Report of the Joint CCAMLR-IWC Workshop to Review Input Data for Antarctic Marine Ecosystem Models

Contents

1 INTRODUCTION

1.1 Opening of the meeting

The Joint CCAMLR-IWC Workshop to Review Input Data for Antarctic Marine Ecosystem Models was held at the CCAMLR Headquarters in Hobart, Australia, from 11 to 15 August 2008. The Workshop was convened by A. Constable and N. Gales from the Scientific Committees of CCAMLR and the IWC respectively.

The CCAMLR Executive Secretary, D. Miller, welcomed the participants. He noted that Article XXIII(3) of the CAMLR Convention expressly referred to cooperation with the IWC to further CCAMLR's work. Discussions between the two organisations as long ago as 1987 had highlighted the importance of baleen whales in particular as krill predators and as an important component in CCAMLR's needs to account for ecosystem interactions in its management approach. Further cooperation between the two organisations during the CCAMLR-2000 Survey in particular, had planted the seeds for the current Workshop. It had also highlighted the importance of advancing Antarctic ecosystem models, particularly on predator–prey relationships, in developing robust management, as well as conservation, advice relevant to both CCAMLR and the IWC. The Executive Secretary wished the Workshop well and emphasised that its outcomes were likely to be of great interest to both organisations.

The Co-convenors welcomed all participants, including representatives from SC-CAMLR and IWC SC, invited experts and experts from the expert groups.

Special thanks were extended to the CCAMLR Secretariat for hosting the Workshop and assisting with its organisation.

1.2 Organisation of the meeting

The terms of reference were (SC-CAMLR, 2007a, paragraph 13.40; SC-CAMLR, 2007b, paragraph 7.25; IWC, 2008a):

(1) for models on the Antarctic marine ecosystem, and in particular predator–prey relationships, that could be developed for providing management and conservation advice relevant to CCAMLR and IWC, consider the types, relative importance and uncertainties associated with input data for those models, in order to understand what is needed to reduce uncertainties and errors in their use;

(2) review the available input data from published and unpublished sources that are currently available for such models;

(3) summarise the nature of input data (e.g. abundance estimates, trend estimates, foraging scales, seasonal diet etc.), based on metadata (see definition below), by describing methodology, broad levels of uncertainty, time series, spatial extent and determine the appropriate scale at which those input data are relevant to these modelling efforts;

(4) identify and prioritise the gaps in knowledge and types of analyses and field research programmes needed to reduce important uncertainties in ecosystem models being developed for CCAMLR and IWC and how scientists from the two Commissions can best collaborate and share data to maximise the rate of development and scientific quality of modelling efforts and input data.

The Workshop thanked the expert group coordinators for coordinating contributions from the expert groups:

- toothed whales – R. Leaper
- baleen whales – A. Zerbini
- pack-ice seals – C. Southwell
- fur seals – K. Reid
- penguins – P. Trathan
- flying birds – B. Weinecke, M. Double and B. Sullivan
- fish – K.-H. Kock
- squid –P. Rodhouse
- krill – S. Nicol
- protists – P. Strutton
- zooplankton – A. Atkinson
- Sea-ice – R. Massom
- Ocean processes – E. Hofmann
- Exploitation – S. Kawaguchi.

The Workshop **agreed** that the discussion would be in three parts.

First, the submissions by the expert groups would be reviewed and feedback provided on how the expert groups could complete the expectations of the terms of reference. These discussions were to be addressed by three small groups: pelagic species, seals and birds, and whales. Each small group comprised experts with experience in research on the respective taxa along with experts with backgrounds in oceanography, sea-ice dynamics, primary production, statistics and/or modelling. Each group addressed the following topics: (1) abundance; (2) habitat; (3) life histories; (4) food-web linkages; and (5) future analytical and research priorities. Each small group was to organise its discussion appropriate to the natural divisions of the taxa and topics being considered. Therefore, the format of the report would vary amongst the small groups. The reports of the small groups were then to be considered in plenary to help the subsequent general discussions. While these reports are included in the plenary report, it was recognised that the degree of plenary discussion on each report would be only short, not necessarily covering the complete detail of each report.

Secondly, the Workshop considered the general issues on metadata for the CCAMLR and IWC modelling efforts and finally it considered the outputs from this process and the requirements for future work.

The adopted agenda is given as Annex A, the participants as Annex B and the documents submitted as Annex C. Acronyms used in this report are listed in Annex G.

The report of the meeting was agreed by all participants, with primary contributions by the coordinators and rapporteurs of the small groups:

- pelagic species – S. Nicol (coordinator) and A. Punt (rapporteur)
- seals and seabirds – . D. Costa (coordinator) and C. Southwell (rapporteur)
- whales – J. Bannister (coordinator) and R. Leaper (rapporteur).

1.3 Workshop background

Background to the Workshop was provided by the Co-convenors in CCAMLR-IWC-WS-08/2.

SC-CAMLR and the IWC SC had agreed to hold a joint workshop to review input data required for ecosystem models being developed to provide management and conservation advice on krill and krill predators in the Antarctic marine ecosystem (SC-CAMLR, 2005, paragraphs 13.44 to 13.53; IWC, 2006).

A Joint Steering Group was established for the 'CCAMLR-IWC Workshop to review input data for Antarctic marine ecosystem models' incorporating steering committees from both organisations:

SC-CAMLR - A. Constable (Co-convenor), M. Goebel, J. Pierre, D. Ramm, K. Reid, C. Southwell, P. Trathan.

IWC SC- N. Gales (Co-convenor), A. Bjorge, D. Butterworth, D. DeMaster, G. Donovan, N. Grandy, S. Hedley, K-H. Kock, R. Leaper, M. Mori, H. Murase and T. Polacheck.

Models developed to support discussions in SC-CAMLR and IWC SC include those of Mangel and Switzer (1998), Thomson *et al.* (2000), Watters *et al.* (2005, 2006), Plagányi and Butterworth (2005, 2006a, 2006b), Mori and Butterworth (2003, 2006a, 2006b) and Constable (2005, 2006). An important difference in the current modelling for SC-CAMLR and IWC SC is the spatial scale and taxa of interest. Models on the dynamics of cetacean populations will necessarily operate at larger scales commensurate with the ability of whales to move widely in Antarctic waters. Modelling of krill availability to all predators is an important issue being addressed by SC-CAMLR and at this stage is focused on krill availability and predator foraging at the scale of land-based predator colonies and of CCAMLR's SSMUs; however, given the potential for appreciable increase in the krill fishery in the longer term, models at a wider spatial scale are also of interest to SC-CAMLR. An important issue for these models is how to ensure that they provide results that are consistent with each other.

Baleen whales are clearly important krill consumers in the Southern Ocean, and their improved parameterisation in CCAMLR models, facilitated in part by this Workshop, should add value to models informing sustainable krill fishery practice.

Similarly, as the IWC considers the ecological aspects of the recovery of the great whales in the Southern Ocean, this collaboration with CCAMLR will importantly link IWC knowledge of whales with that of other krill consumers.

From both perspectives, a consistent approach to modelling by CCAMLR and the IWC should improve ability to provide sound conservation and management advice in the Southern Ocean.

Models discussed at CCAMLR and the IWC are developed from a variety of data types and reflect different spatial and temporal scales with different degrees of ecological detail. These data types may be drawn from the following, *inter alia*:

(1) Population –

   (1) biomass/numbers in different regions of the Southern Ocean in absