

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(Siena, Italy, 12 to 23 July 2004)

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## LIST OF DOCUMENTS

Working Group on Ecosystem Monitoring and Management  
(Siena, Italy, 12 to 23 July 2004)

WG-EMM-04/1	Provisional Agenda and Provisional Annotated Agenda for the 2004 Meeting of the Working Group on Ecosystem Monitoring and Management (WG-EMM)
WG-EMM-04/2	List of participants
WG-EMM-04/3	List of documents
WG-EMM-04/4	The diet of Antarctic fur seals, <i>Arctocephalus gazella</i> , at King George Island, during the summer–autumn period G.A. Daneri, A.R. Carlini, C.M. Hernandez and A. Harrington (Argentina) ( <i>Polar Biology</i> , submitted)
WG-EMM-04/5	Seabird research at Cape Shirreff, Livingston Island, Antarctica, 2003–2004 M. Antolos, A.K. Miller and W.Z. Trivelpiece (USA) ( <i>AMLR 2003/2004 Field Season Report</i> , in press)
WG-EMM-04/6	Summary of notifications of krill fisheries in 2004/05 Secretariat
WG-EMM-04/7	Vacant
WG-EMM-04/8	Draft Revised Management Plan for ASPA 149, Cape Shirreff and San Telmo Island, Livingston Island, South Shetland Islands Delegations of Chile and USA
WG-EMM-04/9	Register of non-CEMP time-series data Secretariat
WG-EMM-04/10	Results of scientific observation on board RKT-S (cannery fishing super trawler) <i>Konstruktor Koshkin</i> in Statistical Area 48 in March–June 2003 as compared with previous seasons V.A. Bibik and S.A. Klementiev (Ukraine)
WG-EMM-04/11	Summary table of current and proposed Antarctic marine protected areas S. Grant (United Kingdom)

WG-EMM-04/12	The biology, ecology and vulnerability of seamount communities A.D. Rogers (United Kingdom) (Published in 2004 by the International Union for the Conservation of Nature and Natural Resources)
WG-EMM-04/13	History of development and completion of tasks put forward by WG-EMM (2001–2003) Secretariat
WG-EMM-04/14	CEMP indices 2004: analysis of anomalies and trends Secretariat
WG-EMM-04/15	Krill fishery information Secretariat
WG-EMM-04/16	The living planet index Secretariat
WG-EMM-04/17	CEMP-related correspondence Secretariat
WG-EMM-04/18	Development of the acoustic survey database Secretariat
WG-EMM-04/19	Revision of Conservation Measure 91-01 (2000), Annex 91-01/A 'Information to be included in Management Plans for CEMP sites' Chair, Subgroup on Protected Areas
WG-EMM-04/20	Acquiring a 'base datum of normality' for a marine ecosystem: the Ross Sea, Antarctica D. Ainley (USA)
WG-EMM-04/21	CCAMLR Scheme of International Scientific Observation: Review of the <i>Scientific Observers Manual</i> Secretariat
WG-EMM-04/22	Foraging patterns in the Antarctic shag ( <i>Phalacrocorax bransfieldensis</i> ) at Harmony Point, Antarctica R. Casaux and A. Baroni (Argentina)
WG-EMM-04/23	Demography of Antarctic krill in the Lazarev Sea (Subarea 48.6) and the Elephant Island area (Subarea 48.1) in 2004 V. Siegel (Germany), V. Loeb (USA), B. Bergström (Sweden), S. Schöling (Germany), M. Haraldsson (Sweden), J. Kitchener (Australia), M. Vortkamp (Germany)

- WG-EMM-04/24 A possible framework in which to consider plausible models of the Antarctic marine ecosystem for evaluating krill management procedures  
A. Constable (Australia)  
(*CCAMLR Science*, submitted)
- WG-EMM-04/25 Report of the Steering Committee for the WG-EMM Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management
- WG-EMM-04/26 Developing conceptual models of the Antarctic marine ecosystem: squid  
K. Phillips (Australia)
- WG-EMM-04/27 Biotopic and spatial distribution of krill *Euphausia superba* Dana (Crustacea, Euphausiacea) length groupings in the Atlantic sector of Antarctic in summer 1984 and 1988  
V.V. Lidvanov, A.V. Zimin, K.E. Shulgovsky (Russia)  
(*Collected Papers AtlantNIRO*, 2004, in press)
- WG-EMM-04/28 Accounting for food requirements of seabirds in fisheries management – the case of the South African purse-seine fishery  
R.J.M Crawford (South Africa)  
(*African Journal of Marine Science*, Vol. 26, in press)
- WG-EMM-04/29 Counts of surface-nesting seabirds at Marion Island in 2003/04  
R.J.M Crawford, N. de Bruyn, B.M. Dyer, B. Hanise, N.T.W. Klages, P.G. Ryan, L.G. Underhill and L. Upfold (South Africa)
- WG-EMM-04/30 The brief review of the AtlantNIRO's investigations of living marine resources: whales, krill and fish, in the Atlantic sector of the Antarctic  
F. Litvinov, D. Tormosov, Zh. Frolkina (Russia)  
(*History of Oceanography*. Abstracts of the VII International Congress on the history of Oceanography. Museum of the World Ocean, Kaliningrad, 8–12 September 2003: 273–278)
- WG-EMM-04/31 Incidental seal entanglements on trawl vessels fishing for krill in CCAMLR Subarea 48.3  
J. Hooper, K. Reid and D. Agnew (United Kingdom)
- WG-EMM-04/32 The applicability of international conservation instruments to the establishment of marine protected areas in Antarctica  
S. Grant (United Kingdom)

- WG-EMM-04/33 Food consumption estimates of southern elephant seal females during their post-breeding aquatic phase at South Shetland Islands  
A.R. Carlini, G.A. Daneri, M.E.I. Márquez (Argentina), H. Bornemann (Germany), H. Panarello, R. Casaux (Argentina), S. Ramdohr and J. Plötz (Germany)
- WG-EMM-04/34 Physical forcing in the southwest Atlantic: ecosystem control  
P.N. Trathan, E.J. Murphy, J. Forcada, J.P. Croxall, K. Reid and S.E. Thorpe (United Kingdom)  
(*Management of Marine Ecosystems: Monitoring Change in Upper Trophic Levels*. Boyd, I.L. and S. Wanless (Eds). (submitted to the Zoological Society of London Symposium))
- WG-EMM-04/35 Near-shore acoustic surveys for Antarctic krill at South Georgia, January 2004  
A.S. Brierley, P.N. Trathan, J. Poncet and A. Morton (United Kingdom)
- WG-EMM-04/36 Dynamoe and albatross papers 2003–2004  
British Antarctic Survey (United Kingdom)
- WG-EMM-04/37 Proposal for an acoustic krill biomass survey in CCAMLR Division 58.4.2  
S. Nicol, S. Kawaguchi, T. Jarvis and T. Pauly (Australia)
- WG-EMM-04/38 Interannual variation in the summer diet of Adélie penguin (*Pygoscelis adeliae*) at Edmonson Point  
S. Olmastroni, F. Pezzo, I. Bisogno and S. Focardi (Italy)
- WG-EMM-04/39 CPUE values derived from Soviet fishery statistics as indicators of Antarctic krill density fluctuations in 1977–1991  
F.F. Litvinov, A.Z. Sundakov and G.N. Andrianov (Russia)
- WG-EMM-04/40 Broadbandwidth sound scattering and absorption from krill (*Meganyctiphanes norvegica*), Mysids (*Praunus flexuosus* and *Neomysis integer*) and shrimp (*Crangon crangon*)  
S.G. Conti, D.A. Demer (USA) and A.S. Brierley (United Kingdom)  
(*Journal of the Acoustical Society of America*, submitted)
- WG-EMM-04/41 Sounds like more krill  
D.A. Demer and S.G. Conti (USA)  
*ICES Journal of Marine Science* (submitted)

- WG-EMM-04/42 Report of scientific observations of commercial krill harvest aboard the Japanese stern trawler *Chiyo Maru No. 5* 2 August 2003–21 September 2003  
T. Hayashi, M. Naganobu and K. Taki (Japan)
- WG-EMM-04/43 Short note: report of bacterial infectious Antarctic krill (*Euphausia superba*) in South Georgia  
T. Hayashi and M. Naganobu (Japan)
- WG-EMM-04/44 Characteristics of seasonal variation in diurnal vertical migration and aggregation of Antarctic krill (*Euphausia superba*) in the Scotia Sea, using the Japanese fishery data  
K. Taki, T. Hayashi and M. Naganobu (Japan)  
(*CCAMLR Science*, submitted)
- WG-EMM-04/45 Comparison of 1981 FIBEX survey and 2000 CCAMLR survey on oceanographic variability in the Scotia Sea, Antarctica  
M. Naganobu and Y. Yoda (Japan)  
(*CCAMLR Science*, submitted)
- WG-EMM-04/46 Spectra analysis of Drake Passage Oscillation Index (DPOI) from 1952 to 2003, Antarctica  
M. Naganobu and K. Kutsuwada (Japan)
- WG-EMM-04/47 A survey plan of Japanese RV *Kaiyo Maru* in 2004/05 for the Ross Sea and adjacent waters, Antarctica  
M. Naganobu, K. Taki and T. Hayashi (Japan)
- WG-EMM-04/48 Reconciling fisheries with conservation: three examples from the Southern Ocean  
R.P. Hewitt (USA), I. Everson (United Kingdom) and C.D. Jones (USA)  
(*Proceedings of the Fourth World Fisheries Congress*, submitted)
- WG-EMM-04/49 Krill caught by predators and nets revisited: interpreting prey selection in proper temporal–spatial scales  
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- WG-EMM-04/50 Developing conceptual models of elements of the Antarctic marine ecosystem: Antarctic krill (*Euphausia superba*)  
S. Nicol and S. Kawaguchi (Australia)
- WG-EMM-04/51 A conceptual model of the krill fishery  
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M. Naganobu (Japan)  
(*CCAMLR Science*, submitted)
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- WG-EMM-04/54      Modelling availability bias using existing time series count data:  
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at regional scales in Antarctica from existing count data: a review  
using Adélie penguins as a case study  
C. Southwell (Australia)  
(*CCAMLR Science*, submitted)
- WG-EMM-04/56      Developing and applying a general abundance estimator for land-  
based predator surveys: Adélie penguins as a case study  
C. Southwell (Australia)  
(*CCAMLR Science*, submitted)
- WG-EMM-04/57      Changes in the foraging range of Adélie penguins as the breeding  
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(*Journal of Animal Ecology*, submitted)
- WG-EMM-04/58      Conceptual model of Antarctic epi- and mesopelagic fish  
R. Williams (Australia)
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R. Williams (Australia)
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K. Reid (United Kingdom) and G. Watters (USA)  
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(United Kingdom)
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K. Reid, E.J. Murphy, J.P. Croxall and P.N. Trathan  
(United Kingdom)  
(*Proceedings of the Zoological Society of London Symposium, March 2004*, submitted)
- WG-EMM-04/64 Shipboard line transect surveys of crabeater seal abundance in the pack-ice off East Antarctica: evaluation of assumptions  
C. Southwell, W. de la Mare (Australia), D. Borchers and L. Burt (United Kingdom)  
(*Marine Mammal Science*, in press)
- WG-EMM-04/65 Developing conceptual models of elements of the Antarctic marine ecosystem: marine mammals  
N. Gales and C. Southwell (Australia)
- WG-EMM-04/66 Rev. 1 The structure and spatial distribution of Antarctic krill aggregations from acoustic observation in the South Georgia area  
S.M. Kasatkina (Russia)  
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(*Polish Polar Biology*, submitted)
- WG-EMM-04/69 Ecological implications of body composition and thermal capabilities in young Antarctic fur seals (*Arctocephalus gazella*)  
M.R. Rutishauser, D.P. Costa, M.E. Goebel and T.M. Williams (USA)  
(*Physiological and Biochemical Zoology*, accepted)

- WG-EMM-04/70                      Review of the CEMP standard methods and their delivery to the CEMP database  
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- WG-EMM-04/72                      Krill and zooplankton populations monitored during AMLR 2004 surveys (Subarea 48.1) with respect to the long-term Elephant Island area datasets  
V.J. Loeb (USA)
- WG-EMM-04/73                      Report of the Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management (Siena, Italy, 12 to 16 July 2004)
- Other Documents
- Options for allocating the precautionary catch limit of krill among small-scale management units in the Scotia Sea  
Hewitt, R.P., G. Watters, P.N. Trathan, J.P. Croxall, M.E. Goebel, D. Ramm, K. Reid, W.Z. Trivelpiece and J.L. Watkins  
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VNIRO, Moscow, 2003: 295 pp.
- Competition between marine mammals and fisheries – can we successfully model this using ECOPATH with ECOSIM?  
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- Consideration of multispecies interactions in the Antarctic: a preliminary model of the minke whale–blue whale–krill interaction  
M. Mori and D.S. Butterworth (South Africa)  
(*African Journal of Marine Science*, in press)

Examining natural population growth from near extinction: the case of the Antarctic fur seal at the South Shetlands, Antarctica  
R. Hucke-Gaete, L.P. Osman, C.A. Moreno (Chile)  
(*Polar Biol.*, 27: 304–311 (2004))

Feeding ecology of Antarctic fur seals at Cape Shirreff, South Shetlands, Antarctica  
L.P. Osman, R. Hucke-Gaete, C.A. Moreno, D. Torres (Chile)  
(*Polar Biol.*, in press)

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| WG-FSA-SAM-04/4               | Further development of the fishery plans<br>Secretariat  |
| WG-FSA-SAM-04/4<br>Attachment | Draft fishery plans sections 1, 2 and 3<br>CCAMLR Secretariat                                  |
| WG-FSA-04/4                   | Report of the Subgroup on Assessment Methods<br>(Siena, Italy, 5 to 9 July 2004)               |
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**REPORT OF THE WORKSHOP ON PLAUSIBLE ECOSYSTEM  
MODELS FOR TESTING APPROACHES TO KRILL MANAGEMENT**  
(Siena, Italy, 12 to 16 July 2004)

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# **REPORT OF THE WORKSHOP ON PLAUSIBLE ECOSYSTEM MODELS FOR TESTING APPROACHES TO KRILL MANAGEMENT**

(Siena, Italy, 12 to 16 July 2004)

## INTRODUCTION

1.1 The Workshop on Plausible Ecosystem Models for Testing Approaches to Krill Management, which was established in the program of work for WG-EMM in 2001, was held at the University of Siena, Siena, Italy, from 12 to 16 July 2004. The meeting was convened by Dr A. Constable (Australia).

1.2 In 2003, the terms of reference for the workshop were agreed to be (SC-CAMLR-XXII, Annex 4, paragraph 6.17):

- (i) to review the approaches used to model marine ecosystems, including:
  - (a) the theory and concepts used to model food-web dynamics, the influence of physical factors on those dynamics and the operations of fishing fleets;
  - (b) the degree to which approximations could be used to form ‘minimally realistic’ models<sup>1</sup>;
  - (c) the types of software or computer simulation environments used to implement ecosystem models;
- (ii) to consider plausible operating models for the Antarctic marine ecosystem, including:
  - (a) models of the physical environment;
  - (b) food-web linkages and their relative importance;
  - (c) dynamics of the krill fishing fleet;
  - (d) spatial and temporal characteristics of models and their potential limitations in space and time;
  - (e) bounding the parameters used in the models;
- (iii) to advance a program of work to develop and implement operating models to investigate the robustness of different management approaches to underlying uncertainties in the ecological, fishery, monitoring and assessment systems, including:
  - (a) the development and/or testing of software;

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<sup>1</sup> A minimally realistic model of an ecosystem is one that includes just sufficient components and interactions to enable the key dynamics of the system to be realistically portrayed.

- (b) specification of requirements of software, including diagnostic features, ability to test the efficacy of observation programs, such as different kinds of monitoring of predators, prey and the fishery;
- (c) consideration of spatial and temporal characterisation of the physical environment (ice, oceanography) that could be used to parameterise the models.

1.3 A steering committee was established in 2003 and comprised Drs Constable (Coordinator) and C. Davies (Australia), P. Gasyukov (Russia), S. Hill (UK), Prof. E. Hofmann (USA), Drs G. Kirkwood and E. Murphy (UK), M. Naganobu (Japan), D. Ramm (Secretariat), K. Reid (UK), C. Southwell (Australia), P. Trathan (UK) and G. Watters (USA). Drs R. Hewitt (Convener, WG-EMM) and R. Holt (Chair, Scientific Committee) have been *ex officio* members of the steering committee (SC-CAMLR-XXII, Annex 4, paragraph 6.16).

1.4 Intersessional activities of the steering committee are reported in Item 2.

1.5 The Scientific Committee agreed to fund the attendance of two invited experts at the workshop, as well as providing some funding so that the invited experts could undertake some preparatory work which would at least involve reviewing the contributions to the workshop.

1.6 The workshop steering committee agreed to invite two external experts who could advise on important areas where sufficient expertise is not available from within the CCAMLR community, and who could help with the following key questions:

- To what extent is it necessary to represent all interactions in a food web?
- How can minimally realistic models be used safely?

1.7 Dr B. Fulton (CSIRO, Australia) was invited for her expertise in considering these questions in the context of the evaluation of management procedures (strategies). A second expert was invited but was unable to attend the workshop due to unexpected circumstances.

1.8 Dr Constable introduced the work of the workshop and provided a summary of the background to the workshop along with some expectations as to the outcomes to be achieved. These points were based on Part I of WG-EMM-04/24, and included:

- (i) A discussion on how observations are the basis of making decisions.
- (ii) A management procedure is a combination of observations, assessments, and decision rules that adjust harvest controls to achieve operational objectives.
- (iii) Long-term planning is improved if the rules surrounding decisions are known and understood.
- (iv) Assessments may comprise statistical estimation of a parameter/indicator, statistical comparisons, or more complex development of models and projections.

- (v) Key questions about the assessments are:
  - (a) Are there sufficient samples to make the correct decision? This often relates to precision of the estimates, which could lead to statistical Type I and II errors (Andrew and Mapstone, 1987).
  - (b) Could the estimates be biased and/or confounded by variables or processes unrelated to the assumed cause of effects?
- (vi) Precision can be handled by analyses of statistical power, such as those being done in the CEMP review.
- (vii) The effect of bias and/or potential confounding on making decisions consistent with the precautionary approach can be addressed by building scenarios and determining whether the bias could lead to incorrect decisions. The issues of bias and confounding in relation to parameter estimation and in relation to the processes that link ecosystem elements to krill, either as food for krill or predators of krill, are more difficult to address. While some relationships could be explored using scenarios of logic, others will need to use more complicated simulations to explore the effects of different types of plausible relationships (structural uncertainty) as well as the effects of natural variation (system uncertainty).
- (viii) A task of the workshop is to develop scenarios in order to help evaluate the potential for biases in our monitoring and in the assessment process and whether those biases could lead to incorrect decisions that would cause the Commission to fail to meet one or more of its objectives.
- (ix) The primary aim of the workshop was to develop the specifications that will be used by programmers to produce the modelling framework in which plausible models of the Antarctic marine ecosystem can be simulated.

1.9 Dr Constable introduced the draft agenda (in WG-EMM-04/25) and the workshop agreed to add another item 'Plausible scenarios for Antarctic marine ecosystems'. With this addition the agenda was adopted (Attachment 1).

1.10 In adopting the agenda, the workshop noted that the discussions would be drawing together information and concepts to provide a common framework for developing one or more ecosystem models for testing approaches to krill management. As such, the workshop acknowledged that the common framework developed in its report may not be using all of the information, concepts or understanding necessary for implementing ecosystem models. For example, the estimation and summary of parameters is not one of the intended outcomes of the workshop. As a result, some tables, figures or text may not be complete in their consideration or presentation of the issues. Nevertheless, the workshop agreed that the format of the workshop should provide the foundation for further development and implementation of ecosystem models for the work of WG-EMM.

1.11 The work was divided into the major sections of the agenda and coordinated by Dr Constable.

1.12 The report was prepared by Dr Constable, Prof. J. Croxall (UK), Drs Davies, Hill, Hewitt, S. Kawaguchi (Australia), Ramm, Reid, K. Shust (Russia), V. Siegel (Germany), Trathan, W. Trivelpiece (USA) and Watters. Workshop participants are listed in Attachment 2.

## REPORT OF THE STEERING COMMITTEE ON INTERSESSIONAL ACTIVITIES

2.1 As agreed at WG-EMM in 2003, intersessional activities included:

- (i) provision of advice on the potential contributions from experts in preparation for the workshop and in participating in the development of models at the workshop (Drs Hill and Murphy and Prof. Hofmann);
- (ii) a review of relevant literature and information on the development of ecosystem models elsewhere as per the first term of reference (Prof. Hofmann and Dr Murphy);
- (iii) compilation of a catalogue of available software and other simulation environments for ecosystem modelling (Drs Ramm, Watters and Gasyukov);
- (iv) preliminary consideration of the requirements for datasets, estimates of parameters and other aspects related to the second term of reference (Drs Trathan, Reid and Naganobu);
- (v) preliminary outline of the aims and specifications for ecosystem modelling as it relates to the development of management procedures for krill (Drs Constable, Davies and Kirkwood).

2.2 The results of this work are outlined in the report from the steering committee (WG-EMM-04/25).

### Literature review on ecosystem models

2.3 A review of relevant literature and information on the development of ecosystem models elsewhere as per the first term of reference was prepared by Drs Hill, Murphy, Reid, Trathan and Constable. It was submitted as WG-EMM-04/67 and presented to the workshop under Item 3 (see also paragraphs 3.1 and 3.15).

2.4 The workshop had also been informed of other research and publications relevant to its evaluation of ecosystem models and processes.

2.5 The workshop requested that the recent evaluations of fishery management models (e.g. Plagányi and Butterworth, in press; Plagányi and Butterworth, in review) and of multispecies interactions in the Antarctic (Mori and Butterworth, in press) be submitted for the consideration of WG-EMM.

## Available software and other simulation environments

2.6 A catalogue of available software and other simulation environments for ecosystem modelling was compiled by Drs Ramm, Gasyukov and Watters. It is summarised in Appendix A of WG-EMM-04/25.

2.7 Dr Gasyukov further outlined the availability of models through the Internet but noted that it would be preferable to develop software specifically for use by CCAMLR.

## Data and parameter requirements

2.8 In preparation for the workshop, Drs Naganobu, Reid and Trathan were asked to make a preliminary consideration of the requirements for datasets, estimates of parameters and other aspects related to the second term of reference.

2.9 The workshop recognised that defining the data requirements for models that are not yet specified meant that there was a limit to the progress that could be made. Nevertheless there are a number of key areas of data that are likely to form the basic requirements of an ecosystem model of the Southern Ocean. In WG-EMM-04/25, a background synopsis of the availability of basic data is provided in the following categories:

- models of the physical environment
- food-web linkages and their relative importance
- dynamics of the krill fishing fleet.

2.10 The workshop noted that there was considerable information available with which to parameterise ecosystem models. However, the workshop also recognised that the availability and utility of data were not synonymous; for example, there are a large number of datasets of physical processes but the utility of these to ecosystem models was not yet defined. In order to progress the development of plausible ecosystem models for use in the management of the krill fishery, it would be necessary to ensure that adequate validated information was available to properly describe both food-web linkages and the dynamics of the krill fleet.

## Aims and specifications for ecosystem modelling

2.11 Drs Constable, Davies, and Kirkwood undertook to consider aims and specifications for ecosystem modelling. Much of the discussion occurred at the Scientific Committee meeting last year, which was distributed in the first and second Scientific Committee circulars concerning the workshop.

2.12 Dr Kirkwood described his involvement in a project funded by the European Community developing fisheries-related models to evaluate management strategies. That work is being coordinated by Dr L. Kell (CEFAS) with much of the code being developed in the free-ware statistical language, R. A central theme of this work is to integrate many different kinds of operating and assessment models in a single framework, an approach similar to the one needed by WG-EMM. It was agreed that this work may provide some useful tools in the future.

2.13 Dr Constable described work undertaken at the Australian Antarctic Division to assist the workshop in initiating discussions on modelling different components of the Antarctic marine ecosystem. This work formed the basis of WG-EMM-04/24 as well as a number of working papers provided to WG-EMM to help initiate discussions.

#### Invited experts

2.14 Dr Constable welcomed Dr Fulton to the workshop and invited her to present illustrations of her use of models in CSIRO in evaluating management strategies for the marine environment. The following paragraphs summarise her presentation.

#### Management strategy evaluation (MSE)

2.15 The MSE approach is made up of a model of the biophysical system (or operating model); submodels of each of the important anthropogenic exploitation or impact activities; submodels for any monitoring activities; and submodels of the decisions process associated with management of each sector. The combined dynamics of these models are used to evaluate how the potential real system might respond to natural events and any human activities. The MSE models must be capable of reproducing historical trends and responses to major events, but they must also be capable of projecting the outcomes of a range of management strategies that have not been used in the past. This is done by ensuring that the main features of the natural system, including uncertainty, are captured in the model, as well as by realistic depiction of sector responses to management strategies. MSE is particularly useful for: (i) determining effective monitoring schemes; (ii) identifying management procedures robust to sampling and model uncertainty; (iii) finding effective compromises between different sectors (or interests) within the system; and (iv) identifying unanticipated problems, issues or dynamics.

2.16 MSE is a tool that has been used at the Australian CSIRO Marine Research (CMR) for nearly 20 years (e.g. Sainsbury, 1988). Over the last six years the approach has been extended from single and multispecies applications to ecosystem-level, multiple-use management MSE. The two marine ecosystem models currently used in this role by CMR are Atlantis and InVitro. Atlantis has been used to consider the effects of model complexity on model performance, and, in MSE, to test potential ecological indicators of the ecosystem effects of fishing (Fulton et al., in press). InVitro is currently being used as the basis of MSE for a range of multiple-use management procedures for the northwest shelf of Australia (Fulton et al., in prep.).

#### Atlantis

2.17 The Atlantis framework was developed from the 'Bay Model 2' ecosystem model (Fulton et al., 2004). It is a deterministic model that tracks the nutrient (nitrogen and silica) flow through the main biological groups (vertebrate and invertebrate) found in temperate marine ecosystems and three detritus groups (labile detritus, refractory detritus and carrion). The invertebrate and primary producer groups are simulated using aggregate biomass pools,

while the vertebrates are represented using age-structured models. The primary processes considered in Atlantis are consumption, production, waste production, migration, predation, recruitment, habitat dependency, and natural and fishing mortality.

2.18 Atlantis is spatially resolved, with a polygonal geometry that matches the major geographical features of the simulated marine system (Figure 1). The size of each polygon reflects the extent of spatial homogeneity in the physical variables represented in the model (depth, seabed type (reef or flat), canyon coverage, porosity, bottom stress, erosion rate, salinity, light and temperature). Atlantis is also vertically structured. For the simulations of this study, there is one sediment layer and up to five water column layers within each box (Figure 1). The biological components mentioned above are replicated in each layer of each box, with movement among boxes and layers dealt with explicitly (for the migration of higher trophic levels), or by a simple transport model (for advective transfer).

2.19 The harvesting submodel in Atlantis allows for multiple fleets, each with differing characteristics (gear selectivity, habitat association, target, by-product and by-catch groups, effort dynamics and management structures). While not as sophisticated as fleet dynamic models that model the behaviour of individual vessels (e.g. Little et al., 2004), Atlantis does represent the dynamics of aggregate fleets and allows for behavioural responses to effects such as effort displacement due to the depletion of local stocks or the creation of marine protected areas.

2.20 The sampling model generates data with realistic levels of measurement uncertainty (bias and variance) based on the outputs from the operating model, given specifications for the precision of the data and how they are collected temporally and spatially. For example, fisheries-dependent data are aggregated spatially and temporally (e.g. total catch over the entire area per quarter), whereas fisheries-independent data (such as surveys or diet composition) are only available infrequently (annually to once every decade) from ‘snap shots’ taken at certain ‘sampling locations’ (Figure 1).

## InVitro

2.21 The biophysical model that forms the operating model in InVitro reproduces the main physical and biological features of the natural marine ecosystem (e.g. bathymetry, currents, waves, seabed types, habitat-defining flora and fauna, and local and migratory populations of marine animals). The InVitro model also includes a representation of the impact of natural forces and activities by the various human sectors found on the northwest shelf of Australia (petroleum exploration and extraction, conservation, fisheries and coastal development). In the management submodel the relevant agencies observe the system produced by the biophysical model (imperfectly) and make decisions about the location and magnitude of the sector activities.

2.22 InVitro is a three-dimensional agent-based, or i-state-configuration, model (Caswell and John, 1992; DeAngelis and Gross, 1992). This form of model provides a convenient framework for dealing with many types of entities (e.g. individuals, populations and communities) – also known as agents. The behaviour of the various kinds of agents in the model can be either passive or on the basis of decision rules, depending on the form of the agent. A summary of the major agent types and the behaviours modelled for each type is

given in Table 1. Mobile agents are represented as either individuals (turtles and fishers) or as aggregates (e.g. subpopulations of finfish, schools of sharks and prawn boils), while habitat-defining biological groups are all represented by more aggregate agents (e.g. entire seagrass beds and reefs). Functional and physical attributes are detailed for each of these agents and rules are specified for growth (at the appropriate scale), as well as for passive and active movement. This intertwining of classical age-structured population and typical agent-based models into hybrid form allows for an efficient representation of all critical spatial and interaction scales.

2.23 The environment of an agent is based on the bathymetry, currents, temperature, light intensity, chemical concentrations, habitat type and resident communities. The environmental attributes are updated so that active agents can evaluate their surroundings and take the appropriate (temporal and spatial) responses. A scheduler (which functions in much the same way as a multi-tasking operating system – assigning priorities to agents and splitting available time to give the illusion of concurrency) handles the timing of the agents' activities (and any interactions among the agents). This allows each agent to work at the time step best suited to its activities while ensuring temporal consistency (no agent may re-live the same instant), maintaining synchronicity (preventing the 'subjective' time of an agent straying far from that of its neighbours), and avoiding any potential for systematic advantage of a particular agent (or agent type) due to internal ordering of processes.

#### Model development

2.24 Ecosystem model development is an iterative, but largely two-stage process. Firstly the ecosystem must be scoped. The following list of checkpoints gives a good sense of the critical processes, components and scales in marine ecosystems:

- oceanography and climate;
- biogeochemistry;
- biogeography;
- biological components (dominant, keystone, vulnerable groups, age or size structuring required);
- links (trophic and otherwise, weights, multiple pathways);
- ecological processes;
- anthropogenic pressures and activities.

2.25 Once a conceptual model of the ecosystem has been sketched out (via multiple classification of the components and processes to allow for discernment of natural groupings), then the most critical step of model development commences – determination of the spatial, temporal and biological scales. Based on previous experience in a number of ecosystem

modelling exercises around the world, it is likely that models incorporating mixed scales (with detail focused where it is needed rather than being applied homogeneously throughout the model) will prove to be the most effective.

## DESIRABLE ATTRIBUTES OF ECOSYSTEM MODELS

### Attributes of models in the literature

3.1 Dr Hill presented WG-EMM-04/67. This paper reviewed approaches to modelling ecosystems in the CCAMLR region with the aim of identifying issues and approaches of relevance to the development of models for evaluating approaches to the management of the krill fishery.

3.2 Models of krill population dynamics have generally addressed the causes of interannual variability in abundance in the Scotia Sea and around South Georgia. Both changes in large-scale distribution and local production seem to play a role. The krill yield model, which is used to set catch limits, uses a Monte Carlo approach to simulate fished krill populations. Parameter values for each year, including recruitment are independently drawn from statistical distributions but there is evidence of autocorrelation in krill recruitment.

3.3 There are various putative effects of environmental variables on aspects of krill biology, including recruitment dynamics and mortality. Most are modelled as simple correlations. A more complex model suggests that hatching of krill embryos on the continental shelf is limited by depth and presence of warm water (Hofmann and Hüsrevoğlu, 2003). Passive drift on ocean currents might be important in determining the large-scale distribution of krill, though active swimming could influence local distribution.

3.4 Early predator–prey models of the Southern Ocean were largely developed in response to the proposition that total krill consumption was reduced with the depletion of the baleen whale stocks. Laws (1977) estimated that this released a krill surplus of 147 million tonnes. The models of May et al. (1979) and others considered a multispecies system with exploitation of both krill and whales. They assumed that prey abundance was driven by predation and that competition and prey consumption were linearly proportional to predator abundance. Among the results of these models were illustrations of multispecies modelling issues.

3.5 Murphy (1995) developed a spatially resolved model of predator and prey dynamics in which krill recruitment was decoupled from predator abundance. The model showed the potential influence on predator dynamics of overlapping foraging ranges and krill concentration. It also illustrated the importance to land-based predators of the retention of krill around islands.

3.6 Butterworth and Thomson (1995) and Thomson et al. (2000) attempted to construct realistic models of the response of the best-studied predators to krill availability. These included non-linear performance responses to prey abundance. The models considered whether krill catch limits could be set on the basis of a target predator population size. There were biases in results due to parameter estimates or model structure. The workshop

considered that such models were not sufficient to determine the level of krill escapement required to meet the conservation requirement for predators because they do not represent the overall krill requirement of all predators.

3.7 The models of Mangel and Switzer (1998) and Alonzo et al. (2003a, 2003b) considered the potential influence of behaviour on the dynamics of populations of krill and their predators. These models suggested that krill behaviour can amplify negative effects of krill harvesting on penguins. The authors suggested that predator behaviour might be used to indicate ecosystem status.

3.8 Models of krill fisheries were constructed by Mangel (1988) and Butterworth (1988a) to investigate the relationship between krill abundance and CPUE from the former Soviet and Japanese krill fisheries respectively. These incorporated the hierarchical structure of krill aggregations as patches within patches as described by Murphy et al. (1988). Marin and Delgado (2001) represented the fishery using a spatial automata model implemented in a GIS.

3.9 The earliest attempt to quantify biomass flow through a simplified food web was made by Everson (1977). Many of the pathways which could not be quantified remain data poor. Croxall et al. (1984) used detailed consideration of energy requirements to model prey consumption by predators. Three detailed ecosystem models have been constructed by Green (1975), Doi (1979) and Bredesen (2003), the latter using ECOSIM software. These models are limited by the availability of data. However they highlight the importance of pathways that do not involve krill or well-studied consumers. They also highlight the need for improved data on energy transfer and assimilation rates.

3.10 Constable (2001) presented a model to integrate ecosystem effects through summing biomass production in predator species arising from consumption of harvested species. This could be summed across predators to give an index of ecosystem status, which could be used to set ecosystem reference points. It could also be summed across prey species within predators to set reference points for individual predator populations.

3.11 Early models of long-term dynamics assumed the system was at equilibrium before harvesting. However, the past status of the ecosystem is likely to be impossible to establish. Also, the assumption of equilibrium in the past or the future might be unrealistic.

3.12 Krill is clearly of central importance, but the food web has pathways that do not include krill.

3.13 There is a need to improve the data available on important trophic interactions. Also, the question of how to manage fisheries when some parts of the ecosystem are difficult to observe needs to be addressed. Other important questions to consider are how to represent important environmental effects in models of the ecosystem, and how to integrate different models when they may give output at different scales.

3.14 Dr Hill requested workshop members to supply details of any relevant literature that was currently missing from the review. Dr Shust suggested the volume on krill distribution and oceanography (Maslennikov, 2003).

3.15 Dr Shust suggested that the estimation of unexploited krill biomass remains a problem. Dr V. Sushin (Russia) commented that there may be other ways to manage the ecosystem than through managing the krill fishery.

#### General attributes of models for evaluation of management procedures

3.16 Dr Constable presented discussion points on the general attributes of models for evaluating management procedures. This presentation was based primarily on Part II of WG-EMM-04/24. He noted that operating models are not intended to capture all of the dynamics of the physical and biological systems but should capture the important properties of the system as they relate to the effects of fishing and the possible monitoring programs (ecology, physical environment, fishery) that can be employed. The important properties to consider and discuss in more detail in WG-EMM-04/24 are:

- (i) the potentially important direct and indirect effects of fishing, thereby defining the characteristics of the ecosystem that may need to be measured in the simulations, whether or not they can be measured in the field;
- (ii) the types of field observations and monitoring programs that could be employed;
- (iii) the biological scales (taxonomic grouping and population subdivision into life stages – which may not be the same for each taxonomic group) required to promulgate the important interactions between species and to provide for monitoring;
- (iv) the spatial scales of interactions, taking account of differences in interactions between different types of locations as well as the potential for biogeographic differences, thereby influencing the degree to which space will need to be explicitly accommodated in the modelling framework and whether spatial units need to be uniform geographic units or may be implied by being represented as compartments accommodating different spatial areas and extents;
- (v) the temporal scales of interactions, taking account of differences in important interactions over time and the duration of different events, such as reproduction or other life stage characteristics, thereby influencing the duration of the time steps necessary to be accommodated;
- (vi) the degree to which interactions (cause and effect) are approximated or explicitly modelled, which may be influenced by the types of measurements able to be achieved in a monitoring program;
- (vii) the degree to which processes peripheral to the central processes concerned with the effects of fishing are simulated;
- (viii) the manner in which the boundaries of the model system are simulated, recognising that the system is unlikely to be a closed system and that processes occurring outside of the model system might impact on the function of that system.

3.17 The workshop agreed that these attributes are important to consider during the workshop and in the implementation of models for use by WG-EMM.

## CONCEPTUAL REPRESENTATION OF ECOSYSTEM MODELS

### General approach

4.1 As indicated in Item 2, Dr Constable had undertaken an exercise with scientists in the Australian Antarctic Division to develop conceptual models of various components of the Antarctic marine ecosystem. He introduced this item by summarising Part III of WG-EMM-04/24. The major points were:

- (i) the aim of developing conceptual models is to provide a flexible framework for considering how each taxon might be influenced by the rest of the ecosystem, thereby providing the means to explicitly decide how best that taxon should be represented in the model to evaluate krill management procedures;
- (ii) some taxa will need to be represented in some detail in order to simulate field monitoring and the local-scale effects of fishing;
- (iii) other taxa might be simulated in a very general way in order to save simulation time while ensuring that ecosystem responses are realistic;
- (iv) the approach is intended to provide a means for explicitly determining how to take account of structural uncertainties given the paucity of data on many aspects of the ecosystem. The approach is also designed to allow an assessment of the sensitivity of model outcomes to assumptions about the relationships between taxa.

4.2 Figure 9 in WG-EMM-04/24 illustrated the components/functions of a single element in a food-web model discussed in that paper. An element was defined as the lowest, indivisible quantity in the food-web model and had the following attributes:

- (i) taxon – the group to which the element belongs, which could be a population, species, guild, ecological group, sex or some other category;
- (ii) stage – the life stage of the element, whether it be age, life stage or some other subdivision of the taxon needed to provide for distinguishing ecological characteristics (below) from other stages;
- (iii) units – the type of units used to measure/monitor the quantity of the element, such as number, biomass, area or some other measure;
- (iv) location – if needed, the spatial compartment or cell in which the element resides;
- (v) depth – if needed, the depth stratum in which the element resides.

4.3 The state of an element is largely governed by its magnitude (abundance) but some knowledge of its age may be important if the proportion of animals of a certain life stage advancing to another life stage is not constant and governed by the present age structure.

4.4 The workshop noted that the conceptual models will require consideration of the characteristics of elements, even though each characteristic may not be explicitly incorporated as separate parts of a model.

4.5 In the first instance, the workshop agreed to undertake the following work in developing conceptual representations of key components:

- (i) develop pictorial representation, as appropriate, of key population processes, primary locations of individuals relative to features in the physical environment and spatial foraging patterns;
- (ii) identify key parameters and processes that will need to be considered in the representation of each element in the ecosystem model, including population dynamics, foraging behaviours and spatial and temporal distributions;
- (iii) undertake initial consideration of:
  - (a) the interactions between taxa and between taxa and the environment;
  - (b) the representation of space, time and depth in ecosystem models;
  - (c) consideration of the requirements for modelling field observations, which will be undertaken in the evaluation process.

4.6 The workshop noted that the major considerations for the development of operating models are with respect to

- physical environment
- primary production
- pelagic herbivores and invertebrate carnivores
- target species
- mesopelagic species
- marine mammals and birds.

4.7 Other taxa may need to be considered in future, such as demersal and bathypelagic species, including *Dissostichus* spp., *Macrourus* spp., skates and rays. It was noted that the current framework was sufficient for initiating work on evaluating approaches to krill management.

4.8 The remainder of this section sets out the results of discussions on conceptual representation of these components.

4.9 The Antarctic marine ecosystem considered at the workshop is primarily that ecosystem south of the Sub-Antarctic Front (SAF), including most of the Polar Frontal Zone (PFZ) and the ocean south of that zone, which comprises the west–east flow of the Antarctic Circumpolar Current (ACC) and the east–west flow of the Antarctic coastal current. This is primarily contained within the CCAMLR Convention Area, although some features of the

PFZ occur to the north of the CCAMLR Convention Area (Figures 2 and 3). The workshop noted that the boundaries of the ACC described by Orsi et al. (1995) are also important features to consider. In that respect, the subtropical front, which is to the north of the primary area of interest, was also considered important for flying birds.

4.10 The other main feature of the Antarctic marine ecosystem is the annual progression and retreat of the pack-ice zone (Figure 4). In this respect, the MIZ at the edge of the pack-ice as well as the role of pack-ice to predators needing haul out locations and as a substratum for productivity need to be considered.

4.11 A view of the biological productivity of the Southern Ocean can be viewed using SeaWiifs data (Figure 5).

4.12 The main biotic components considered by the workshop were primary production, pelagic herbivores and invertebrate carnivores, target species (*Euphausia superba* and *Chamsocephalus gunnari*), mesopelagic species (myctophid fish and squid) and widely distributed and migratory species, the marine mammals and birds (Table 2).

#### Physical system

4.13 The workshop considered those elements of the physical environment that it noted were of potential importance in the operation of the Southern Ocean marine ecosystem and that would also be of considerable utility in a coupled ecosystem model. The workshop considered these various elements from a number of perspectives.

4.14 Firstly, it considered a range of environmental factors each with a set of properties and each with a set of motivating forces; secondly, it considered a set of dynamic processes and how these structure the environment; thirdly, it considered seasonality and how this affects a number of the environmental factors; and finally it considered the natural spatial properties of the ecosystem. The results of these deliberations are contained in Tables 3 to 6. The workshop agreed that considerably greater detail could be included, but it recognised that, for a first attempt, the identified elements were sufficient to scope the modelling process.

4.15 The workshop noted that, conceptually, the physical environment provides four main ecological functions in the Antarctic marine ecosystem:

- (i) a substratum for production, with the attendant physical conditions in space, depth and time;
- (ii) stratification of the physical environment into natural units, including oceanic zones, depth zones, bathymetric features and ice;
- (iii) substratum for transport between areas and depths;
- (iv) sources of mortality, such as extreme atmospheric conditions.

4.16 At each stage of the process, the workshop identified which of these ecological functions and processes was affected; examples of potential functional impact are identified in square brackets ([ ]) in Tables 3 and 4.

4.17 The workshop considered physical factors in different seasons (Table 5). It recognised that the division of the calendar year into seasons depended on latitude. Initially it decided to focus on two seasons, winter and summer.

4.18 The workshop also recognised that the Southern Ocean had a number of natural spatial divisions (Table 6).

4.19 The workshop attempted to develop a conceptual model of the environment and how the various factors and processes interacted. This is illustrated in Figure 6.

4.20 The workshop recognised that there were a number of areas where environmental models would be of considerable utility in a coupled ecosystem model. These included:

- (i) Delineating two-dimensional areas and three-dimensional polygons of spatial operation; these would potentially delineate a framework of habitats for use elsewhere in the ecosystem framework. The workshop recognised that direct coupling of a physical general circulation model may not be necessary, so long as inputs and outputs could be defined at appropriate spatial and temporal scales. These outputs would need to encompass the ecosystem functions described in paragraph 4.15.
- (ii) The delineated habitats and processes should relate to the intended biological complexity of the model.
- (iii) There could be utility in considering separate frameworks for each of continental, island and low-latitude situations.

#### Primary production

4.21 As part of its deliberations the workshop considered primary production, recognising that there was only general (and not specific) expertise within the group. Some consideration of primary production is given in WG-EMM-04/24. It noted that the formation of particulate matter for secondary producers could arise from primary production, particulates in the microbial loop as well as particulate detritus (Figure 7). The workshop also considered the factors that might influence primary production discussed in that paper (Figure 8, Table 7). It noted that remotely sensed ocean colour data, such as from SeaWiFS or MODIS, had the potential to help partition the Southern Ocean for the purposes of building an ecosystem model coupled with a physical oceanographic model. An example of summer Chl-*a* distribution from SeaWiFS is shown in Figure 5.

4.22 The workshop noted that future work will be needed in developing models of primary production, including reviews of the forcing functions provided in WG-EMM-04/24 as well as alternative formulations available in other models. The workshop recognised that, at some future point, it would also need to consider more detailed primary production models that included successional elements and seasonal elements.

## Invertebrate herbivores and carnivores

4.23 Five taxonomic groups were considered as important pelagic herbivores and carnivores: salps, copepods, mysids, amphipods and euphausiids (other than *E. superba*).

4.24 Salps are open-water pelagic filter feeders and include several species, the most important of which is *Salpa thompsoni*. Copepods include approximately 60 species, of which 10 to 15 are common. Mysids include three common epibenthic species associated with continental shelves, shelf breaks and canyons. Hyperiid amphipods include approximately six common species, the most important of which may be *Themisto gaudichaudii*. Important euphausiids other than *E. superba* include *E. crystallorophias* and *Thysanoessa macrura*.

4.25 Attributes that were considered to be important with regard to the functioning of the pelagic ecosystem included spatial distribution, diet, generation time and depth distribution.

4.26 With regard to spatial distribution, it was recognised that distinct zooplankton communities were difficult to identify in the Southern Ocean, that there was a general decline in the number of species and their abundance progressing from north to south. Nevertheless, three non-exclusive species groupings were recognised: namely oceanic, island shelf and high-latitude shelf groups with large overlaps between them. Species indicative of the ocean group include salps; species indicative of the island shelf group include mysids; and species indicative of the high-latitude shelf group include *E. crystallorophias*.

4.27 With regard to diet, salps were considered to be primarily herbivores. Copepods, depending on species, were considered to include herbivores, carnivores and omnivores. Mysids and amphipods were considered to be carnivores. Euphausiids were considered to be omnivores.

4.28 With regard to generation time, salps and copepods were considered to be capable of responding the fastest to favourable conditions with generation times of 0.5 to 1 year. Mysids were considered to have a generation time in the order of 2 years; amphipods 1 to 2 years and euphausiids 2 years.

4.29 With regard to depth distribution, three depth zones were defined: the epipelagic from 0 to 400 m depth, the mesopelagic greater than 400 m depth, and the epibenthic within 50 m of the bottom in water depths of 100 to 400 m. During the summer months all taxa were considered to occupy primarily the epipelagic zone, with the exception of mysids, which occupy the epibenthic zone. Little is known of the winter-time depth distribution of these zooplankton.

4.30 The above attributes are summarised in Table 8.

## Target species

4.31 The workshop considered WG-EMM-04/24, 04/50 and 04/59 for its deliberations to define elements of target species to be used in ecosystem models for testing approaches to

krill management. Discussions concentrated on two species, the icefish (*C. gunnari*) and krill (*E. superba*). It considered that *Dissostichus* species might be incorporated in the modelling framework in the future but these species were not considered further at this workshop.

## Icefish

4.32 The properties of *C. gunnari* for inclusion in the general structure of the Antarctic ecosystem model are summarised in Table 9.

4.33 *C. gunnari* is one of the key components in the sub-Antarctic marine ecosystem in the Scotia Sea and northern Kerguelen Plateau areas. *C. gunnari* has a high biomass within its distribution range, although this can vary widely between locations and over time. The workshop noted that the species has a disjunct distribution within the sub-Antarctic region; a population in the South Atlantic region around South Georgia and Shag Rocks, South Orkney and South Shetland Islands and the tip of the Antarctic Peninsula (Figure 9); and populations on the northern part of the Kerguelen Plateau around Kerguelen and Heard Islands.

4.34 Within its distribution range *C. gunnari* is restricted to shelves around islands. Subpopulations in each major distribution area show distinct biological properties, e.g. maximum size, growth, fecundity, spawning season and fluctuations in abundance. Abundance is highly variable at any location, and fluctuations are not synchronised between areas. The variability in abundance in this species appears to derive both from large variations in recruitment strength as well as changes in abundance of adult fish between years. The documented high degree of variability in year-class strength in all populations is presumably driven by environmental factors. These may include:

- poor feeding conditions leading to a low proportion of mature fish reaching spawning condition, e.g. in the South Georgia area;
- low hatching rate of eggs due to sub-optimal temperatures or predation;
- low larval survival due to inadequate food supply, advection by currents from nursery grounds, or predation.

Although the processes behind this are not well understood, the workshop felt it necessary that variability in recruitment should be included in the modelling framework.

4.35 *C. gunnari* could be modelled as length- and age-structured populations, the methods of which are well described in the literature. While there is sufficient information to develop length-structured dynamic models that could be overlaid on bathymetric features, the workshop indicated that this species could be modelled as three life stages – early life-history stages, juveniles and adults (Figure 10).

4.36 It was recognised that icefish is a component of two different prey environments:

- In the South Atlantic area, the principal food item is *E. superba*. Larval as well as juvenile and adult icefish feed on various stages of krill from furcilia larvae to adult individuals. During times when krill is scarce, all stages of *C. gunnari* can switch prey to *T. macrura* or amphipods and mysids.

- On the Kerguelen Plateau, where *E. superba* does not exist, the principal diet component is *E. valleritini* with *T. gaudichaudii* being a secondary component.

4.37 In the Atlantic sector predators include other fish species, albatross in certain years and penguins. Fur seals increase the proportion of *C. gunnari* in their diet in those years when krill is scarce. In the Kerguelen Plateau area, predation appears to be less intense.

4.38 Since the late 1990s, fisheries have resumed for this species at South Georgia and Heard Island. It has been suggested that the nature of the ecosystem may have changed since the period of intensive fishing in such a way as to reduce the carrying capacity of *C. gunnari*. Whether this phenomenon is a result of unsustainable fishing in the past or of environmental change or other ecosystem change has not been established. A decline in the *C. gunnari* fishery at Kerguelen during the last 10 years has been attributed to a southward shift of the Polar Front (WG-EMM-04/59).

4.39 Regular surveys of *C. gunnari* around South Georgia suggest a highly heterogeneous distribution, which may be important to include in models.

4.40 The workshop considered that in each geographic location *C. gunnari* should be considered as at least three elements (larvae, juveniles and adults). It was also considered that it may be worth considering eggs as an additional element if there was reason to believe that predation on eggs is an important factor to consider.

## Krill

4.41 The properties of *E. superba* for inclusion in the general structure of the Antarctic ecosystem model are summarised in Table 10.

4.42 The workshop noted that, although krill has a circumpolar distribution, the highest concentrations of the species and the broadest latitudinal distribution range are found in the Southwest Atlantic (Figures 11 and 12). Two different views were expressed on the distribution of krill size groups/developmental stages (the juvenile and spawning adult component):

- (i) Existing concepts of krill distribution on the onshore–offshore separation of juveniles, the breeding stock and larvae were generalised as a conceptual life-history model in WG-EMM-04/50. The model attempted to take into account the observed relationships between properties of Antarctic krill and its biotic and abiotic environment, focusing on the effect of environmental forces such as sea-ice properties and gyre systems (Figures 13 and 14). The workshop recognised that there is some debate as to whether the South Georgia region should be regarded as an area where successful spawning of krill does not occur and the degree to which the source of recruitment is from outside South Georgia.
- (ii) An alternative view was also presented for the South Orkney Islands and considered (Figure 15).

4.43 For the purposes of the model, the workshop agreed that krill could be modelled as four life stages – eggs, larvae, juveniles, adults – because of their spatial separation and that

the fishery targets primarily adult krill. The life-history strategy of krill places the developing embryos and larvae in locations distinct from the adult population which avoids competition for food, but also prevents predation on larval krill by adults.

4.44 Two alternative conceptual horizontal distributions were discussed:

- (i) The first alternative described krill distribution as a coherent flow across large scales including some high-density retention areas where local production was important.
- (ii) The second alternative described krill distribution as a set of discrete populations restricted to the major gyre systems of the Southern Ocean (WG-EMM-04/50).

4.45 The workshop discussed alternative hypotheses regarding seasonality in the horizontal movement of krill in the Southwest Atlantic; the workshop concluded that an operating model of the krill-centric ecosystem could be useful to explore the possible alternatives:

- (i) The first hypothesis suggests that krill are advected from west to east with the flow of the ACC during the summer. Further, that transport of krill slows (or ceases) as the sea surface freezes during the early winter. Krill are then distributed within 50 m of the underside of the ice where they utilise ice algae as a food source and experience reduced predation. When the ice retreats the following spring, krill are again exposed to advection by the ACC.
- (ii) An alternative hypothesis would be that over shelf areas with little sea-ice cover, krill move to the bottom and reside there during the winter months.

4.46 Additional to the two-dimensional dispersion of krill, plausible ecosystem models must also account for the diel vertical migration (DVM) pattern. This DVM has a seasonal and latitudinal component which is probably linked to the prevailing light regime (evolutionary), but may also reflect a response to predators (avoidance behaviour).

4.47 DVM behaviour of *E. superba* during the summer appears to vary with latitude. In the northern part of their distribution (South Georgia) krill migrate between 0 and 150 m. Further south krill appear to migrate less, and in the southern part of their distribution (Ross Sea, Weddell Sea) krill do not appear to migrate at all. It is hypothesised that the tendency to migrate vertically is related to summertime changes in daylight (greatest at lower latitudes, least at high latitudes). A general picture of DVM behaviour during the winter is less obvious. During the winter months krill trawlers set their nets deeper at South Georgia and krill have been observed in swarms close to the bottom, although it is not known how typical this behaviour may be. Diel variation in krill catches during a recent wintertime research cruise to the Weddell Sea suggests vertical migration between 0 and at least 200 m.

4.48 Interannual abundance and recruitment vary substantially. The population is driven by reproductive output and larval survival over winter. The important key variable is sea-ice, which is probably an indicator for food resources in winter (ice-algal) and spring (ice-edge bloom).

4.49 Adult krill are viewed as indiscriminate feeders on suspended matter in the pelagic zone, consuming autotrophs, small heterotrophs and detrital material, and because of their aggregating nature, they can have the effect of locally clearing particulate material from the

euphotic zone. The critical feeding periods for krill larvae are in the late summer through until spring whereas for adults it is in spring through to late summer. This further avoids competition for food resources between the life-history stages.

4.50 The workshop noted that sufficient data are available to characterise the population to implement the conceptual model summarised in Tables 3 and 4. This includes the life cycle, the interaction between ice and oceanographic features and the different life stages, as well as important components in demography and food-web linkages.

4.51 The hierarchical structure of krill aggregations is understood to consist of individuals within swarms within patches within concentrations. This structure will influence the interactions between krill, their predators and the fishery (see also paragraph 4.94).

## Mesopelagic species

### Mesopelagic fish

4.52 The workshop had WG-EMM-04/24 and 04/58 on which to base considerations of how to structure mesopelagic fish in an operating model for the Antarctic ecosystem.

4.53 For the purposes of the operating model the workshop considered that mesopelagic fish could be divided into four elements based on:

- the distributions of taxa between those associated with the PFZ and those distributed from the PFZ to the south;
- the differences between distributions on the shelves of islands and the Antarctic continent and those associated with high-productivity frontal features in offshore waters.

A summary of the rationale for the division is provided in Table 11. The properties of each element are provided in Tables 12(a) to 12(c).

4.54 This categorisation was considered to be appropriate given the information and expertise available to the workshop. It may be that future consideration may elaborate on this categorisation in terms of taxon included (e.g. species), distribution, size classes, sexual maturity, or other considerations. The workshop suggested that this task (reviewing this categorisation) could usefully be referred to WG-FSA.

### Questions for further consideration

4.55 Should we include benthic fish, e.g. notothenids and *Dissostichus* spp. as a separate component in the model?

4.56 The extent to which predators based on the Antarctic Continent, e.g. breeding birds and seals tend to consume squid, notothenioid fish and krill over or near the continental shelf (WG-EMM-04/59).

## Squid

4.57 The workshop had WG-EMM-04/24 and 04/28 on which to base considerations of how to include squid in an operating model for the Antarctic ecosystem.

4.58 For the purposes of the operating model the workshop considered that squid could be divided into five elements based on:

1. Onychoteuthid squid – juveniles
2. Onychoteuthid squid – adults
3. Ommastrephid squid – juveniles
4. Ommastrephid squid – adults
5. Small to medium nektonic squid.

The properties of each element are provided in Tables 13(a) to 13(c).

4.59 In the case of both onychoteuthid and ommastrephid squid, the workshop considered that it was necessary to have juvenile and adult elements, given the size differences, the spatial separation and the different prey and predators of each of the life-history stages.

4.60 In the case of the ommastrephid squid it was noted that the spawning grounds and distribution of juveniles from the dominant species in the Southwest Atlantic are on the Patagonian shelf, outside the CCAMLR Convention Area. Consideration will need to be given to how this spatial separation is modelled. It was also noted that there was research suggesting that some species of onychoteuthid squid may have a two-year life cycle, rather than an annual cycle.

4.61 The workshop noted that there is generally thought to be a high degree of cannibalism in squid, although there is little data available to determine the extent. The workshop suggested that it would be important to include predation functions that allow the implications of different assumptions about cannibalism to be explored.

4.62 The workshop also noted that the larger species of squid, such as *Mesonychoteuthis hamiltoni*, may represent a functional equivalent to large pelagic vertebrate predators in temperate and tropical systems, such as the Scombridae. The workshop considered that it would be important to explore the implications of assuming different functional roles for such squid in trophic pathways.

4.63 While the above categorisation of squid was considered to be appropriate given the information and expertise available to the workshop, further review of the roles of psychroteuthid, galiteuthid and cranchid squid would be appropriate. The role of epibenthic cephalopods might also warrant consideration.

## Marine mammals and birds

4.64 Marine mammals and birds potentially forage widely in the Southern Ocean. This large group of animals was divided into two broad categories associated with the degree of distributional constraint imposed by breeding:

- (i) those that have a part of their life cycle in which they are constrained to be central-place foragers (i.e. they have a requirement to breed on land where the dependent offspring remains until independence; one or both parents make repeated foraging trips from that point to provision the offspring), e.g. Antarctic fur seals, penguins and flying birds;
- (ii) those that have pelagic distribution (i.e. cetaceans) or come on land or ice to pup, such as phocid seals.

4.65 The life-history characteristics of these two groups also reflect the extent to which species are income breeders, those species that acquire the resources required to provision offspring during the offspring rearing period (e.g. Antarctic fur seal), or capital breeders, those species for which the resources required to provision offspring are acquired prior to offspring birth (e.g. Southern elephant seal).

4.66 The workshop considered WG-EMM-04/22 (shags), 04/24 (general and migratory species), 04/53 (Adélie penguins) and 04/65 (marine mammals) to help describe the elements of these taxa.

4.67 The workshop concentrated on:

- (i) identifying the important elements/components of each of the major groups;
- (ii) developing visual representations of the conceptual models of the dynamics of each group, including the functions that might cause transition from one life stage to another and the locations of the main foraging areas relative to the main oceanographic and topographic features of the Southern Ocean. Examples of these are given in Figures 16 to 20;
- (iii) developing the framework for considering the estimation of parameters and functions required in population transition matrices and in the spatial and temporal foraging activities of the predators;
- (iv) identifying future work to validate the conceptual models and for obtaining appropriate parameters.

4.68 These were considered for the following species/taxa:

1. Central-place foragers:

- (i) Adélie, chinstrap, gentoo, macaroni, emperor and king penguins
- (ii) Antarctic fur seal
- (iii) black-browed, grey-headed, wandering and light-mantled sooty albatrosses
- (iv) giant petrels
- (v) large petrels (white-chinned, cape, snow, Antarctic, Antarctic fulmar etc.)
- (vi) small petrels (prions, diving petrels, storm petrels)
- (vii) skuas, gulls, terns, shags.

2. Non-central-place foragers:
  - (i) baleen whales
  - (ii) toothed whales (sperm whale and small cetaceans)
  - (iii) killer whale
  - (iv) pack-ice seals (crabeater, Ross and leopard seals)
  - (v) Weddell seal
  - (vi) southern elephant seal.

## Life-history characteristic and demography

### Birds

4.69 The workshop noted that the conceptual model provided in WG-EMM-04/53 provided the basis for describing transitions between the different elements in a generalised life cycle of a bird. The generalised model is shown in Figure 21. Further consideration may be needed for some birds as to whether pre-breeders might become non-breeders (either in good or poor condition) as a result of having a different size, foraging behaviours or factors influencing survivorship.

### Penguins

4.70 Adélie, chinstrap, gentoo, macaroni, emperor and king penguins were considered by the workshop to have a period during breeding when they are central-place foragers (Figure 22). Some pre-breeders and non-breeders may also be central-place foragers for a period. This is because they can be found in colonies along with the breeders, however, the costs/constraints are unlikely to be equivalent to those of breeding birds (WG-EMM-04/53). The demography of these populations could be summarised in a manner shown in Figure 23. The workshop considered that these attributes may need to be further refined for Adélie penguins in areas other than Béchervaise Island and for other penguins.

4.71 For Adélie penguins, the workshop reviewed the conceptual model in WG-EMM-04/53 and developed some options for the various functions that might influence the dynamics of Adélie penguin populations. To that end, the transition matrix in Table 14 provided the basis for these discussions.

4.72 Points for consideration in respect of the transition matrix for Adélie penguin are:

- (i) survival in first winter is low:
  - (a) where  $S_{1,t} = f(\text{FA}, \text{biomass of population and other competitors, condition, predation})$ , where FA is food availability;
  - (b) the relationship between  $S_{1,t}$  and FA is sigmoidal and with biomass of the population and competitors is a sigmoidal decay;

- (ii) survival up to breeding, which may be over a period of three to five winters, has an expectation of an increased survivorship compared to the first year;
- (iii) transition from pre-breeder to breeder is governed by the condition after winter and FA;
- (iv) transition from non-breeder to breeder is likely to be high because few birds are non-breeders for two consecutive years;
- (v) winter survival of breeders is likely to be higher than that of fledglings;
- (vi) summer survival of the breeders is influenced by leopard seal predation, energetic costs and other factors, with the breeders expected to have a lower survivorship than non-breeders;
- (vii) breeding success is influenced by age and experience of the breeders (step function), FA (increasing sigmoidal), predation by skuas (exponential decrease) and weather (step function).

4.73 A number of potential functions were also considered by the workshop concerning the impacts of various factors on survivorship and reproductive success. These included those related to:

- (i) fledgling survival in the first winter; these functions may be related to:
  - (a) condition at fledging (possibly a skewed distribution)
  - (b) food availability (possibly a positive sigmoidal function)
  - (c) predation (possibly a negative sigmoidal function);
- (ii) ice extent and density (may increase food availability, alternatively it may reduce foraging habitat, therefore associated functions may take various forms).

#### Flying birds

4.74 Similar principles and processes will affect the transition matrices of the different groups of flying birds. Additional factors of particular (or potential) relevance to the group might include effects of incidental mortality (both within and outside the Convention Area), and availability of supplementary food through waste and/or discards from the fisheries.

4.75 The workshop noted that the following factors might influence different life stages of flying birds, including:

- (i) effects on chick survivorship include disease in the sub-Antarctic, exposure, provisioning, scavengers, other predators and, primarily, starvation;
- (ii) fledglings will be influenced by food supply, which could result in mortality from starvation;

- (iii) immatures and adults at sea will be influenced by predation, as well as anthropogenic effects from longlining (especially large species and white-chinned petrels) and pollutants, but scavengers will also benefit from discards and waste.

4.76 Following the example given in Table 14, a matrix of taxonomic categories and their potential states was developed to provide a basis for developing appropriate transition matrices for these taxa (Table 15).

#### Marine mammals

4.77 Seals have a similar process of transition between states to that depicted in Figure 22, however, they differ from birds in respect of sexual size dimorphism and the relative contribution of the different sexes to the costs of offspring rearing. In the case of Antarctic fur seals, there is a similar constraint of central-place foraging for breeding females, however, in the case of phocid seals and cetaceans these particular constraints will not apply.

4.78 Following the example given in Table 14, a matrix of taxonomic categories and their potential states was developed to provide a basis for developing appropriate transition matrices for these taxa (Table 15).

#### Trophic dynamics

4.79 Representation of trophic dynamics is required for all the relevant species/species-groups and will include characterisation of:

- (i) diet
- (ii) distribution (horizontal and vertical as appropriate).

Both of these may vary by time of year and region.

#### Diet

4.80 Table 16 provides an example of various potential levels of detail required to characterise the main prey types in the diet of predators. Table 17 provides a qualitative illustration of how diet categories might be allocated at the level of predator species and other species groups. Consideration of diet, including relating it to the desired levels of temporal and spatial subdivision, is an important element of future work.

## Spatial scales of distribution and foraging movements by depth

4.81 A generalised model of the vertical foraging distribution of air-breathing predators was developed for several taxonomic groups (Figure 24). In general, those predators found in the upper 100 m are predominantly krill-feeding species, whilst those that consume fish and squid are predominantly found at greater depth.

4.82 With respect to the conceptual diving model in Figure 24 the penguins, seals (other than southern elephant seal) and flying birds, i.e. groups 1–7, can be characterised as surface-dwelling species that make excursions from the surface to feed. Southern elephant seals and odontocete whales can be characterised as species that live and feed at depths of 500–1 500 m and make excursions to the surface to breathe. The arrows on the figure indicate the direction of movement from the primary location in which the foragers spend the greater part of their time budget.

4.83 The horizontal distribution of the species/taxa considered at different life-history stages is considered for breeding and non-breeding periods in Tables 18 and 19. The workshop also considered the importance of boundary conditions for any operational model to allow for the dispersal and seasonal migrations of marine mammals and birds that takes account of the time spent inside/outside the Convention Area.

## Fisheries

4.84 The workshop considered WG-EMM-04/24 and 04/51 during its deliberations to define elements of fisheries that can be used in ecosystem models for testing approaches for ecosystem management. The discussion focused on two fisheries: the krill fishery and the icefish fishery.

### Krill fishery

4.85 The nature of the krill fishery was considered based on the behaviour of the Japanese krill fishery reported in WG-EMM-04/51. The workshop recognised that the kind of information provided, such as the decision-making processes made by the skipper according to changing circumstances during the course of the fishing season (Table 20), is an important factor when considering the development of a model of the krill fishery.

4.86 In Area 48, fishing areas usually occur adjacent to the islands. Some of these fishing areas are further divided into local fishing grounds (Figure 25).

4.87 Throughout the fishing season, there is a preference by the Japanese fleet for using fishing areas closer to the ice edge rather than using any of the other areas available (Figure 26). The fishing patterns were further characterised according to seasonal succession of physical and biological properties at the fishing grounds (Figure 27).

4.88 Individual vessels moved frequently between local fishing grounds, and sometimes moved to different fishing areas seeking suitable aggregations (e.g. density, structure, krill condition etc.) to fish.

4.89 Properties of the krill fishery were considered by the workshop; firstly, by identifying possible options for taxon, stage and units as outlined in WG-EMM-04/24. Following this exercise, the options for basic model elements, the types of decision made, and the different factors affecting fishery behaviour, were discussed.

4.90 Although krill fishing vessels tend to operate in national fleets, the behaviour of each vessel is strongly influenced by individual skippers. The ‘taxon’ should be defined at the level of individual vessels to reflect these behavioural differences between vessels. This is particularly appropriate as there are few vessels (5–10) and some of the observation data are available at vessel level. These properties are detailed in Table 21.

4.91 The fishing patterns examined by the workshop were derived from data from the Japanese krill fishery. Given the fact that there may be national/fleet differences in preference for fishing area as well as strategies for fishing operations (Figure 28) (CCAMLR-XXI), the workshop agreed that such differences may need to be included in any model of the krill fishery. The workshop recommended that this type of analysis should be undertaken for krill fisheries of other nations.

4.92 Overall, the workshop recognised that the fishing patterns considered were related to fishing under current fishery levels and regulations. Recalling that the aim of plausible models of the Antarctic marine ecosystem would be to evaluate krill management scenarios, the workshop thought it essential that any model should be capable of testing management scenarios by reproducing fisheries behaviour under various regulation scenarios, including catch limits set at smaller spatial and/or temporal scales than those defined by the conservation measures presently in force.

4.93 In order to achieve this, the fishery model may need to simulate individual vessels fishing under different operational strategies and requirements (see paragraphs 4.22 and 4.51). Therefore, the operational model may need to:

- (i) generate regional concentrations of krill that would constitute the ‘local fishing grounds’ including:
  - (a) concentrations corresponding to ‘known’ fishing grounds
  - (b) concentrations in currently unfished areas;
- (ii) characterise the types and distributions of aggregations within local fishing grounds well enough to allow discrimination between the results of the different fishing strategies of the different fleets;
- (iii) model the effect of fishing on aggregations (e.g. reduced abundance and size of aggregations resulting from removals or dispersion; reforming of swarms after catching/dispersal, flux etc.) in order to:
  - (a) be able to handle the effects of different fleet fishing strategies
  - (b) describe the effects on predator feeding success;
- (iv) model factors which affect catch quality such as phytoplankton and salp distributions at the level of resolution that allows the model to represent vessel behaviour in response to these properties.

4.94 With respect to 4.93(iii), the workshop noted that some work has captured the properties of krill aggregations to examine catch per unit effort in krill fisheries (Butterworth, 1988b; Mangel, 1988; Kasatkina and Latogursky, 1990; Kasatkina and Ivanova, 2003; Litvinov et al., 2002; Litvinov et al., 2003, WG-EMM-03/31), as discussed in WG-EMM-04/24 and 04/67. A number of studies have also been carried out on the effects of predation on krill concentrations, including WG-EMM-96/20, WG-EMM-96/67, Boyd et al. (1997), WG-EMM-97/28, 97/64, Murphy et al. (1988), Miller and Hampton (1989) and Alonzo et al. (2003a, 2003b). The Workshop agreed that it may be possible to examine the effects of fishing activities on predator foraging by integrating these approaches. It also recognised that further work was needed on these aspects and noted also that issues of model detail, complexity and scale would need to be considered when incorporating these interactions into the overall ecosystem model.

#### Icefish fishery

4.95 The Data Manager described general properties of this fishery drawing on his knowledge of CCAMLR data holdings.

4.96 It was recognised that fishing in Area 48 is currently permitted only around South Georgia and that the size of the current fishing fleet is small (<5 vessels in any season). However, in the past, the icefish fishery was larger (>80 000 tonnes), and was also present around the South Orkney Islands and the South Shetland Islands. The use of bottom trawling is prohibited in this fishery and icefish are largely taken by pelagic trawl (Figure 29).

4.97 Icefish fisheries have also operated in Area 58 and the fishing in Division 58.5.2 is regulated under Conservation Measure 42-02.

4.98 One of the significant differences between icefish fisheries and krill fisheries is that icefish fisheries are assessed annually by WG-FSA and strict management regulations are in place. In Subarea 48.3, these regulations include a temporal spatial closure during the spawning season, a move-on rule to minimise the catch of fish <240 mm in length and catch limits for by-catch species (Conservation Measures 33-01 and 42-01).

4.99 Properties of the icefish fishery were considered following the procedure for the krill fishery. These properties are detailed in Table 22.

4.100 In order to be able to model the icefish fishery operations, the operational model may need to be able to:

- (i) generate realistic age structure and distribution in relation to the bottom topography;
- (ii) model the dynamics of by-catch species.

## PLAUSIBLE SCENARIOS FOR THE ANTARCTIC MARINE ECOSYSTEM

5.1 The workshop considered the types of scenarios that need to be considered in evaluating the robustness of krill management procedures to structural uncertainties of the model. This discussion focused on two broad topics. The first was concerned with the plausibility of the model and the second with questions of ecosystem dynamics that could be explored with the model.

5.2 With regard to model plausibility, several questions were raised. These include:

- (i) How sensitive is the model to alternate hypotheses regarding critical processes?
- (ii) What data and/or research are required to distinguish between important alternatives?
- (iii) How closely should model ecosystem behaviour match observations?
- (iv) What level of detail will be required to make a plausible model?

5.3 Examples of the above questions include consideration of:

- (i) various hypotheses on interactions between species (e.g. whales and seals)
- (ii) various hypotheses on trophic pathways
- (iii) use of different life-history parameter values (e.g. demographics)
- (iv) use of alternate component formulations.

5.4 With regard to questions of ecosystem dynamics, it was recognised that it was important to limit the number of scenarios to be explored. The possible scenarios were organised into a series of topics. These include:

- (i) Response of the model system to changes in environmental forcing factors. This would require a choice of forcing factors, the degree and direction of change. For example, the response of the model to gradual climatic change versus a more abrupt regime shift could be explored. More specific examples include system response to a change in formation of Antarctic bottom water or change in Antarctic surface circulation; rapid reduction of winter ice extent or large changes in primary production occurring over decadal time scales; enhanced ultraviolet radiation and its subsequent effect on epipelagic organisms such as krill larvae.
- (ii) Sensitivity and dynamics of the model system to various starting conditions and/or artificial forcing functions. For example, different starting population sizes of baleen whales and fur seals, or an initial excess krill production could be explored. The effects of random noise or periodic cycles in forcing functions could be explored.
- (iii) The effects on the model system of external processes and boundary conditions. Examples of this include processes affecting the population dynamics of whales, squid and birds outside the CCAMLR Convention Area. Another possible class of examples includes the invasion of temperate species due to ocean warming and/or changes in currents.

- (iv) The required behaviour of the model system to achieve a specified state. For example, recovery of depleted whale or seal populations.
- (v) Effects on the model system of developments in various fisheries. These might include expansion of the krill fishery, overfishing of toothfish, expanded harvest of icefish, as well as developments in fisheries external to CCAMLR.
- (vi) Effects of system feedback on modelled populations. Examples include changes over time in life-history traits, genetic selection, spatial distribution and other density-dependent population effects.

5.5 After some discussion, the workshop concluded that the following scenarios should be accorded the highest priority:

- (i) behaviour of the model system in response to artificial (i.e. known) forcing functions in order to better understand the properties of the model;
- (ii) effects of alternative formulations of krill transport on ecosystem dynamics;
- (iii) effects of climate change on primary production and/or ocean circulation.

5.6 The workshop also requested guidance from the Scientific Committee with regard to the priorities for exploring realistic scenarios and future work.

## MODEL FORMULATION AND SPECIFICATION

6.1 The workshop discussed a number of items that relate to the formulation and specification of ecosystem models in general (paragraphs 6.2 to 6.4) and to Antarctic ecosystems in particular (paragraphs 6.5 to 6.25).

6.2 The workshop agreed that it would be desirable to develop an ecosystem model as a set of connected modules rather than a single, large piece of software. Individual modules might be used to model various oceanographic processes (e.g. separate modules for ocean currents and the seasonal development of sea-ice) and the population dynamics of individual taxonomic groups (e.g. separate modules for Antarctic krill and fur seals). The modular approach described here would facilitate:

- (i) the development of population dynamics models that are consistent with the data and knowledge available for each taxonomic group (e.g. to simultaneously use an age-structured model for one group and a biomass-dynamics model for another group);
- (ii) the construction and implementation of modules that describe processes differently (e.g. comparing foraging models that are based on functional relationships or individual decision making);
- (iii) the construction and implementation of modules that describe alternative hypotheses (e.g. regional variations in krill biomass being determined by advection or local population dynamics);

- (iv) the implementation, where appropriate and helpful, of existing models;
- (v) the progress of model development regardless of whether modules describing the dynamics of all taxonomic groups or forcing mechanisms are complete.

6.3 Although a modular approach to model building has distinct advantages, the workshop recognised that such an approach would introduce specific technical issues that will need to be addressed. These issues include:

- (i) the need to reconcile processes that are modelled on different scales using accepted ecosystem structuring rules like thermodynamic laws and particle-size distributions;
- (ii) the need to manage overall model complexity by ensuring that individual modules are developed with reasonable intuition and a focus that relates to specific questions of interest;
- (iii) the need to develop protocols, software, and database architectures that link and manage the flow of information among modules.

6.4 The workshop recognised that linking modules describing oceanographic process and population dynamics to observation models will also be necessary. These links can be developed by ensuring that various modules within the operating model describe variation in state variables that are typically (or might eventually be) observed in the field. For example,

- (i) a module describing the dynamics of Antarctic krill should describe spatial variation in the distribution of swarms, concentrations etc. with sufficient detail to provide reasonable linkage to observation models describing hydroacoustic surveys and krill fisheries;
- (ii) modules describing the dynamics of some predator populations should describe variation in reproductive performance with sufficient detail to link to observation models describing data collection under CEMP;
- (iii) a module describing ocean currents might characterise variation in the contribution of different water masses to a region of particular interest and thereby link to observation models describing the results of an oceanographic survey within that region;
- (iv) modules describing the dynamics of fish populations might describe variation in the size (or age) composition of the population and thereby link to observation models describing the size (or age) composition of trawl survey or fishery catches.

#### Modelling interactions between species

6.5 Ecosystem models typically describe interactions between species and taxonomic groups in the context of predator–prey and competitive interactions (although many other

types of interactions are possible), and the manner in which such interactions are characterised typically has profound effects on the behaviour of, and predictions from, ecosystem models.

6.6 The workshop focused its discussion on predator–prey interactions, but recognised that competitive interactions should also be considered during future developments of Antarctic ecosystem models. In this regard, the workshop drew a distinction between competition that might occur within and among taxonomic groups and competition that might occur among krill predators and krill fisheries. The processes by which such competitive interactions might occur, if they occur at all, would potentially be different. In the first case, some animals might, for example, use aggressive behaviours to compete with other animals for food. In the second case, substantive localised removals of krill by a fishery might limit availability of food for predators. Developing appropriate models of competition will also be important for understanding the degree to which krill ‘surpluses’ caused by the removal of one predator can result in the expansion of another predator population.

6.7 The workshop summarised the predator–prey interactions described throughout Section 4 of this report by developing conceptual illustrations of various Antarctic food webs. These webs are presented in Figures 30 to 34. Each of the arrows illustrated in these figures represents a possible predator–prey interaction that might need to be modelled, and the workshop recognised that the interactions illustrated in these figures might increase or decrease after further review and consideration. The workshop further recognised that modelling all of the predator–prey interactions illustrated in these figures may not be necessary to describe how most energy flows through the food web. Care needs to be taken that the dynamics of any taxonomic group are not necessarily dominated by weak predator–prey links.

6.8 The easiest way to consider the trophic linkages is to subdivide them based on geographic location and central prey type. The workshop discriminated two major web-types based on geographical area: continental (including high-latitude seamounts) and island based (which includes the Scotia Sea). This split is also reflected in the respective taxonomic composition of these webs. The continental shelf webs are further subdivided into krill-centric and squid-centric subwebs. Similarly, the island-based webs are subdivided into krill-centric, squid-centric and fish-centric subwebs. The workshop was less confident in its ability to characterise the squid- and fish-centric subwebs than in its ability to characterise the krill-centric subwebs, and the group ‘other fish’ reflects a recognition that many predator groups probably consume a fish fauna that is less well described. Despite increased uncertainty regarding the structure of the squid- and fish-centric subwebs, it will be important to consider these alternative energy pathways because they are likely to have a marked effect on model predictions.

6.9 The age and size-dependent links included in the food webs illustrated in Figures 30 to 34 indicate two processes. The first is ontogenetic shifts in the spatial distributions of predator or prey. The second is when predators take only a certain size range of prey resulting in prey outside this range (either smaller or larger) being safe from that predator. If these food webs were redrawn with the life stages for each group explicitly represented, such age- and size-dependent links might be clearer.

6.10 Depth structuring is a potentially important aspect of the trophic links in Antarctic food webs that is not illustrated in Figures 30 to 34. The trophic structure shown in these

figures has greater resolution at the surface and in mid-water than in deep water. This is not an issue if the focus of the study and the dynamics of the ecosystem do not change. However, predictions by models developed from the links illustrated in Figures 30 to 34 may be misleading if the research and management focus or system dynamics become dominated by processes that occur in deep water (e.g. demersal or benthic groups and processes). It would be worthwhile to consider whether any of the ecological, environmental, or fisheries scenarios identified in Section 5 of this report would be affected by this potential problem.

6.11 With respect to Figures 30 to 34, the workshop also noted that some food webs which are not presented in this report (e.g. entirely pelagic webs or webs associated with deep seamounts like those in the Ross and Weddell Seas which are dominated by toothfish, rajids and oceanic squids) may need to be developed to completely represent the full range of major food webs in the Antarctic.

6.12 The workshop considered two methods of modelling predator–prey interactions: functional response curves and individual foraging models. Functional response curves describe the relationship between prey abundance (or density) and the per capita consumption of that prey by a group of predators. Individual foraging models describe predator–prey relationships by modelling the decisions that predators and prey make in response to the abundance (or density) and distribution of each other and to variations in environmental conditions.

6.13 It was agreed that both methods of describing predator–prey interactions should be investigated and the workshop commented on each approach.

6.14 Two types of functional response curves might be useful for describing many predator–prey interactions in Antarctic ecosystems: Type II and Type III response curves. These two types of curves are illustrated in Figure 35. For those predators whose foraging is based on interactions with individual prey organisms (e.g. a killer whale that forages on a seal), Type II response curves might be appropriate. For those predators whose foraging is based on interactions with prey organisms that must be aggregated into some threshold density (e.g. a baleen whale that forages on krill), Type III curves might be appropriate. When considering Type III curves, the workshop recognised that prey abundance (or density) might need to be measured on different scales. For example, foraging by baleen whales might be influenced more by the density of swarms within an area of relatively high krill concentration than by the density of krill within a swarm, but this might be reversed for other predators.

6.15 The workshop noted that a single functional response curve might not be appropriate for any given species or taxonomic group. Functional responses might change over the course of a reproductive cycle, be dependent on an animal's condition, age, or sex, and vary in response to the predator's perceived risk of themselves becoming prey. Although such refinements to functional response models will complicate this approach to modelling predator–prey interactions, they may be more realistic.

6.16 Foraging models based on individual decision making have previously been developed for penguins and krill fisheries (Alonzo and Mangel, 2001; Alonzo et al., 2003a, 2003b;

Mangel and Switzer, 1998). The predictions from this work were reviewed in WG-EMM-04/67, and the workshop considered that such models might, after additional review and modification, be useful dynamic modules to include in operational models of Antarctic ecosystems.

6.17 The workshop noted that multiple cues can be used by predators to make individual foraging decisions. These cues are not necessarily related to the absolute abundance or density of prey and probably include, but are not likely limited to, habitat features (e.g. the shelf break), previous experience (e.g. travelling back to the last location where prey were successfully captured and eaten) and variation in the local retention of prey. It might be particularly important to recognise when foraging decisions are based on group dynamics (e.g. when animals adopt foraging strategies like their neighbours or when they cue on aggregations of other predators).

6.18 The workshop noted that foraging models based on individual decision making are often generated from data collected during foraging trips, and some care should be taken in making inferences from these data. Animals that forage in the Antarctic adopt a variety of foraging strategies. As a result of these strategies, foraging events might be uniformly or randomly distributed in space and time. Alternatively, foraging events might be aggregated in space and time, and such aggregation might occur over a range of scales (e.g. at both diurnal and annual scales). For example, diving behaviours might occur in bouts when animals are foraging on shoaling/swarming species, and a single foraging trip might include several periods with and without dive bouts. Inferences from data collected during foraging trips can be facilitated by considering the physiological and ecological context in which the data were collected (e.g. time-energy budgets can be useful for understanding the foraging behaviour of animals that are provisioning offspring).

6.19 Unfortunately, data on foraging behaviours are not available for many species in the Antarctic, and this lack of information will make it difficult to construct decision-based models. The workshop noted that it may be possible to alleviate this problem by looking for information on analogous species outside the Antarctic.

6.20 In concluding its discussion of predator–prey interactions, the workshop agreed that two items of future work would be useful. First, sensitivity analyses should be done to explore how predictions from Antarctic ecosystem models change in response to different assumptions about predator–prey interactions (e.g. assuming a Type II or Type III functional response or assuming different decision criteria in individual-based foraging models) and to different ways of modelling these interactions (i.e. using functional response curves or individual (group) based foraging models). Second, studies should be done to determine whether, and under what conditions, functional response curves can be satisfactory approximations of individual-based foraging models. Although the latter approach may be more realistic, the former approach is likely to be more efficient in a modelling context.

## Modelling space

6.21 The workshop had considerable discussion regarding appropriate spatial resolution for operating models of Antarctic ecosystems. It was agreed that spatially explicit models would be appropriate in many circumstances. The workshop considered that, at a minimum, it

would be useful to resolve differences between high-Antarctic and sub-Antarctic areas and between pelagic areas and areas on or near the continental shelf (e.g. Figures 30 to 34). It was noted, however, that substantially greater spatial resolution might be appropriate in many instances. Cases in which greater spatial resolution might be warranted are identified throughout section 4 of this report.

6.22 The workshop recognised that spatial resolution can vary among the modules that are developed as components of operating models of the Antarctic ecosystem (i.e. a fixed spatial resolution is not required by the envisioned approach). It was also recognised that having module-specific spatial resolution would further increase the need to address the issues identified in paragraph 6.3. The workshop noted that modules with varying spatial resolution have successfully been implemented in the Atlantis and InVitro models (see section 2).

6.23 The workshop also considered the degree to which depth should be resolved in operating models of Antarctic ecosystems. In contrast to the minimum horizontal resolution identified in paragraph 6.21, the workshop did not identify a minimum vertical resolution. This was difficult because there is considerable overlap in the depths used by animals that spend time in Antarctic waters. Nevertheless, resolving processes across depths may be critical for describing the spatial overlap of predators and prey. Information on depth distributions is provided throughout section 4 of this report.

#### Modelling time

6.24 The workshop considered that the temporal resolution of the operating model should, at a minimum, discriminate summer from winter. Such discrimination is sensible for a variety of reasons, including the resolution of breeding/spawning seasons and seasons in which most observational data are collected. Finer temporal resolution might, however, be required to adequately describe the dynamics of various oceanographic processes and taxonomic groups. Thus, temporal resolution can also be module-specific, and the workshop reiterated the points that were raised in paragraph 6.22.

#### Peripheral processes and boundary conditions

6.25 The workshop discussed peripheral processes and boundary conditions in the context of animals that move in and out of the spatial arena described by operating models. How such processes and conditions are modelled must be case-specific because operating models of Antarctic ecosystems might cover a range of spatial arenas, potentially varying on scales from the entire CCAMLR Convention Area down to SSMUs. Nevertheless, the workshop noted that the key to dealing with such processes and conditions is to recognise:

- (i) how much time animals spend outside a model's spatial arena (e.g. see Tables 18 and 19);
- (ii) what processes (e.g. recruitment) occur when animals are outside the spatial arena;

- (iii) how both physical and biological conditions outside the spatial arena might contribute to variation in processes that ultimately occur inside the arena.

Dealing with peripheral processes and boundary conditions will require future work.

## FUTURE WORK

### Further development of plausible models

7.1 The workshop agreed that its work has achieved a foundation for conceptual models of the physical environment and taxa of the Southern Ocean ecosystem and how to place these into a modelling framework. It recognised that future work will entail validating the work presented here and further developing conceptual models as indicated in sections 4, 5 and 6. As such, the workshop recommended continued refinement of these conceptual models and encouraged their implementation in the modelling framework.

7.2 An important task is to collate the appropriate parameter values for implementing functions and model components derived from these conceptual models. In this respect, the workshop noted that reviews of available information would be useful and that a common database of available parameters could be developed to facilitate a coordinated use of such parameters and information.

7.3 The workshop also recognised that there was a lack of expertise and time at the meeting to fully develop the components concerned with fish, squid and fisheries. The workshop therefore requested WG-FSA to review the details provided and develop component details for toothfish and demersal species. These include:

- (i) check the existing details on icefish life history as listed in paragraphs 4.32 to 4.40 providing changes where appropriate;
- (ii) check that the existing details listed in paragraphs 4.95 to 4.100 have correctly captured the dynamics of the icefish fishery;
- (iii) check the existing details on mesopelagic fish and squid life history as listed in paragraphs 4.52 to 4.63, providing changes where appropriate;
- (iv) develop similar profiles (tables, figures and text) for *D. eleginoides* and *D. mawsoni* as target species (i.e. as for species in paragraphs 4.52 to 4.63);
- (v) develop similar profiles (tables, figures and text) for the *D. eleginoides* and *D. mawsoni* fisheries (i.e. as for fisheries in paragraphs 4.84 to 4.100);
- (vi) develop a new key component of the ecosystem which includes the other demersal fish species (e.g. macrourids, rajids, other nototheniids etc.);
- (vii) check food webs for interactions including toothfish, icefish, other demersal fish, myctophids and *Pleuragramma antarcticum*.

7.4 The workshop recommended that the Working Group seek guidance from the Scientific Committee with regard to the priorities for exploring realistic scenarios and future work (paragraph 5.6).

#### Further development of a modelling framework

7.5 The workshop agreed that it has provided a suitable framework to continue the development of plausible ecosystem models for testing approaches to krill management. It recognised that the development of complex models will take some time to complete.

7.6 With respect to next year's workshop on evaluating candidate management procedures, the workshop noted that initial exploration of management options could be achieved using spatially structured krill population models that allow exploration of the interaction between

- the krill population
- spatial catch limits and the fishery
- krill predators
- transport of krill.

This may be feasible next year with the further development of existing models and new basic models taking account of outcomes of this workshop.

7.7 The workshop noted that further development of the framework and the implementation of one or more ecosystem models will require coordinated work. It recommended that the Working Group consider establishing a steering committee to coordinate this work. Such a committee will need to consider, among other things,

- (i) framework
  - data, parameters, database
  - code, platforms, components, protocols
  - model architecture, modularity, flexibility
  - the process of validation of the models to ensure appropriate application;
- (ii) collaboration
  - timetable
  - authorship and ownership issues
  - components;
- (iii) role of the Secretariat;
- (iv) coordination with the conveners of next year's workshop.

7.8 The workshop noted that a number of research groups of CCAMLR Members are developing ecosystem models for the Southern Ocean. It recommended that the Working Group establish the steering committee as quickly as possible in order to have the work coordinated among groups as far as is practicable as well as taking advantage of the momentum generated from this workshop.

7.9 It was noted that the development of models for next year's workshop is a different task from the longer-term work. Nevertheless, it was recommended that the conveners of next year's workshop coordinate the preparatory work for the workshop with the coordinator of the steering committee. This will help provide the opportunity for modelling work for next year to be developed in such a way that it might contribute to the longer-term modelling work.

## ADOPTION OF THE REPORT

8.1 The report, with figures, tables and attachments, was adopted.

## CLOSE OF THE WORKSHOP

9.1 The Convener of WG-EMM, Dr Hewitt, thanked Dr Constable for his hard work in convening the workshop and his guidance throughout in ensuring its success.

9.2 Dr Constable thanked all the participants, rapporteurs and members of the workshop steering committee for their contributions to the workshop. He also thanked Dr Fulton, the invited expert, for her valuable contribution and for her guidance during the discussions. Dr Constable thanked the Secretariat for their support both intersessionally and at the workshop, and Prof. S. Focardi (Italy) and his team for hosting the workshop.

9.3 The workshop closed on 16 July 2004.

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Table 1: InVitro: Summary of the major agent types and behaviours that may be modelled in the InVitro Northwest Shelf (Australia) management strategy evaluation model. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Agent type	Description	Instances (species or groups)	Behaviours and characteristics
Population	Age-structured sub-populations of mobile species	Finfish (small and large lutjanids, lethrinids, nemipterids and saurids)	Ageing through age classes, growth, feeding, mortality, movement to preferable habitat, spawning and recruitment to age class zero.
Animal	Individuals or schools of mobile species	Prawns (banana and king prawns), turtles, sharks, dugongs, seabirds	Ageing, growth, mortality, feeding, evasion, movement to preferable habitat, spawning and recruitment of new individuals or schools.
Larva	Larval (or infant) and juvenile stages of other agent types	Finfish (small and large lutjanids, lethrinids, nemipterids and saurids)	Advection, settling, growth, mortality, consumption, movement to recruiting sites, recruitment.
Polyorganisms	Large patches (or mean field representations) of high turnover rate species or groups	Oyster leases, ponyfish schools	Movement, feeding, mortality, reproduction, advective and dispersive growth.
Benthic	Mosaic of habitat-defining patches	Macrophytes (seagrass and macroalgae), reefs (sponge and coral), mangroves	Mortality, depth and sediment-type dependent reproduction and patch growth (may be resource limited), vertical growth into larger size/age classes.
Vessel	Ore carriers	Cargo vessels	Route following, cargo content, fuel load, state (port operations, steaming, dithering).
Boat	Fishing vessels	Trawlers, trappers, fishing survey boats	Cargo content, fuel load, state (port operations, steaming, dithering), licences, past fishing sites, effort allocation, gear types.
Recfisher	Recreational fisher area of influence	Recreational fishers	Access points, fishing pressure (dependent on human population size and distance to port).
Catastrophe	Infrequent, large-scale events	Cyclones, spills, dredging	Damage (potentially fatal) to all appropriate agents in the path of impact (dependent on intensity and type of event).
Environment	Physical environmental characteristics	Temperature, light, depth, seabed type, currents	Current flow, advection, diffusion, absorption, erosion.
Tracker	Monitoring or sampling bodies	Buoy, monitoring sites, random samples of catch	Drift (if appropriate), monitoring.
Fixtures	Fixed locations	Ports, rigs, pipelines	Production, capacity, population size.
Fisheries management authority	Fisheries assessment and management body	FMA	Stock assessment, decision procedures, management rules, enforcement, monitoring.

(continued)

Table 1 (continued)

Agent type	Description	Instances (species or groups)	Behaviours and characteristics
Environmental protection agency	Water quality and contamination assessment and management body	EPA	Monitoring, decision procedures, management rules, enforcement.
Port Authority	Port capacity and vessel traffic assessment and management body	Department of Transport Department of Primary Industries	Monitoring, decision procedures, management rules, enforcement.

Table 2: List of taxa considered at the workshop (\* represents suitable future work). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

General grouping	Taxa		
Primary production	Phytoplankton	Microbial loop	
Pelagic herbivores and invertebrate carnivores	Microzooplankton * Copepods Euphausiids (excluding <i>E. superba</i> )	Mysids Amphipods	Salps Jellyfish *
Target species	<i>Euphausia superba</i> <i>Champocephalus gunnari</i>	<i>Dissostichus eleginoides</i> * <i>Dissostichus mawsoni</i> *	
Mesopelagic species	<i>Pleuragramma antarcticum</i> Myctophid species	Squid – ommastrephids Squid – onychoteuthids	Squid – other *
Demersal fish species *	Skates * Other demersal species	Rays *	<i>Macrourus</i> spp. *
Penguins	Adélie Chinstrap	Macaroni Gentoo	Emperor King
Seals	Antarctic fur Southern elephant	Crabeater Ross	Leopard Weddell
Baleen whales	Minke Humpback Other baleen whales – high latitudes	Southern right Fin Other baleen whales – sub-Antarctic	
Toothed whales	Sperm	Orca	Other small cetaceans
Large flying birds	Wandering albatross Light-mantled sooty albatross	Grey-headed albatross Black-browed albatross	Giant petrel
Small flying birds	White-chinned petrel Cape petrel Antarctic petrel	Snow petrel Diving petrel Storm petrel	Antarctic fulmar Antarctic prion Other prions
Other birds	Skuas, gulls etc.	Shags	

Table 3: Factors in the physical environment that are of potential importance in the operation of the Southern Ocean marine ecosystem and that would also be of considerable utility in a coupled ecosystem model; each factor has a set of properties and a set of motivating forces. Roman numerals in square brackets ([ ]) refer to the subparagraphs in paragraph 4.15 outlining the main ecological functions of the physical environment. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Factor	Properties	Motivating forces
Sea-ice [i, ii, iv]	Ice texture, e.g. brine channels Ice cover – aerial density Ice extent Ice duration	Temperature Salinity Wind stress Ocean currents Local geography
Ocean currents [i, ii, iii]	Magnitude (volume flow) Magnitude (spatial dimensions) Direction Eddies (variance) Fronts (dimensions)	Temperature Salinity Bathymetry Wind stress
Light [i]	Magnitude Duration – daily/seasonal Wavelength	Latitude Water column depth Ice cover Cloud cover Season
Nutrients [i]	Micronutrients (Fe etc.) Macronutrients (N, P etc.) Form (NH <sub>4</sub> , NO <sub>3</sub> etc.)	Distance from land Biological cycling
Bathymetry [ii]	Depth – pressure	

Table 4: Processes in the physical environment that are of potential importance in the operation of the Southern Ocean marine ecosystem and that would also be of considerable utility in a coupled ecosystem model; each process has a set of motivating forces. Roman numerals in square brackets ([ ]) refer to the subparagraphs in paragraph 4.15 outlining the main ecological functions of the physical environment. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Processes	Motivating forces
Vertical exchange in water column [ii, iii]	Upwelling/down-welling/mixing
Atmospheric deposition [i]	Wind Precipitation
Stratification [ii]	Wind Ocean currents
Ekman transport [ii]	Wind
Polynya formation [i, ii]	Upwelling Wind Ocean currents
Local processes [i, ii, iv]	Glacial rock flour Ice scour Land run off – rivers, nutrients, pollution
Nutrient depletion/enrichment [i]	Biological cycling Run off from predator breeding colonies
Climatic forcing [iv]	El Niño Southern Oscillation Antarctic Circumpolar Wave Drake Passage Oscillation Index
External boundaries [i, ii, iii, iv]	Land Water mass Atmosphere

Table 5: Potential variation in some physical factors between winter and summer seasons. Seasons may vary in time with latitude. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Seasonality		
Winter months April–November		Summer months December–March
Low	Temperature	High
High	Ice cover	Low
Low intensity	Light	High intensity
Short day	Day length	Long day
Higher at surface	Salinity	Lower at surface
Magnitude/breadth/shifts	Ocean currents	Magnitude/breadth/shifts
Change in patterns (latitude)	Wind	Change in patterns (latitude)

Table 6: Natural spatial divisions in the Southern Ocean that may affect the operation of the Southern Ocean marine ecosystem. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

NATURAL SPATIAL DIVISIONS	
Latitude	High ←-----→Low
Land	Continent vs Islands and peninsulas
Sea	Nearshore vs Shelf vs Slope vs High Sea vs Fronts Depth
Ice cover	Bottom ←-----→Surface Land vs Ice shelf vs Permanent ice vs Seasonal ice vs MIZ vs Never freezes

Table 7: Factors related to primary productivity that are of potential importance in the operation of the Southern Ocean marine ecosystem and that would also be of considerable utility in a coupled ecosystem model; each factor has a set of properties and a set of motivating forces. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Factor	Properties	Motivating forces	
Size fractionation	Species composition	Micronutrients (e.g. Fe)	Temperature
		Macronutrients (e.g. N, Si)	Salinity
		Distance from land	Light regime
		Water mass	Light wavelength
		Proximity to fronts	Ice cover
		Winds	Ice retreat
		Stratification	Grazers
Species distribution	Species composition	Micronutrients (e.g. Fe)	Temperature
		Macronutrients (e.g. N, Si)	Salinity
		Distance from land	Light regime
		Water mass	Light wavelength
		Proximity to fronts	Ice cover
		Winds	Ice retreat
		Stratification	Grazers

Table 8: Summary of attributes of the main pelagic invertebrate herbivores and carnivores in the Southern Ocean, excluding *Euphausia superba*. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Taxa	Habitat	Diet	Generation time (years)	Summer depth zone
Salps	Oceanic	Herbivore	0.5–1	Epipelagic
Copepods	Oceanic	Herbivore Carnivore Omnivore	0.5–1	Epipelagic
Mysids	Island shelf	Carnivore	2	Epibenthic
Hyperiid amphipods	Oceanic, Island shelf	Carnivore	1–2	Epipelagic
Euphausiids				
e.g. <i>Thysanoessa macrura</i>	Oceanic	Omnivore	2	Epipelagic
<i>Euphausia crystallorophias</i>	High-latitude shelf	Omnivore	2	Epipelagic

Table 9: Properties of *Champocephalus gunnari* for inclusion in the general structure of the Antarctic ecosystem model. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Parameter	Stage		
	Larvae	Juveniles	Adults
Geographic distribution		South Georgia to Antarctic Peninsula, Kerguelen/Heard	South Georgia to Antarctic Peninsula, Kerguelen/Heard
Spatial distribution	Features of the physical environment that are important to this life stage  Factors/functions influencing spatial coverage, including temporal changes to distribution	Pelagic in near-shore waters  Prey availability and oceanic variability likely to influence spatial coverage, but no relationships have yet been determined. Ontogenetic descent down slope influences temporal distribution.	Benthopelagic in shelf waters to about 350 m depth  Prey availability and oceanic variability likely to influence spatial coverage, but no relationships have yet been determined. Ontogenetic descent down slope influences temporal distribution.
	Depth Factors/functions influencing depth distribution, including temporal changes to distribution	0–150 m Gradually spreads over inner plateau in pelagic zone and occupies lower position in water column.	150–350 m Arrives at feeding grounds when about 2 years old. Diurnal vertical migrations from bottom during day into water column at night.
Age structure		0–2 years	2–5 years

(continued)

Table 9 (continued)

	Parameter	Stage		
		Larvae	Juveniles	Adults
Condition	Size		<240 mm	240–>350 mm
	Reproduction		Immature	Mature
Input	Reproduction		-	Generally autumn/winter spawners but spawning season varies with locality. Estimated total fecundity 1 294–31 045.
	Mortality		Highly variable juvenile population, which is a result of variable spawning success and juvenile survival.	Mortality probably relatively low in 2 and 3 year olds, then rising abruptly in 4 year olds. Few fish remain after 5 years.
Output	Predators		Larval stages probably prey for a wide range of planktonic (e.g. Chaetognaths) and nektonic (e.g. fish) predators, but no direct data. Later stages same as for adults.	Fur seals, king penguins are main predators but rate varies between years, depending on abundance of icefish and/or of krill. Other fish, birds and mammals prey on icefish to some extent.
	Exploitation		By-catch of trawl fisheries but rate limited by conservation measures.	Target of trawl fisheries.
	Death (other sources of mortality)		-	Rapid disappearance of 4+ year olds not attributable to fishing or completely top predation.
Consumption	Classification, e.g. generalist or specialist feeders		Specialist feeder on aggregating zooplankton.	Specialist feeder on aggregating zooplankton.
	Food types		Crustaceans (in particular euphausiids and amphipods). <i>Euphausia superba</i> in Atlantic sector.	Crustaceans (in particular euphausiids and amphipods). <i>E. superba</i> in Atlantic sector.

Table 10: Properties of *Euphausia superba* for inclusion in the general structure of the Antarctic ecosystem model. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

			Stage			
			Eggs	Larvae	Juveniles/Immatures	Adults
Spatial distribution	Features of the physical environment that are important to this life stage	Intrusion of upper CDW		Ice cover	Ice cover	Circulation
		Water depth		Intrusion of upper CDW	Water temperature	Water temperature
	Spatial extent of distribution	Water temperature		Water temperature	Position of frontal systems	Position of frontal systems
		Position of frontal systems		Position of frontal systems	Position of frontal systems	Position of frontal systems
	Spatial area of distribution	Water temperature		Water temperature	Water temperature	Water temperature
				Extent of water masses	Extent of water masses	Extent of water masses
	Factors/functions influencing spatial coverage, including temporal changes to distribution	Water mass intrusions		Sea-ice extent	Sea-ice extent	Sea-ice extent
			Advection		Extent of water masses	Extent of water masses
Displacement				Sea-ice extent	Sea-ice extent	Sea-ice extent
				Water mass intrusions	Water mass intrusions	Water mass intrusions
Depth (if applicable)	0–1 500 m		Advection	Advection	Advection	
			Displacement	Displacement	Displacement	
Factors/functions influencing depth distribution, including temporal changes to distribution	Spawning locations		Displacement	Displacement	Displacement	
		Developmental descent		<500 m	<500 m	<500 m
			Spawning locations	DVM with latitudinal and temporal changes (predator escapement – evolutionary or behavioural reaction)	DVM with latitudinal and temporal changes (predator escapement – evolutionary or behavioural reaction)	
			Developmental ascent	Ontogenetic migrations	Ontogenetic migrations	

(continued)

Table 10 (continued)

Condition	Size	Function or estimate of size for the stage (e.g. growth curve or set size)	Stage			
			Eggs	Larvae	Juveniles/Immatures	Adults
	Reproduction	Function relating, as appropriate, food availability (carrying capacity), environmental conditions, abundance of conspecifics and other competitors		Developmental pathway known, size at stage structure thought to be fixed (Ikeda, 1984). Effect of food supply and temperature (Ross et al., 1988; Yoshida et al., 2004).	Growth curves published (Ikeda, 1985; Hofmann and Lascara, 2000). Question of shrinkage. Age structure still problematic. Length/weight, seasonal differences (Siegel, 1992). Effect of food supply and temperature on growth.	Growth curves published (Rosenberg et al., 1985; Siegel, 1987; Hosie, 1988). Question of shrinkage (Ikeda and Dixon, 1982). Effect of food supply and temperature on growth.
	Health	Function relating, as appropriate, the effect of food consumption		After critical point larvae die.	Reduced food can lead to cessation of growth or shrinkage.	Reduced food can lead to cessation of growth or shrinkage.
	Waste	As appropriate, function defining the production of waste based on activity, consumption and environment		Excretion, defecation and moulting rates estimated (Quetin and Ross, 1991).	Excretion, defecation and moulting rates estimated (Ikeda and Thomas, 1987).	Excretion, defecation and moulting rates estimated (Ikeda and Mitchell, 1982; Clarke et al., 1988).

(continued)

Table 10 (continued)

Input			Stage			
			Eggs	Larvae	Juveniles/Immatures	Adults
	Reproduction	Function relating to reproductive condition, environment and abundance of breeding individuals, e.g. stock-recruitment relationship modified by condition, or fecundity modified by feeding condition.				See above
	Physical movement	Relative locations in space and rates of movement between locations, including movement over the course of a year.	Eggs spawned offshore	Larvae must move inshore as they metamorphose into juveniles.	Generally found inshore.	Distribution centred on shelf break, gravid females move offshore to spawn, all adults may move inshore in winter.
		Relative locations in depth and rates of movement between depths, including movement over the course of a year.	Eggs laid at surface, embryos sink	Early larvae swim upwards as they develop, later larvae stay in surface waters and probably under ice in winter.	Undergo DVM in summer.	Undergo DVM in summer. May vary between regions (daylight length?).

(continued)

Table 10 (continued)

			Stage			
			Eggs	Larvae	Juveniles/Immatures	Adults
Output	Predators	Identify predators, including, as appropriate, relative importance at different locations, depths and times.			Land-based predators restricted to foraging area, seabirds and pelagic predators less restricted in range.	Land-based predators restricted to foraging area, seabirds and pelagic predators less restricted in range.
	Exploitation	Identify, as appropriate, the degree of exploitation at different locations, depths and times and by which types of methods.				Along shelf break-slope, close to ice edge. In summer exploitation by midwater trawl at 20–80 m depth, in autumn 30–150 m depth and in winter ~400 m depth.
Consumption	Food types	Identify prey, including, as appropriate, relative importance at different locations, depths and times.		Phytoplankton, zooplankton and under ice microbial community. First feeding stage calyptopis, 30 days after spawning.	Most particles >5 µm in diameter in surface 200 m. In deeper water probably detrital food. Under-ice feeding in late winter.	Most particles >5 µm in diameter in surface 200 m. In deeper water probably detrital food. Under-ice feeding in late winter.
	Functional feeding relationships for different prey	Include, as appropriate, variations in the feeding relationships likely to be experienced in different locations, depths and/or times or influenced by environmental features (e.g. ice).			Maximum retention efficiency >30 µm. Functional response curves described for different food types and concentrations (Ross and Quetin, 2000).	Maximum retention efficiency >30 µm. Functional response curves described for different food types and concentrations (Quetin and Ross, 1985; Ross et al., 2000).

Table 11: Rationale and characterisation of elements for mesopelagic fish. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Element	Description	Dominant species	Questions/Issues
Sub-Antarctic shelf	Restricted to insular shelves of sub-Antarctic islands.	<i>Champscephalus gunnari</i>	May be equivalent to <i>C. gunnari</i> element. Question of whether it is important to consider taxa other than <i>C. gunnari</i> .
Sub-Antarctic mesopelagic	Broadly distributed in off-shelf pelagic environment north of the southern boundary of the ACC.	<i>Electrona carlsbergi</i> <i>Krefflichthys anderssoni</i>	Other species may be important depending on location. Is it necessary to include <i>Nototheniops larseni</i> ?
Antarctic neritic	Restricted to insular shelves of the Antarctic continent.	<i>Pleuragramma antarcticum</i> <i>Chaenodraco wilsoni</i>	Suggested as functional alternative to icefish for Antarctic continental shelf. Question of whether other taxa need to be considered.
Antarctic mesopelagic	Broadly distributed in off-shelf pelagic environment south of the southern boundary of the ACC.	<i>Electrona antarctica</i> <i>Gymnoscopelus nicholsi</i>	

Table 12: Properties of pelagic fish for inclusion in the general structure of the Antarctic ecosystem model. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

(a) Sub-Antarctic mesopelagic fish (e.g. *Electrona carlsbergi*, *Krefflichthys anderssoni*).

Geographic distribution		Circumpolar
Spatial distribution	Features of the physical environment that are important to this life stage	Broadly distributed in off-shelf pelagic environment north of the southern boundary of the ACC.
	Factors/functions influencing spatial coverage, including temporal changes to distribution	Spatial, seasonal and depth distribution influenced by water temperature/water mass. Main feeding grounds in the Polar Front. Greatest abundances associated with Polar Front.
	Depth	50–200 m depth in areas south of 50°S depending on DVM. Progressively deeper to the north of the Polar Front (500–600 m) towards the STC (>1 000 m).
	Factors/functions influencing depth distribution, including temporal changes to distribution	Water temperature/water masses (i.e. position of the Polar Front). DVM: migrates from 80–140 m to the surface at 18:00h. Found at 200–250 m during the day.
Age structure		Unknown, <5–6 years maximum age
Condition	Size	70–100 mm maximum size, growth thought to be approximately 30 mm per year for first 2–3 years.
	Reproduction	Size at maturity ~75mm Age at maturity ~2–3 years Serial spawning in late winter/early spring or summer/autumn to the north of the Polar Front.
Input	Reproduction	Suggest lognormal distribution with potential for correlation with environment.
	Mortality	-
Output	Predators	Primary: king, royal/macaroni, rockhopper and gentoo penguins, Antarctic fur seals depending on geographic location, squid (?), <i>Dissostichus eleginoides</i> . Secondary: <i>C. gunnari</i> at Heard Island and other fish species (?).
	Exploitation	Historical commercial trawl fishery.
	Death (other sources of mortality)	Unknown
Consumption	Classification, e.g. generalist or specialist feeders	Generalist (?)
	Food types	Principal components copepods with smaller amounts of hyperiids, euphausiids, pteropods and ostracods. Two main feeding periods: an extended evening period and a shorter morning period.

(continued)

Table 12 (continued)

(b) Antarctic neritic fish (e.g. *Pleuragramma antarcticum*, *Chaenodraco wilsoni*)

Geographic distribution		Circumpolar (?)
Spatial distribution	Features of the physical environment that are important to this life stage	Restricted to insular shelves of the Antarctic continent. Suggest that <i>P. antarcticum</i> may represent a functional alternative to <i>C. gunnari</i> for Antarctic continental shelf. Question of whether other taxa need to be considered.
	Factors/functions influencing spatial coverage, including temporal changes to distribution	-
	Depth	100–500 m
	Factors/functions influencing depth distribution, including temporal changes to distribution	DVM: yes 100 (night) to 200 m (day)
Age structure	maximum of 10 years	Unknown
Condition	Size	Adult size = 120–250 mm
	Reproduction	Mature at 3–4 years Spawning period October–December
Input	Reproduction	Suggest lognormal distribution with potential for correlation with environment.
	Mortality	-
Output	Predators	<i>D. mawsoni</i> , other fish, seals (?)
	Exploitation	Historical trawl fishery for <i>C. wilsoni</i> .
	Death (other sources of mortality)	Unknown
Consumption	Classification, e.g. generalist or specialist feeders	Generalist zooplankton feeder (?)
	Food types	<i>E. superba</i> (?), other krill (?), copepods (?)

(continued)

Table 12 (continued)

(c) Antarctic mesopelagic fish (e.g. *Electrona antarctica*, *Gymnoscopelus nicholsi*).

Geographic distribution		Circumpolar
Spatial distribution	<p>Features of the physical environment that are important to this life stage</p> <p>Factors/functions influencing spatial coverage, including temporal changes to distribution</p> <p>Depth</p> <p>Factors/functions influencing depth distribution, including temporal changes to distribution</p>	<p>Abundant south of the Polar Front to the shelf of the continental slope.</p> <p>Concentrated along shelf and the Polar Front during spring–summer.</p> <p>Upper 250 m during spring and summer, 350–700 m during winter.</p> <p>Suggested that there is a seasonal pattern of: (i) concentration in surface 100–200 m at shelf break, or Polar Front during spring and summer; (ii) movement to deeper water (350–700 m) in winter.</p> <p>Suggested that the seasonal movement is in response to movement of invertebrate food sources.</p>
Age structure	Maximum of 5–6 years	Unknown
Condition	Size	<p>Size range of species (<i>E. antarctica</i>, <i>G. nicholsi</i>) 100–200 mm TL with <i>G. nicholsi</i> being at the upper end of the range.</p> <p>15–51 g</p> <p>&lt;5 years</p> <p>Growth rate 27–34 mm per year</p> <p>May be worth considering having two classes based on size and maturity.</p>
Input	<p>Reproduction</p> <p>Reproduction</p>	<p>Winter spawners</p> <p>Suggest lognormal distribution with potential for correlation with environment.</p>
Output	<p>Mortality</p> <p>Predators</p>	<p>-</p> <p>Primary: king penguin, Antarctic fur seals.</p> <p>Secondary: royal/macaroni and gentoo penguins, Antarctic fur seals, black-browed and grey-headed albatrosses, white-chinned and snow petrels, <i>D. eleginoides</i>, cormorants at Heard Island.</p>
Consumption	<p>Exploitation</p> <p>Death (other sources of mortality)</p> <p>Classification, e.g. generalist or specialist feeders</p> <p>Food types</p>	<p>Historical trawl fishery</p> <p>Generalist</p> <p>Feeds on any abundant organisms, principally copepods and euphausiids, but also includes amphipods, pteropods, ostracods. Proportion of euphausiids increases in larger fish.</p>

Table 13: Properties of the five elements of squid for inclusion in the general structure of the Antarctic ecosystem model. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

(a) Onychoteuthid squid

		Juveniles	Adults
Geographic distribution		Circumpolar in the sub-Antarctic and Antarctic.	Circumpolar in the sub-Antarctic and Antarctic.
Spatial distribution	Features of the physical environment that are important to this life stage	Shelves and slopes of landmasses in the sub-Antarctic and Antarctic.	Slopes of landmasses in the sub-Antarctic and Antarctic.
	Spatial extent or area of distribution	Shelf/slope (see above)	Slope (see above)
	Factors/functions influencing spatial coverage, including temporal changes to distribution	Prey availability and oceanic variability likely to influence spatial coverage, but no relationships have yet been determined. Ontogenetic descent down slope influences temporal distribution.	Prey availability and oceanic variability likely to influence spatial coverage, but no relationships have yet been determined. Ontogenetic descent down slope influences temporal distribution.
	Depth (if applicable)	0–1 000 m	400 – $\geq$ 2 000 m
	Factors/functions influencing depth distribution, including temporal changes to distribution	Undergoes ontogenetic descent down slope over time with increasing size/maturation. Diurnal vertical migrations have not been recorded. Clarify whether DVM occur in other species (e.g. Rodhouse and Clarke, 1986), and/or include as an alternative to no DVM.	Undergoes ontogenetic descent down slope over time with increasing size/maturation. Diurnal vertical migrations have not been recorded.
	Does pack-ice affect distribution?	Distribution includes pack-ice zone; relationship with pack-ice extent and retreat unknown.	Distribution includes pack-ice zone; relationship with pack-ice extent and retreat unknown.
Age structure (if applicable)		-	-
Units		Biomass	Biomass
Condition	Size	See WG-EMM-04/26, Figure 8	See WG-EMM-04/26, Figure 8
	Reproduction	-	-
	Health	-	-
	Waste	-	-

(continued)

Table 13(a) (continued)

		Juveniles	Adults
Input	Reproduction	-	Two spawning peaks per year (late summer and late winter). Estimated total fecundity (i.e. ovarian egg number estimates) for <i>Moroteuthis ingens</i> : 84 379–286 795.
	Physical movement	Ontogenetic descent down slope over course of life stage.	Ontogenetic descent down slope over course of life stage.
	Movement between life stages	All juveniles (minus those lost to predation, by-catch and natural mortality) move into adult life stage after 6–7 months (approximately 200 days).	100% natural mortality of all adults (minus those lost to predation and by-catch) after approximately 1 year. Possibility of two-year life-cycle for some species of Antarctic squid (see Ommastrephids below)
Output	Predators	Cephalopod and vertebrate predators foraging in epipelagic and upper mesopelagic in shelf/slope environments from the sub-Antarctic to the Antarctic.	Cephalopod and vertebrate predators foraging in the mesopelagic and bathypelagic in slope environments from the sub-Antarctic to the Antarctic.
	Exploitation	By-catch of trawl fisheries in shelf/slope environments.	By-catch of trawl fisheries in shelf/slope environments.
	Death (other sources of mortality)	-	-
Consumption	Classification, e.g. generalist or specialist feeders Food types	Opportunistic, generalist predator. Crustaceans (in particular euphausiids, also amphipods and copepods), small cephalopods and juvenile fish. Important to consider potential for higher predation (via cannibalism) on second cohort by first cohort within a season and, in the case of a two-year life-cycle, one year class on the following year class.	Opportunistic, generalist predator. Myctophids, other mesopelagic fish, e.g. <i>Bathylagus antarcticus</i> , cephalopods including juvenile onychoteuthids.

(continued)

Table 13(a) (continued)

		Juveniles	Adults
Consumption (continued)	Functional feeding relationships for different prey	Minimum prey size >10 mm; maximum prey size <200 mm. Will only take pelagic, mobile prey.	Minimum prey size >10 mm; maximum prey size = approx. size of the (mantle length? of) individual squid. Will only take pelagic, mobile prey.
(b) Ommastrephid squid			
Geographic distribution			Circumpolar in the sub-Antarctic and Antarctic but not high Antarctic.
Spatial distribution	Features of the physical environment that are important to this life stage	Shelves	Shelves (for spawning) and slopes of landmasses and in the open ocean for feeding.
	Spatial extent or area of distribution	In the southwest Atlantic juvenile distribution is largely outside the area (Patagonian shelf). Distribution outside the southwest Atlantic not known/uncertain.	Large proportion of biomass associated with the Polar Front.
	Factors/functions influencing spatial coverage, including temporal changes to distribution	Spawning occurs on the (Patagonian) shelf where juveniles develop.	Feeding and spawning migrations influence spatial distribution. Aggregations often associated with oceanic frontal systems. Distribution varies significantly over time and space.
	Depth (if applicable)	0–200 m	0–≥ several hundred metres.
	Factors/functions influencing depth distribution, including temporal changes to distribution	DVM on shelf	Diurnal vertical migrations to approach surface during darkness.
	Does pack-ice affect distribution?	No, because juveniles occur elsewhere.	Not known to be distributed in the high Antarctic, pack-ice unlikely to affect distribution.
Age structure (if applicable)			-
Units		Biomass	Biomass

(continued)

Table 13(b) (continued)

Condition	Size	Juveniles	Adults
			See WG-EMM-04/26, Figure 9
	Reproduction	-	-
	Health	?	-
	Waste	?	-
Input	Reproduction	Spawns throughout the year, potential fecundity per individual female estimated at 115 000–560 000 (from ovarian egg number estimates).	Incoming juveniles, minus consumption.
	Physical movement	Juveniles passively migrate with current systems away from spawning grounds to feed.	Adult population actively migrates to spawning ground to spawn, which in the southwest Atlantic is the Patagonian shelf.
	Movement between life stages	Size-based progression between juvenile and adult.	Die/consumed
Output	Predators		Cephalopod and vertebrate predators foraging in epipelagic and upper mesopelagic in shelf/slope environments and in the open ocean. Total predation in the Scotia Sea estimated at 326 000–381 000 tonnes per year.
	Exploitation	-	By-catch of other squid jig fisheries around Falkland/Malvinas Islands and on Patagonian shelf, is occasionally a direct target for commercial jiggers in Subarea 48.3.
	Death (other sources of mortality)		100% natural mortality of remaining adult population after spawning.
Consumption	Classification, e.g. generalist or specialist feeders	Opportunistic, generalist predator.	Opportunistic, generalist predator.

(continued)

Table 13(b) (continued)

		Juveniles	Adults
Consumption (continued)	Food types	?? assume smaller zooplankton and larval fish, conspecifics.	Myctophids (particularly <i>Krefflichthys anderssoni</i> ), cephalopods including cannibalism on conspecifics, crustaceans including <i>E. superba</i> and amphipod <i>T. gaudichaudii</i> .
	Functional feeding relationships for different prey	Will only take pelagic, mobile prey. An individual squid may take prey as large as itself while continuing to take smaller prey??	Will only take pelagic, mobile prey. An individual squid may take prey as large as itself while continuing to take smaller prey.
(c) Small to medium nektonic squid			
Geographic distribution		Uninterrupted circumpolar distribution throughout the sub-Antarctic and Antarctic.	
Spatial distribution	Features of the physical environment that are important to this life stage	Shelves and slopes of landmasses and in the open ocean from the sub-Antarctic to the high Antarctic. Ubiquitous distribution throughout.	
	Spatial extent or area of distribution	See above	
	Factors/functions influencing spatial coverage, including temporal changes to distribution	Until further data are available, the spatial coverage of this model group should remain static throughout the sub-Antarctic to the high Antarctic. (For species-specific differences see WG-EMM-04/26, Figure 8.)	
	Depth (if applicable) Factors/functions influencing depth distribution, including temporal changes to distribution	0 – ≥ 2 000 m Until further data are available, the depth distribution of this model group should remain static throughout the sub-Antarctic to the high Antarctic. (For species-specific differences see WG-EMM-04/26, Figure 8.)	
	Does pack-ice affect distribution?	Distributed within pack-ice zone, pack-ice not known to affect distribution.	
Age structure (if applicable)		-	
Units		Biomass	
Condition	Size	See WG-EMM-04/26, Figure 1	
	Reproduction	-	
	Health	-	
	Waste	-	
Input	Reproduction	Spawns throughout the year, on shelf breaks/slopes in the sub-Antarctic and high Antarctic and in the open ocean.	
	Physical movement	-	
	Movement between life stages	-	

(continued)

Table 13(c) (continued)

Output	Predators	Important dietary component for many vertebrate predators in the southwest Atlantic; ≥ 3 squid species co-occur in the diets of 11 predators including penguins, albatrosses, seals, whales and fish. Also preyed on by other cephalopods.
	Exploitation	Occasional by-catch, discarded.
	Death (other sources of mortality)	100% natural mortality of remaining adult population after spawning.
Consumption	Classification, e.g. generalist or specialist feeders	Opportunistic, generalist predators.
	Food types	Small mesopelagic fish, small cephalopods, zooplankton including euphausiids, copepods and amphipod <i>T. gaudichaudii</i> .
	Functional feeding relationships for different prey	Will only take pelagic, mobile prey. An individual squid may take prey as large as itself while continuing to take smaller prey.

Table 14: Possible transition matrix for Adélie penguins. Numbers refer to functions and discussion in the text. (X represents a transition probability; Time represents the amount of time spent in the stage on the left; Function represents the ecological or physical function that results in the transition probability.) Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

	Fledgling	Pre-breeder (Itinerant)	Pre-breeder (Colony)	Non-breeder (Itinerant)	Non-breeder (Colony)	Breeder
Chick	X Time: Function:					
Fledgling		X Time: 1 year Function: 1	X Time: 1 year Function: 1			
Pre-breeder (Itinerant)		X Time: Function:	X Time: Function:			X Time: 3–5 winters Function: 2, 3
Pre-breeder (Colony)		X Time: Function:	X Time: Function:			X Time: 3–5 winters Function: 2, 3
Non-breeder (Itinerant)				X Time: annual Function:	X Time: annual Function:	X Time: annual Function:
Non-breeder (Colony)					X Time: annual Function:	X Time: annual Function:
Breeder					X Time: annual Function:	X Time: annual Function:

Table 15: Potential transition matrix categories for other taxa of marine mammals and birds. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Albatrosses and large petrels	Small petrels	Antarctic fur seals	Pack-ice seals (crabeater, Ross and leopard seals)	Weddell seals	Southern elephant seals	Baleen whales	Toothed whales
Chick	Chick	Pup	Pup	Pup	Pup	Calves	Calves
Fledgling	Fledgling	Juvenile	Juvenile	Juvenile	Juvenile	Juvenile	Juvenile
Juvenile	Juvenile	Sub-adult male	Non-breeder	Non-breeder	Sub-adult male	Non-breeder	Non-breeder
Breeder	Breeder	Non-breeder male	Breeder	Breeder	Non-breeder male	Breeder	Breeder
Failed breeder	Failed breeder	Breeder male			Breeder male		
Non-breeder	Non-breeder	Breeder female			Breeder female		
		Failed breeder female			Failed breeder female		

Table 16: Classification of components of the diet of seabirds and marine mammals. [ ] show general guide but these will need to be refined further. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Diet category	Level of classification	
Copepod	[large, small]	
Amphipod	Themisto, other	
Mysids	[taxon]	
Krill	[sex, status, size]	
Squid	[large, small; alive, dead]	Onychoteuthid Ommastrephid Other
Fish	[adult, juvenile]	Toothfish Icefish Myctophid Other [large, small]
Carrion	[taxon]	
Birds	[taxon]	
Marine mammals	[taxon]	

Table 17: Qualitative analysis of prey of marine mammals and birds in the Atlantic sector of the Southern Ocean. Predators are listed in the left column. Other columns represent prey groups based on the classification in Table 4.16. The number of X's corresponds to potential importance of prey. (X) means present occasionally. L – large, S – small. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

	Copepods	Amphipods	Krill	Squid		Icefish	Myctophids	Other fish		Carrion	Seals	Seabirds
				S/live	L/dead			L	S			
Large flying birds												
Wandering albatross					XX			X		XX		
Light-mantled sooty albatross				X	X			X		X		(X)
Grey-headed albatross			X	XX			X					
Black-browed albatross			XX	X			X			X		
Giant petrel			X		X					XXX		X
Small flying birds												
White-chinned petrel			XX	XX			XX		X			
Antarctic prion	XX	X	XX									
Cape petrel			XX				X	XX				
Antarctic fulmar			XX	X				X				
Antarctic petrel			XX	X				X				
Snow petrel			XX					X				
Diving petrel	XX	X	XX									
Storm petrel	XX	X	X				X					
Penguins												
King				X			XXX					
Emperor			X	X				XXX				
Gentoo			XX			XX		X	X			
Adélie/chinstrap			XXX				X					
Macaroni		X	XXX									
Marine mammals												
Whales:												
Baleen			XXX									
Toothed				XX				XX				
Sperm				XXX								
Killer								X			XXX	
Seals												
Fur			XXX			XX	X		X			
Crabeater			XXX									
Weddell				XX				XXX				
Leopard			XX					XX			XX	
Ross				XX	X			XX				
Elephant				XX	XX			XX				







Table 19: Foraging locations for marine mammals and birds during the respective non-breeding seasons (see Table 18 for explanation of abbreviations). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Group	Taxon	Life stage	Part of year/ breeding cycle	Sea-ice				Coastal current			Antarctic Circumpolar Current													
								S	SB	O	Antarctic Zone					Polar Frontal Zone					Sub-Antarctic Zone			
				Polynya	Pack	MIZ	Off-MIZ				SACCB	SACCF	S	SB	O	PF	SAF	S	SB	O	STF	S	SB	O
Large flying birds	Wandering albatross	Adult	Sabbatical												X			X	X				X	X
	Light-mantled sooty albatross	Adult	Winter				X								X				X					
	Grey-headed albatross	Adult	Sabbatical												X	X			X	X		X		X
	Black-browed albatross	Adult	Winter																X		X			
	Giant petrel	Adult	Winter														X		X			X		X
Small flying birds	White-chinned petrel	Adult	Winter												X	X			X			X	X	X
	Antarctic prion	Adult	Winter														X	X						
	Other prions	Adult	Winter												X	X			X					
	Cape petrel	Adult	Winter				X								X	X	X	X	X			X	X	X
	Antarctic fulmar	Adult	Winter				X								X	X	X	X	X			X	X	X
	Antarctic petrel	Adult	Winter	X		X	X												X					
	Snow petrel	Adult	Winter	X		X	X												X					
	Diving petrel	Adult	Winter														X	X	X					
Storm petrel	Adult	Winter										X					X	X	X		X	X	X	X
Penguins	Adélie	Adult	Winter		X	X		X	X	X														
	Chinstrap	Adult	Winter			X	X	X	X	X	X				X	X								
	Gentoo	Adult	Winter	X			X	X				X												
	Macaroni	Adult	Winter												X	X			X					
	King Emperor	Adult	Sabbatical Winter		X										X	X			X					

(continued)



Table 20: Seasonal succession of reasons to decide on fishing locations by skippers across months in Subareas 48.1, 48.2 and 48.3 (WG-EMM-04/51). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

		Reasons for the decision					
	Month	Density	Change in krill size	Krill too green	Too many salps	Ice conditions	Transshipping
South	December	16	0	1	0	0	0
Shetland	January	34	2	14	1	0	3
Islands	February	19	2	9	5	0	0
Subarea	March	37	1	6	2	0	2
48.1	April	46	4	4	0	0	2
	May	32	2	0	0	4	1
	June	10	1	0	0	2	0
	July	5	0	0	0	2	1
South	December	3	0	2	0	0	0
Orkney	January	0	0	2	0	0	1
Islands	February	2	0	1	0	1	0
Subarea	March	7	0	1	0	2	0
48.2	April	4	1	1	0	0	0
	May	3	1	0	0	3	0
	June	4	1	0	0	7	0
South	May	1	0	0	0	0	0
Georgia	June	4	0	0	0	0	0
Subarea	July	0	0	0	0	0	0
48.3	August	1	1	0	0	0	0
	September	3	0	0	0	0	0

Table 21: Properties of the krill fishery. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Taxa	<p>Krill fishing vessels in general</p> <p>Nations</p> <p>Fleets</p> <p>Individual vessels</p> <p>Vessel size</p> <p>Factory type (products)</p> <p>Factory capacity (raw krill basis)</p> <p>Type of gear</p>
Stage	Learning, established
Units	Numbers (vessel), number of hauls (effort), catch (tonnes), length of operation (days, hours)
Fishing ground formation	<p>Relation to environmental features</p> <ul style="list-style-type: none"> <li>• ice edge</li> <li>• bottom topography (distance relative to the shelf edge)</li> <li>• hydrodynamic characteristics of the area → complex currents around islands together with topographically induced effects;</li> <li>• krill flux, krill spatial distribution pattern</li> </ul> <p>Area 48 fishing areas</p> <p>South Georgia, South Orkney Islands, Elephant Island, King George and Livingston Islands, Antarctic Peninsula</p> <p>and within these fishing areas, there are several local fishing grounds</p>
Decision making	<p>Skippers</p> <p>Based on experience and accumulation of information (biological, environmental, regulation, physical, logistics)</p> <p>Company (market demand, price, remaining stocks, economy, logistics)</p>
Factors affecting behaviour	<p>Physical aspects</p> <ul style="list-style-type: none"> <li>• Non-seasonal → bottom topography (depth and space)</li> <li>• Seasonal → weather</li> </ul> <p>Biological</p> <ul style="list-style-type: none"> <li>• Krill → distribution, colour (green, red/white), size, maturity, aggregation size, type</li> <li>• Other species → salp, fish, predators</li> </ul> <p>Communication with other vessels, or monitoring</p> <p>Logistics → cargo transfer, emergencies</p>

Table 22: Properties of icefish fishery. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

Taxa	Icefish fishing vessels in general Nations Fleets Individual vessels Vessel size Factory type (products) Type of gear
Stage	Learning, established
Units	Numbers (vessel), number of hauls (effort), catch (tonnes), length of operation (days, hours)
Fishing ground formation	Relation to environmental features bottom topography (shelf area) Biological features aggregation Area 48 fishing area Subarea 48.3 Area 58 fishing area Divisions 58.5.1 and 58.5.2
Decision making	Skippers Based on experience and accumulation of information (Biological, environmental, regulation, physical, logistics) Company (market demand, price, remaining stocks, economy, logistics)
Factors affecting behaviour	Physical aspects <ul style="list-style-type: none"> <li>• Non-seasonal → bottom topography (depth and space)</li> <li>• Seasonal → ice, weather</li> </ul> Biological <ul style="list-style-type: none"> <li>• Icefish → distribution, size, maturity</li> <li>• Aggregation → size, type</li> <li>• Other species → by-catch species</li> </ul> Communication with other vessels, or monitoring Logistics → cargo transfer, emergencies Regulations → temporal spatial closure, minimum size, by-catch.

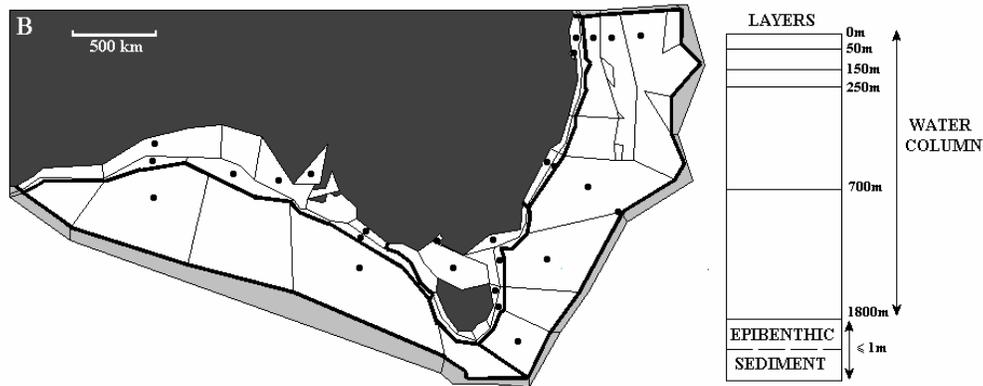


Figure 1: Example of the horizontal and vertical spatial geometries used to define an ecosystem in Atlantis. Vertically, if the depth of the polygon is less than the maximum vertical depth, the water column layer(s) are truncated to match (e.g. a box in B that is 100 m deep would have 2 x 50 m water column layers). Any open ocean cells in B that are >1 800 m deep have no epibenthic or sediment layers, and are treated as having an open boundary under the deepest water column layer. Note that fine black lines indicate the boundaries of model boxes, thick black lines mark the edges of management zones, and sampling locations (used in the observation model) are indicated by black dots (reproduced from Fulton et al., in press). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

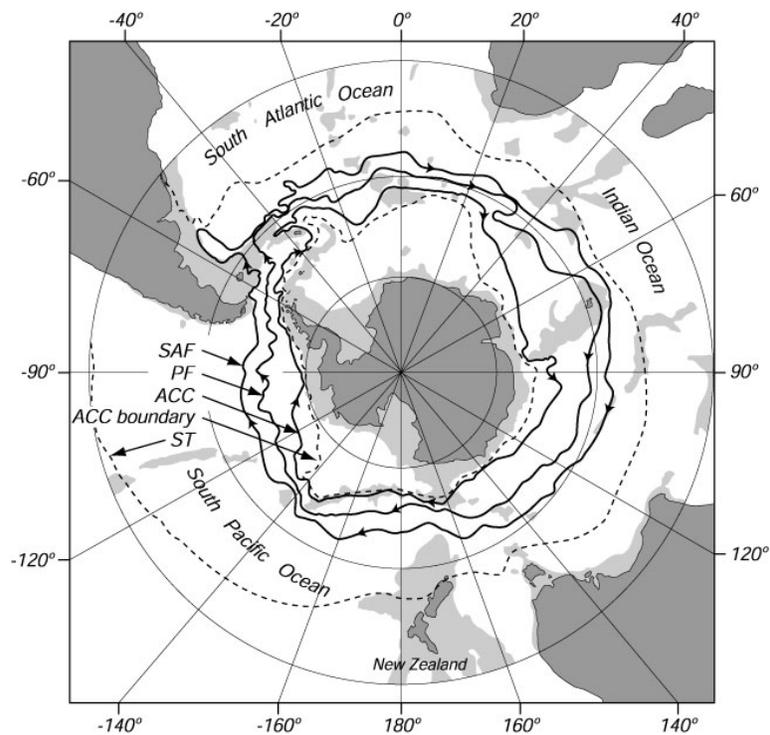


Figure 2: Main frontal features in the Southern Ocean (Orsi et al., 1995) and the CCAMLR boundaries (figure obtained from [http://oceanworld.tamu.edu/resources/ocng\\_textbook/chapter13/Images/Fig13-13.htm](http://oceanworld.tamu.edu/resources/ocng_textbook/chapter13/Images/Fig13-13.htm)). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

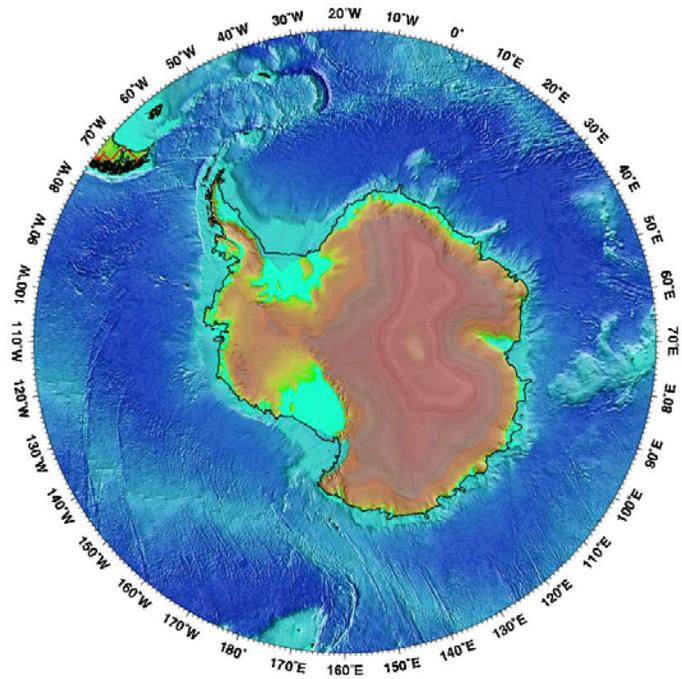


Figure 3: Main topographic features of the Southern Ocean (figure obtained from [http://oceancurrents.rsmas.miami.edu/southern/img\\_topo2/antarctic-coastal2.jpg](http://oceancurrents.rsmas.miami.edu/southern/img_topo2/antarctic-coastal2.jpg)). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

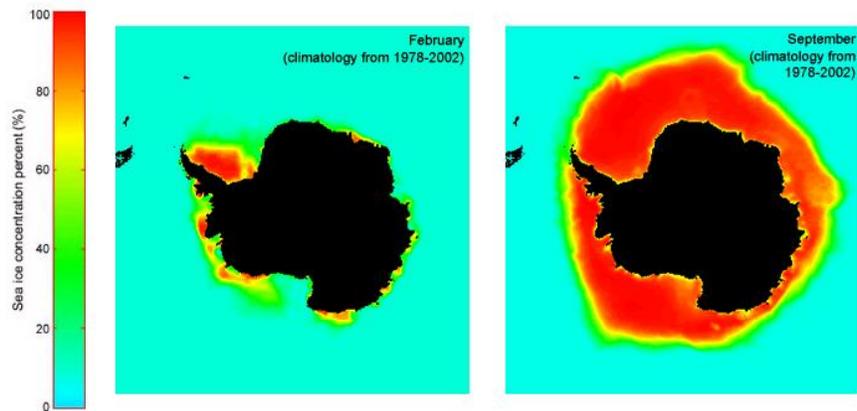


Figure 4: Seasonal extent of pack-ice around Antarctica in summer and winter (figures obtained from [http://nsidc.org/sotc/sea\\_ice.html](http://nsidc.org/sotc/sea_ice.html)). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

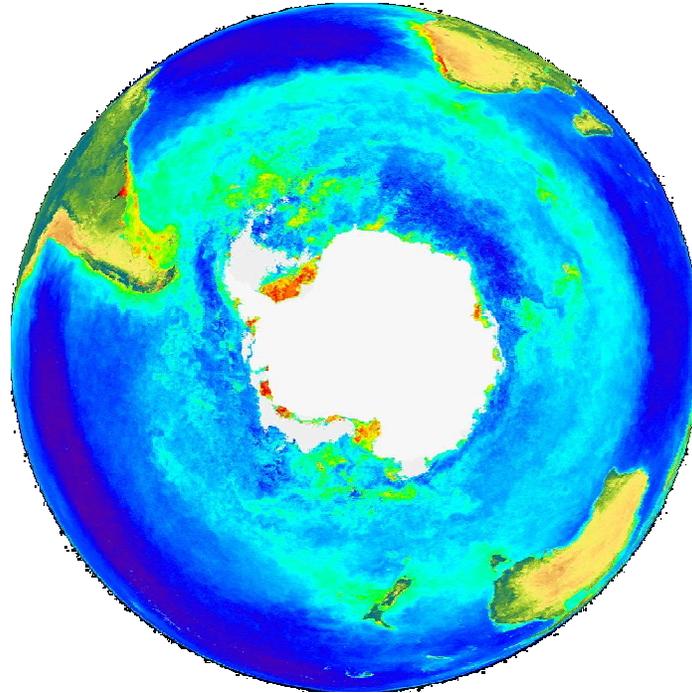


Figure 5: Average chlorophyll distribution in the polar region from SeaWiFS September 1997–July 1998 (figures obtained from <http://seawifs.gsfc.nasa.gov/SEAWIFS.html>). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

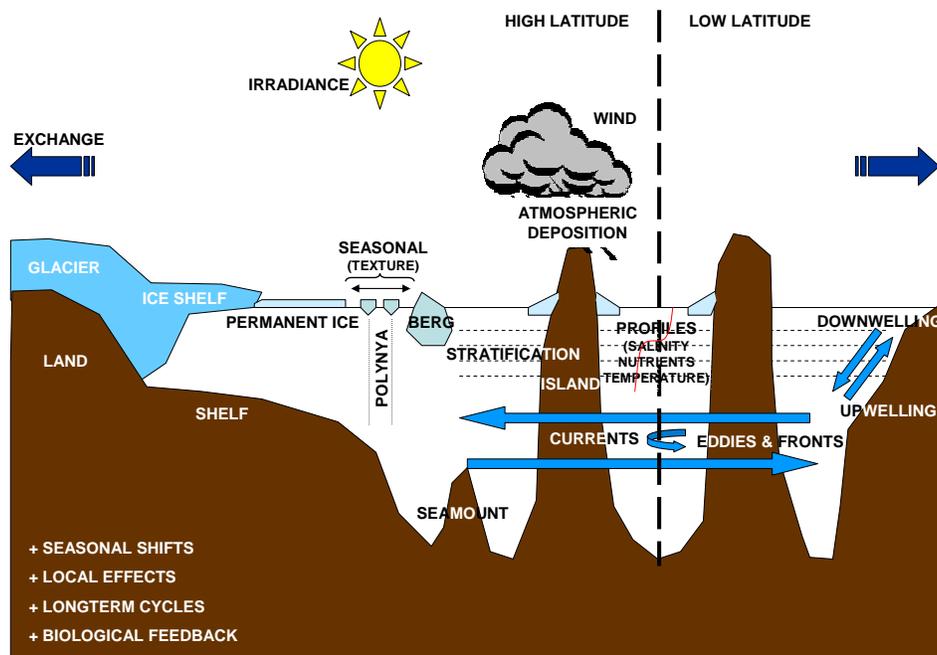


Figure 6: Conceptual diagram of major physical factors and processes affecting the Southern Ocean marine ecosystem. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

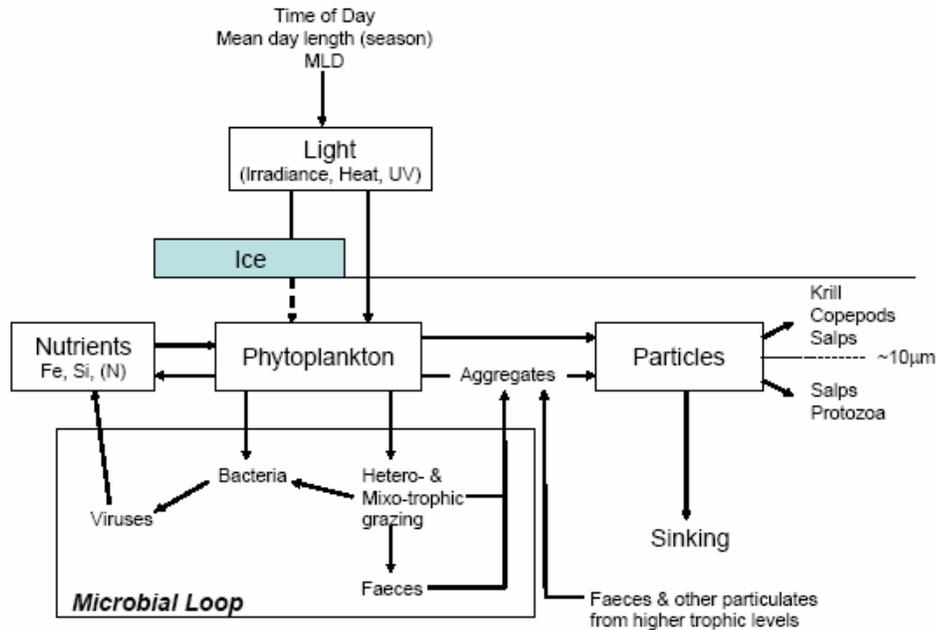


Figure 7: Conceptual model of the important linkages influencing production of particulates used as food by zooplankton. MLD – mixed layer depth. Note that Dissolved Organic Matter (DOM) is a waste product from all organisms, and DOM and Particulate Organic Matter are an important source of carbon in winter (from WG-EMM-04/24). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

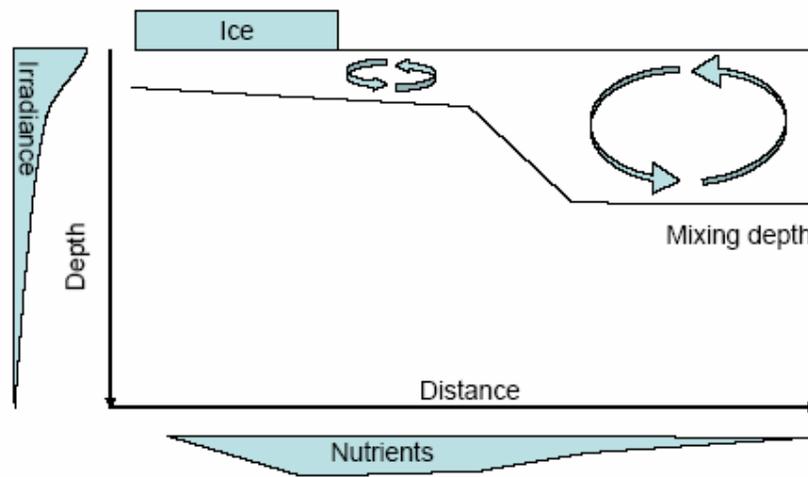


Figure 8: Diagrammatic representation of how the spatial characteristics of the environment might influence primary production in the ice-edge region. Arrows indicate possible mixing. The width of the shapes surrounding nutrients and irradiance indicate the quantities that might be available to phytoplankton given proximity to ice and the depth of the mixing layer (from WG-EMM-04/24). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

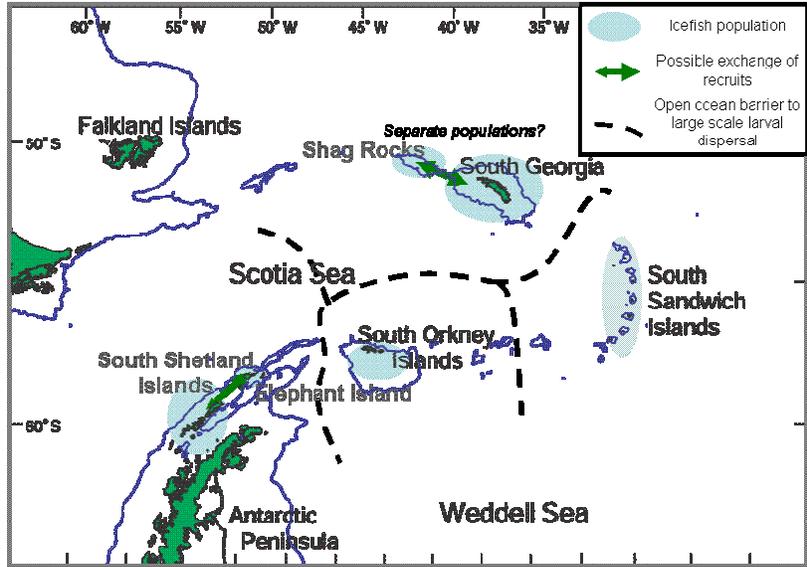


Figure 9: Conceptual model of the distribution of *Champscephalus gunnari* in the southwest Atlantic. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

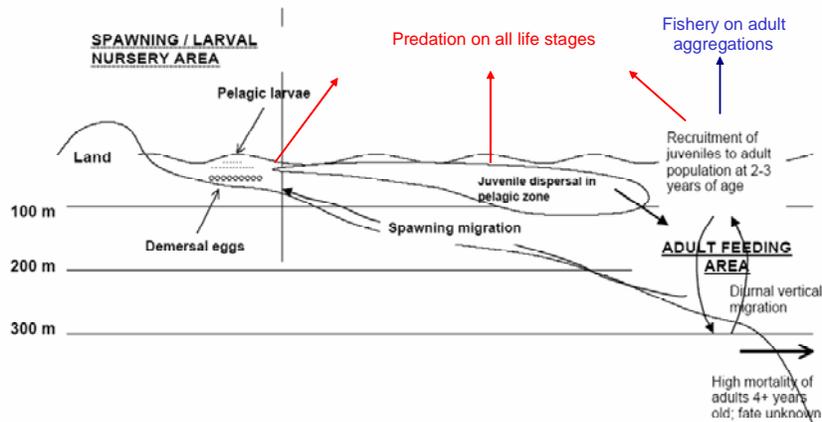


Figure 10: Summary of life history of *Champscephalus gunnari* (modified from WG-EMM-04/59). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

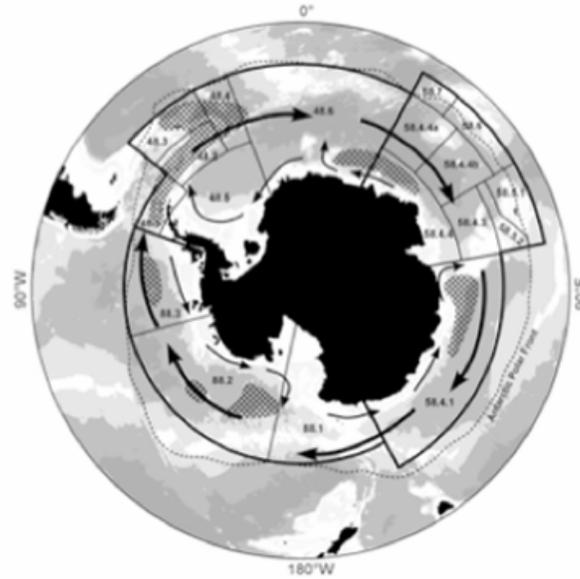


Figure 11: Antarctic Polar Front, CCAMLR boundaries, FAO statistical areas, areas of high krill densities (cross-hatched), ACC (West Wind Drift) and East Wind Drift (sources: CCAMLR, Hobart, Australia; Laws, 1985; Amos, 1984; Mackintosh, 1973). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

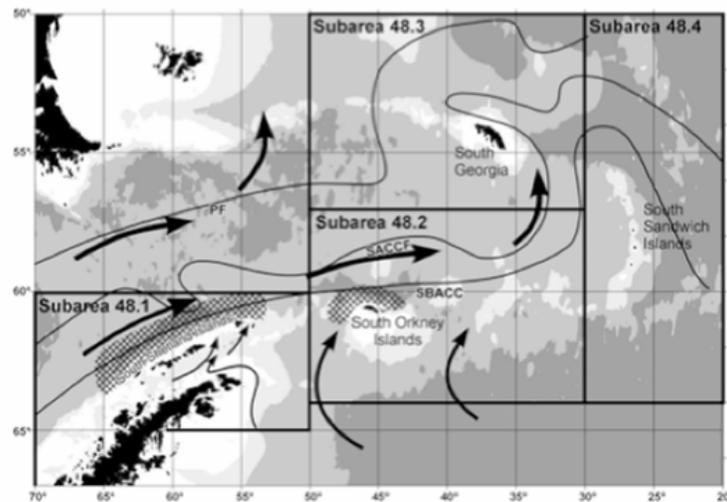


Figure 12: Krill spawning areas (cross-hatched), major currents and frontal zones in the southwest Atlantic sector of the Southern Ocean; PF – Polar Front, SACCF – Southern Antarctic Circumpolar Current Front, SBACC – southern boundary of the ACC (sources: Marr, 1962; Orsi et al., 1995; Hofmann et al., 1998). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

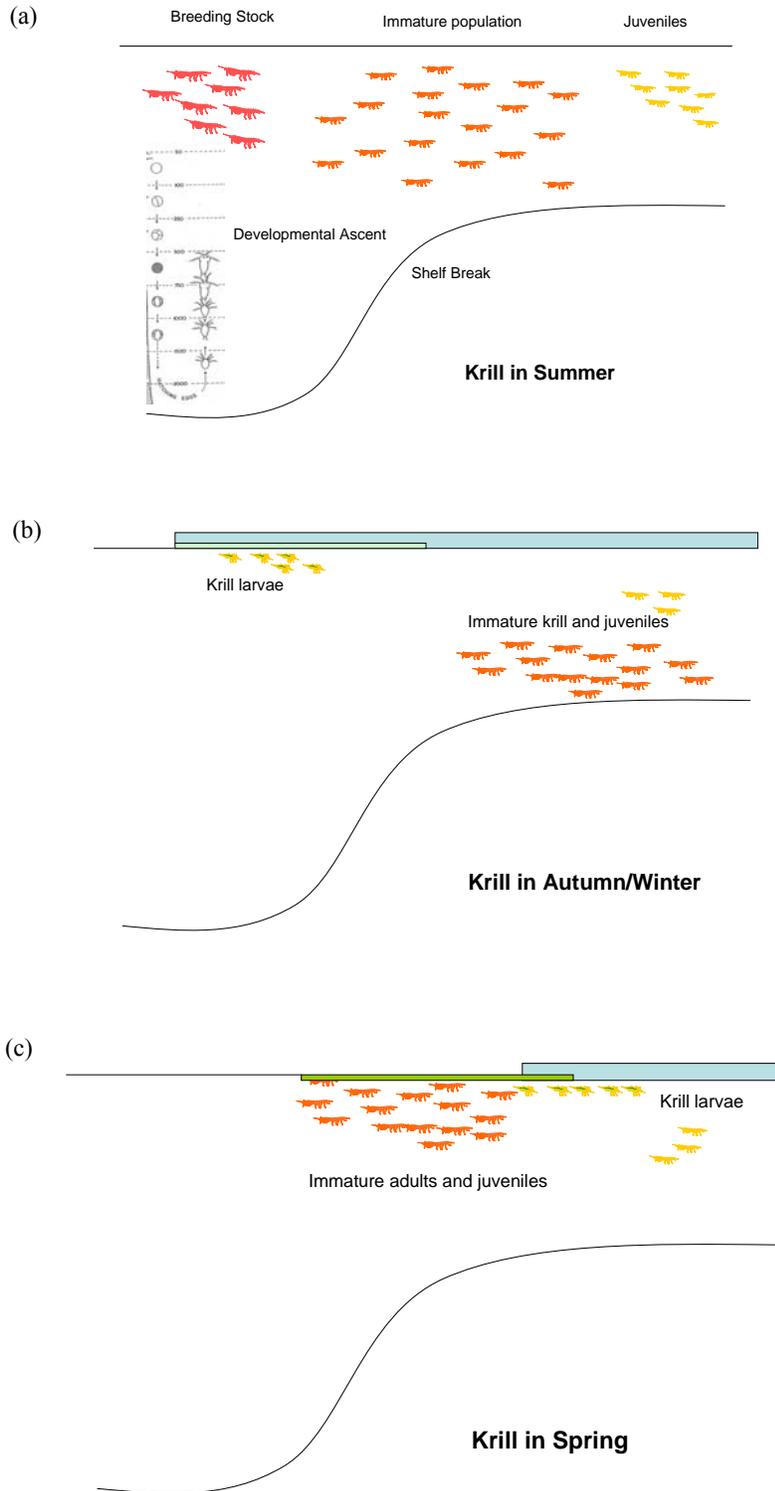


Figure 13: Conceptual model of krill population in summer and winter (modified from WG-EMM-04/50). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

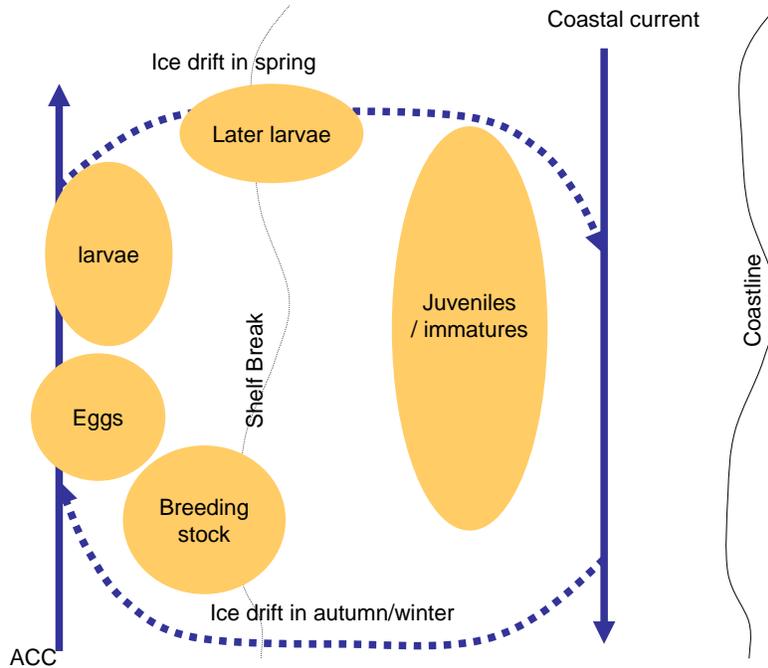


Figure 14: Conceptual model of krill in spring and plan view of ontogenetic migration pattern (modified from WG-EMM-04/50). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

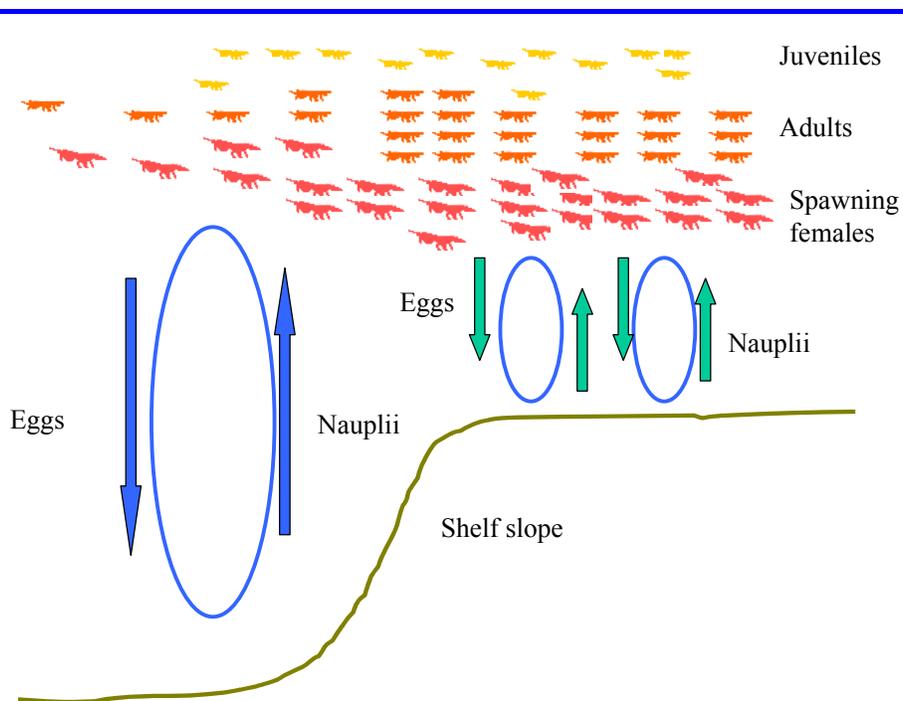


Figure 15: Alternative summer distribution of krill at South Orkney Islands. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

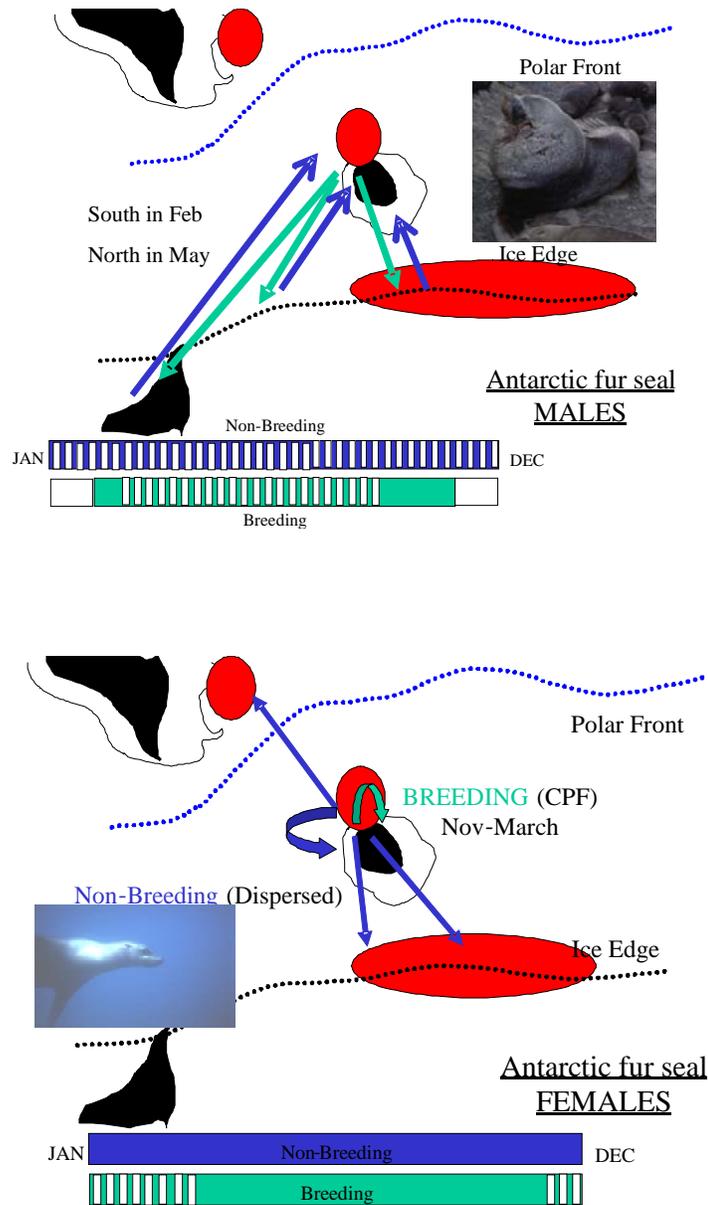


Figure 16: Conceptual model of the seasonal distribution of Antarctic fur seals associated with a sub-Antarctic island in Area 48. Top panel shows males. Bottom panel shows females. The lower bars in each panel indicate the time spent at sea by non-breeding and breeding individuals. For male seals there is a southward dispersal away from the breeding site in January with a northward return in early winter. Female seals that are central-place foragers during the breeding season disperse away from the island to other foraging areas (indicated by the filled ellipses) outside the breeding season. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

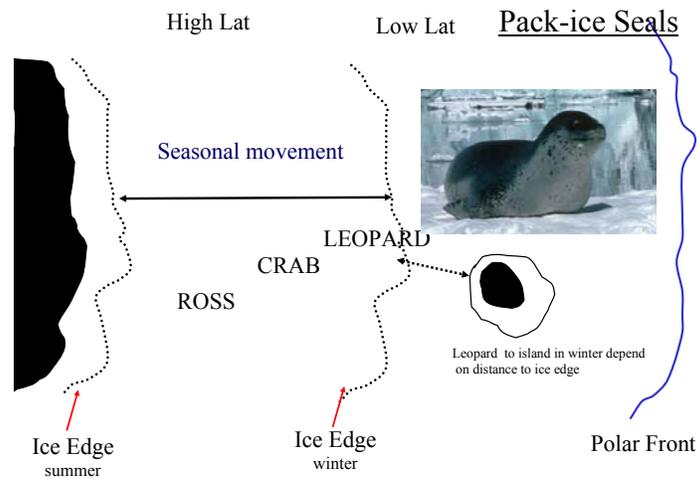


Figure 17: The spatial and temporal distribution of pack-ice seals that follow the seasonal advance and retreat of the pack-ice and the extent of the dispersal of leopard seals to sub-Antarctic islands as a function of the proximity of the pack-ice edge. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

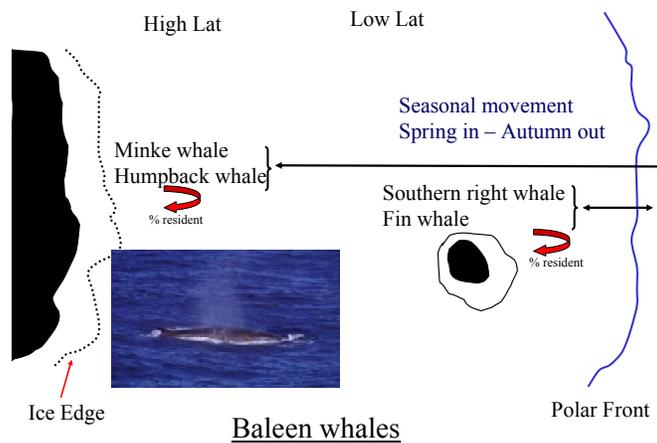


Figure 18: The spatial and temporal distribution of baleen whales separated into a high-latitude group comprising minke and humpback (possible also blue) and a lower latitude group, associated with the sub-Antarctic, comprising fin and southern right whale categories (possibly also sei). The straight arrows indicate the major migration directions, the looped arrows indicate a small proportion that stay over winter in the system. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

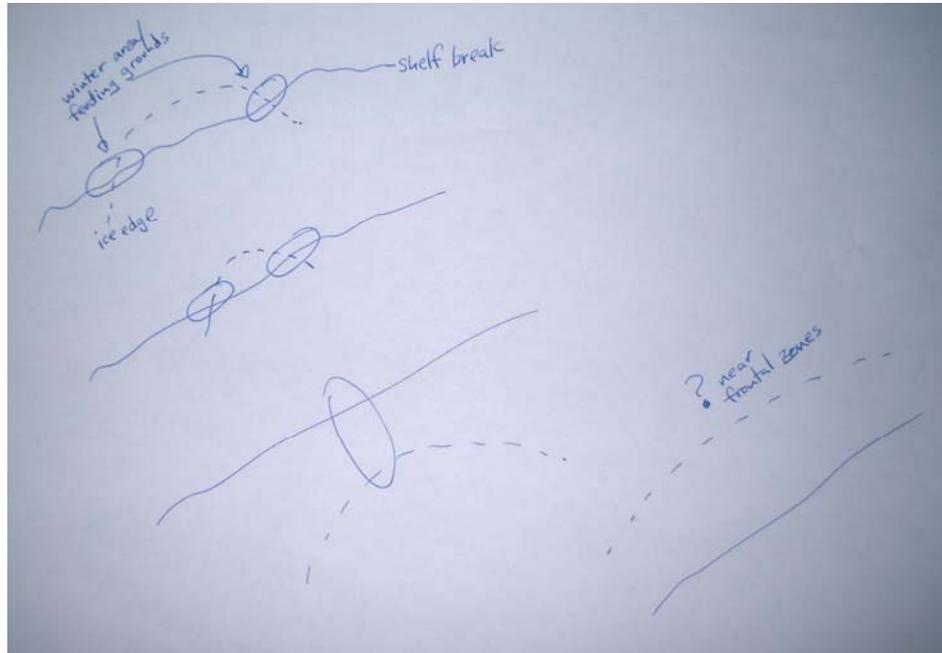


Figure 19: Graphical representation of Adélie penguin foraging locations relative to the ice-edge and shelf break. In the absence of ice, the penguins are expected to forage on the shelf break. Otherwise they would be expected to forage near the ice-edge. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

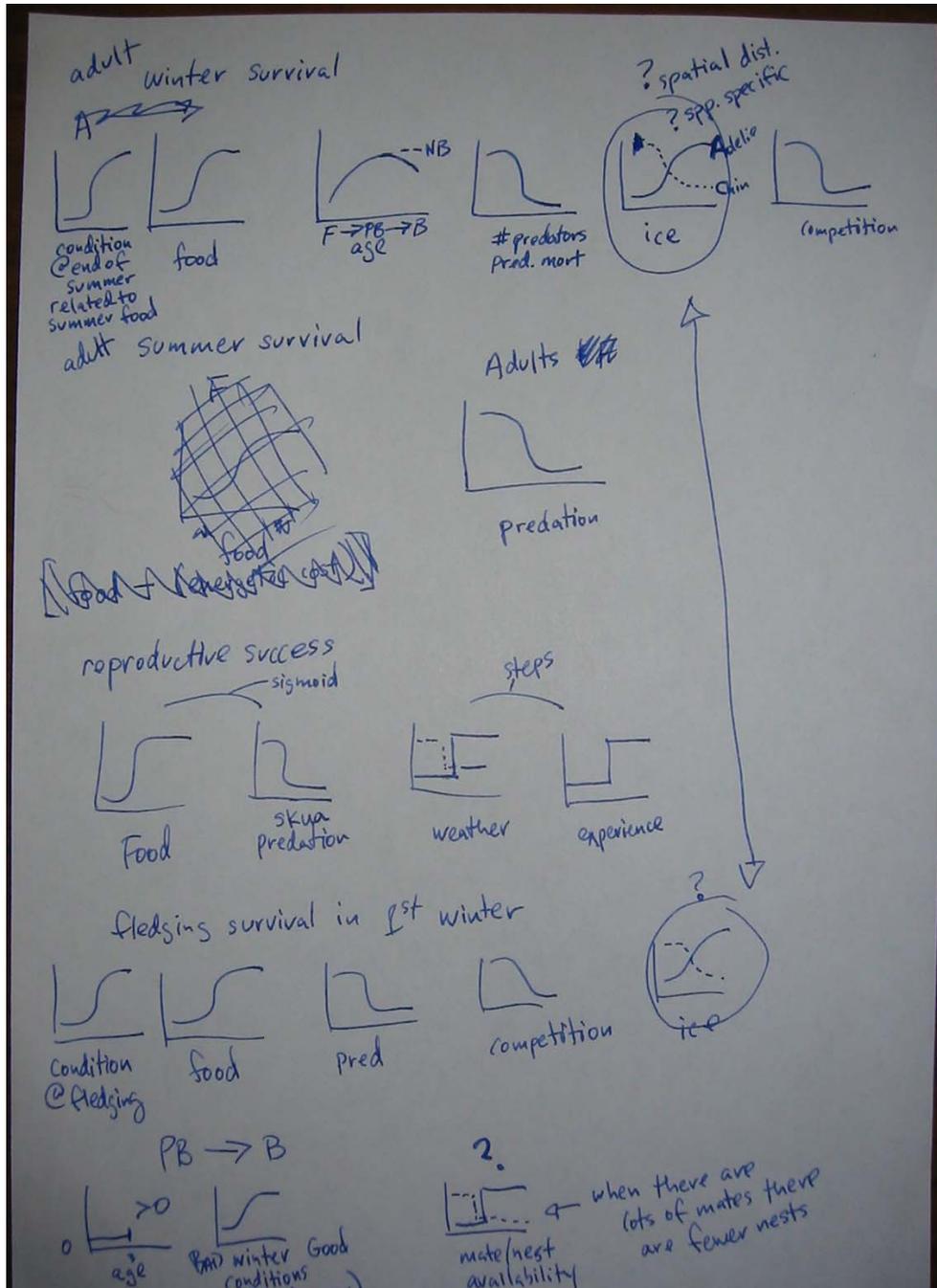


Figure 20: Graphical representations of the form of relationships affecting Adélie penguin demography. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

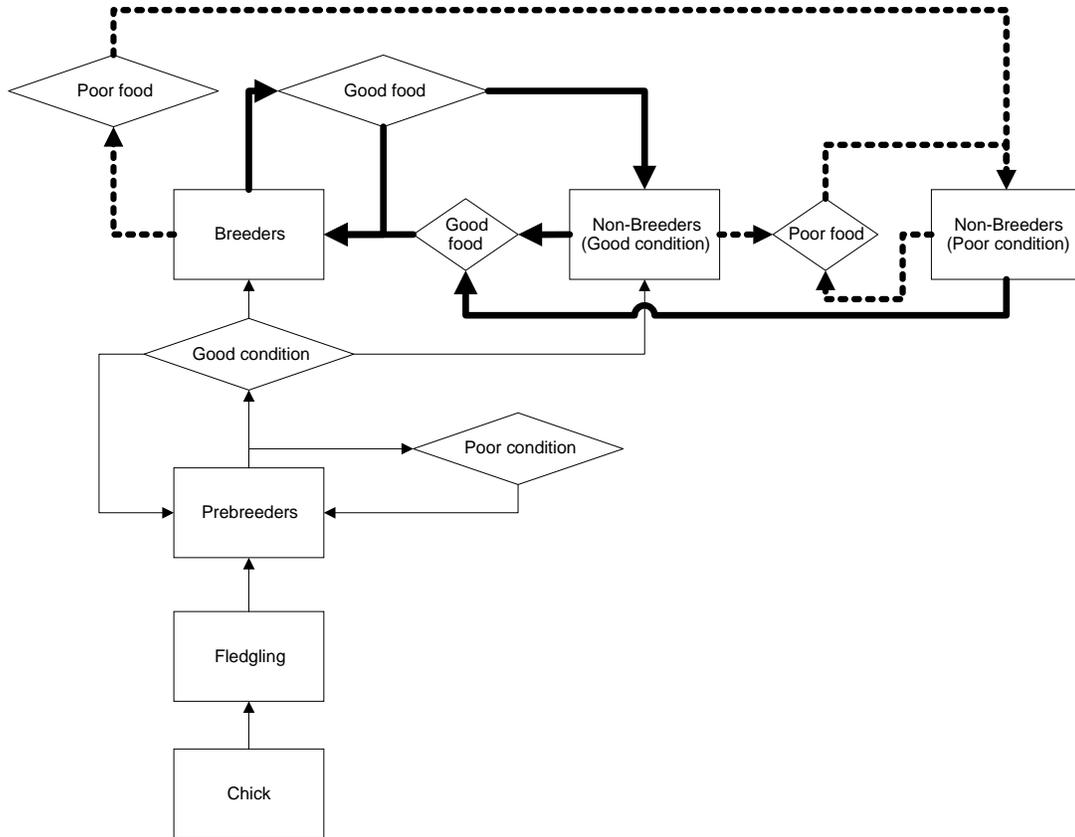


Figure 21: A generalised conceptual model of the transition between different phases in birds. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

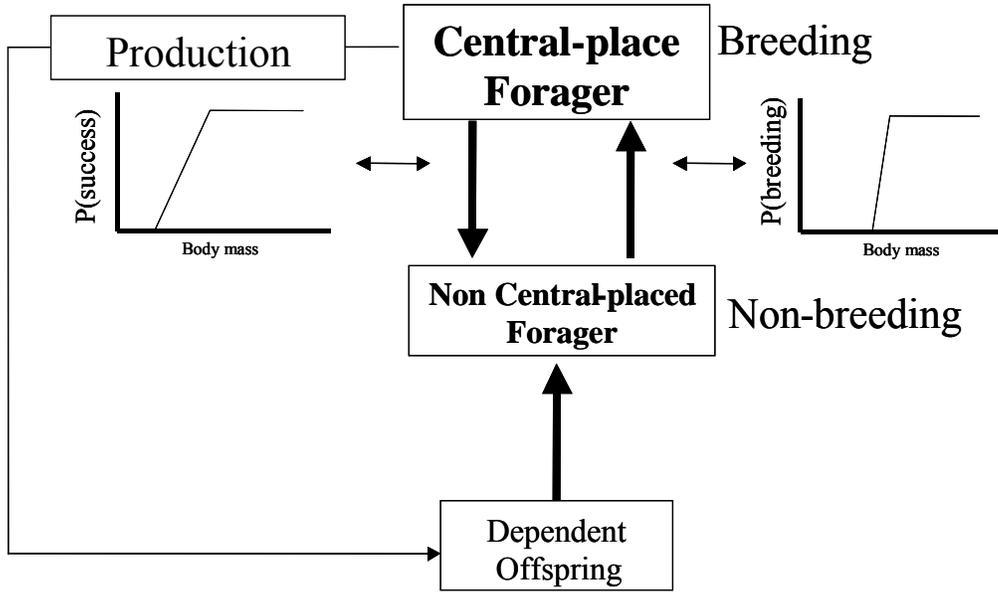


Figure 22: Diagram showing the three main elements of an investment breeder – dependent offspring, non-breeder (wide foraging distribution) and breeder (central-place forager). The transition from non-breeding to breeding depends on the non-breeder being a minimum age; thereafter its body condition will influence whether it can become a breeder, shown by the function of probability of breeding with body condition (substituted by body mass in this case) prior to the breeding season. Successful breeding will depend on the maintenance of body mass during the breeding season. The transition to having non-breeding foraging behaviours will occur at the time at which it no longer has dependent offspring, i.e. when the pup/chick dies or weans/fledges. This transition may be determined by a condition function in a similar way to that described above. Body condition will be affected by the costs of different activities, such that parental investment could be a substantial cost to a breeder (i.e. relative costs of activities comparing breeders to non-breeders might be in the order of 2:1, with dependent offspring not having any cost). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

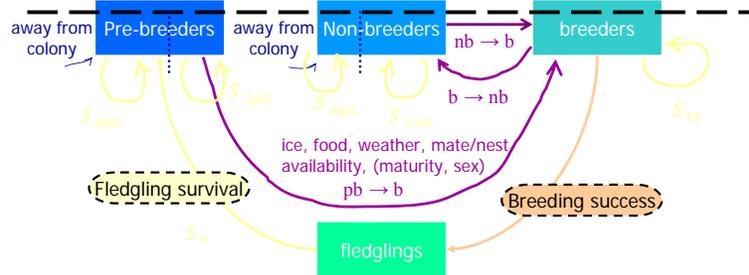


Figure 23: Demography of Adélie penguins at Béchervaise Island (WG-EMM-04/53). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

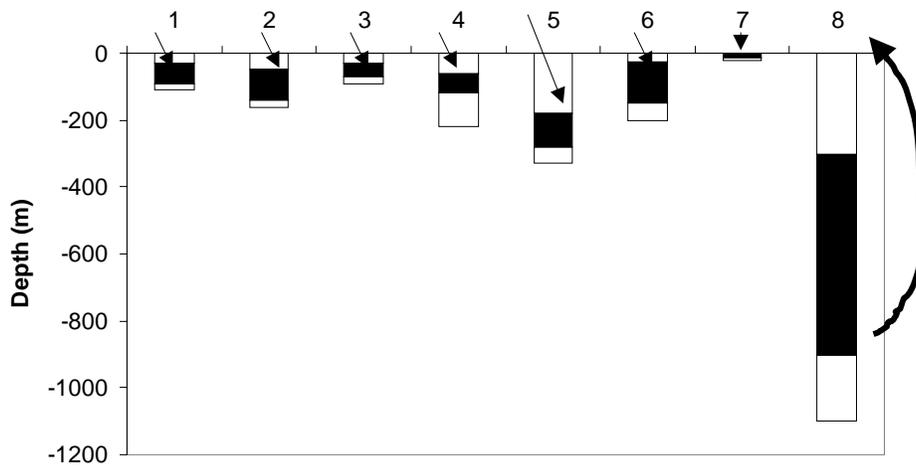


Figure 24: Generalised conceptual model of the vertical foraging distribution of air-breathing predators. The filled sections of the bars indicate the depth region of highest frequency, the upper and lower quartiles of the dive depths are indicated by the unfilled sections. The arrows on the figure indicate the direction of movement from the primary location in which the foragers spend the greater part of their time budget. The numbers refer to the taxonomic grouping:

1 – chinstrap, Adélie and macaroni penguins, 2 – gentoo penguins, 4 – Antarctic fur, leopard and crabeater seals, 5 – king and emperor penguins, 6 – Weddell seals, 7 – baleen whales, 8 – flying birds, 9 – southern elephant seals and odontocete whales.

Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

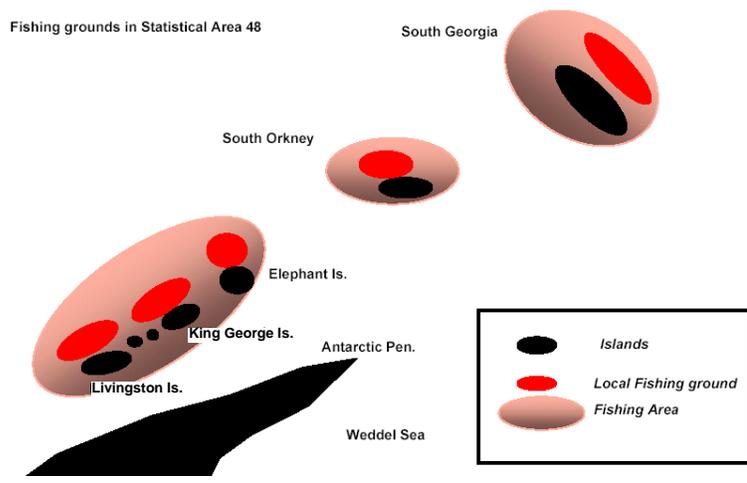


Figure 25: Conceptual illustration of krill fishing areas and grounds in Area 48 (WG-EMM-04/51). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

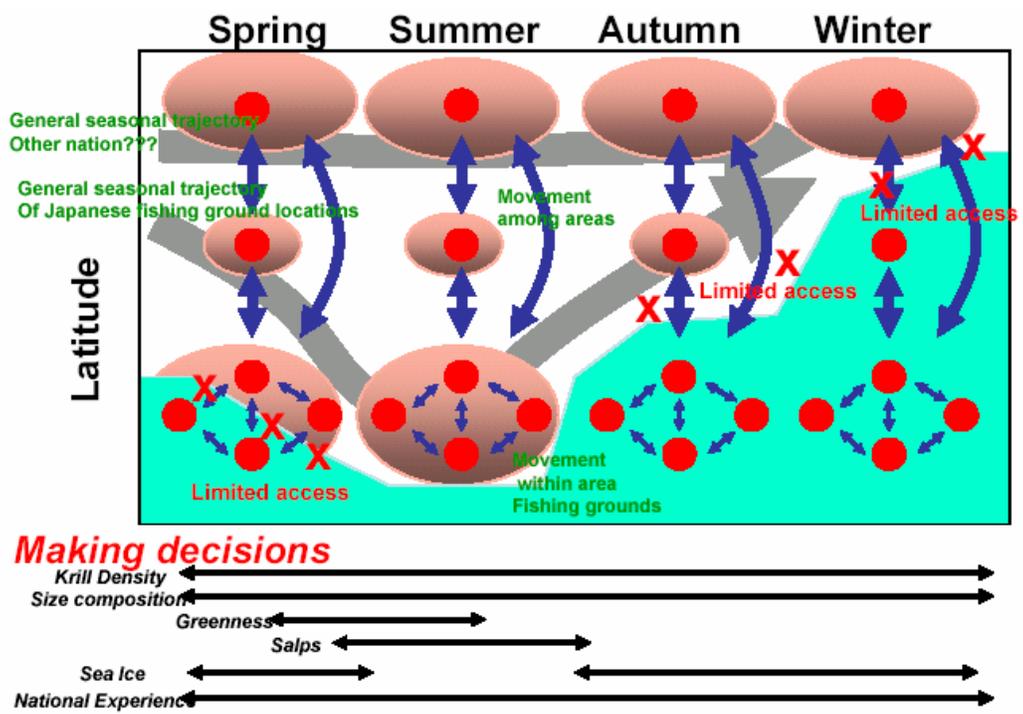


Figure 26: A conceptual illustration of the behaviour of the krill fishery through a season, and related major decision rules (WG-EMM-04/51). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

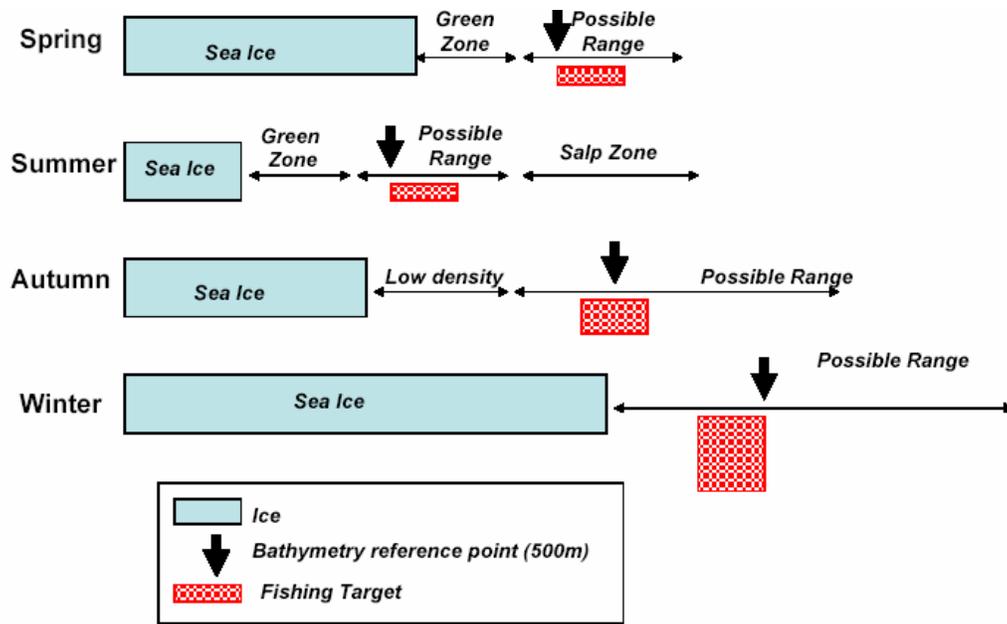


Figure 27: Krill fishing patterns characterised according to seasonal succession of physical and biological properties around the fishing grounds (generated according to information in WG-EMM-04/50). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

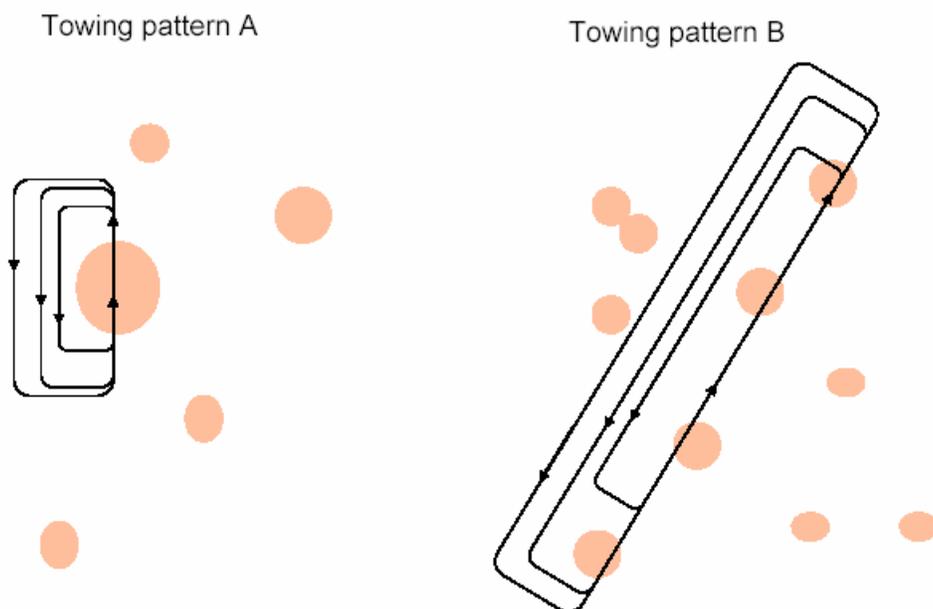


Figure 28: Different strategies of fishing operational pattern at same regional krill density but under different aggregation structure (generated according to information in WG-EMM-04/50). Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.



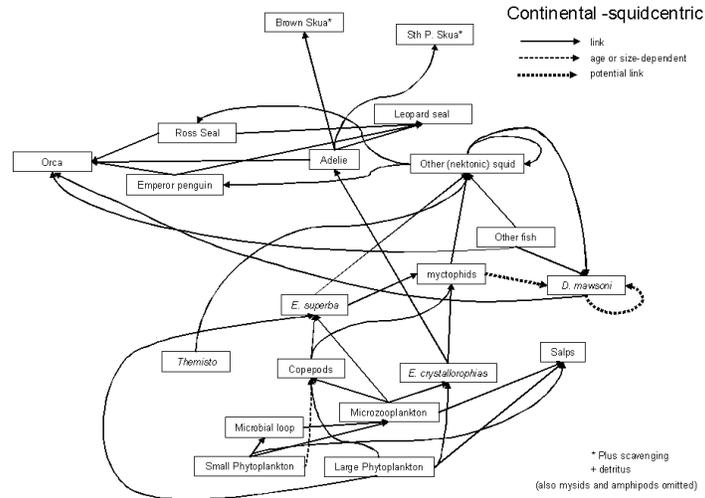


Figure 31: Schematic representation of the squid-centric food web around the Antarctic continent. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

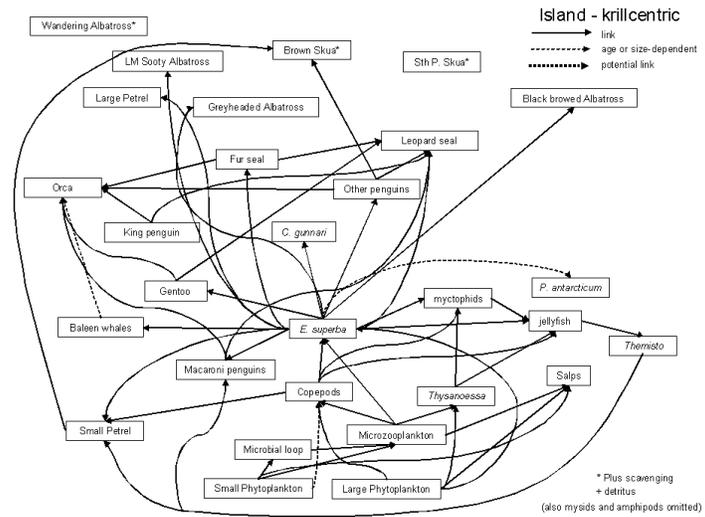


Figure 32: Schematic representation of the krill-centric food web around sub-Antarctic islands. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

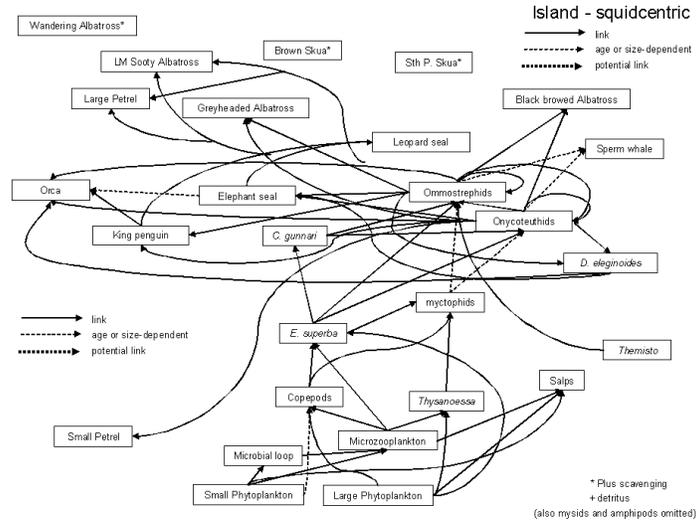


Figure 33: Schematic representation of the squid-centric food web around sub-Antarctic islands. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

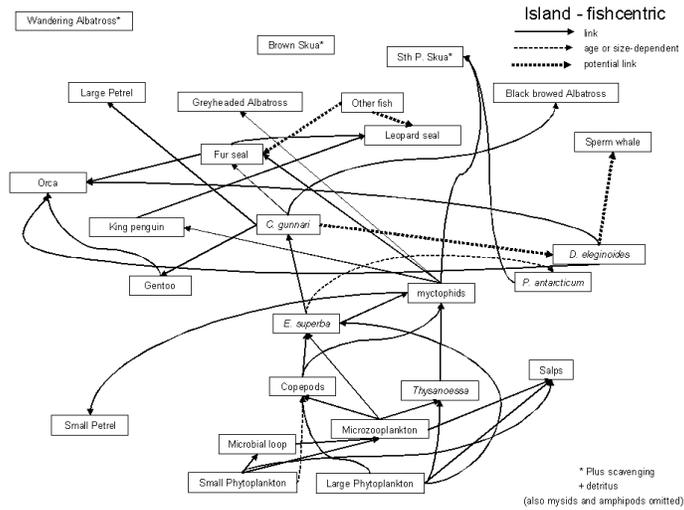


Figure 34: Schematic representation of the fish-centric food web around sub-Antarctic islands. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

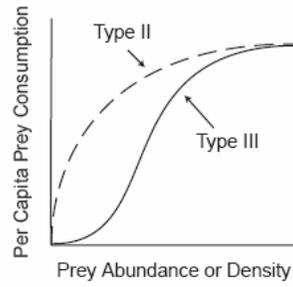


Figure 35: Functional responses that could be used to describe foraging by predators in Antarctic ecosystems. Not to be cited except for the purpose of CCAMLR: only the main features considered at the workshop are shown and, as such, this may be incomplete.

**AGENDA**

Workshop on Plausible Ecosystem Models  
for Testing Approaches to Krill Management  
(Siena, Italy, 12 to 16 July 2004)

1. Opening of the workshop
  - 1.1 Purpose of the workshop
  - 1.2 Rapporteurs
2. Report from the Steering Committee on intersessional activities
  - 2.1 Invited experts
  - 2.2 Literature review of ecosystem models
  - 2.3 Catalogue of available software
  - 2.4 Existing data and estimates of parameters
  - 2.5 Aims and specifications for ecosystem modelling as it relates to the development of management procedures for krill
3. Desirable attributes of ecosystem models
  - 3.1 Attributes of models in the literature
  - 3.2 General attributes of models for evaluation of management procedures
4. Conceptual representation of key components
  - 4.1 General approach
    - 4.1.1 Biological scales
    - 4.1.2 Important attributes to consider
    - 4.1.3 Identifying needs for 'field observations'
    - 4.1.4 Direct and indirect effects of fisheries
  - 4.2 Physical environment
  - 4.3 Primary production
  - 4.4 Pelagic herbivores and invertebrate carnivores
  - 4.5 Target species
  - 4.6 Mesopelagic species
  - 4.7 Central point foragers within the system
  - 4.8 Widely distributed and migratory species
  - 4.9 Fisheries
5. Plausible scenarios for Antarctic marine ecosystems
6. Model formulation and specification
  - 6.1 Modelling interactions between species
  - 6.2 Handling space
  - 6.3 Handling time
  - 6.4 Peripheral processes and boundary conditions

7. Future work
  - 7.1 Tools available
  - 7.2 Software development
  - 7.3 Software requirements
  - 7.4 Coordination
8. Report adoption
9. Close of workshop.

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Workshop on Plausible Ecosystem Models  
for Testing Approaches to Krill Management  
(Siena, Italy, 12 to 16 July 2004)

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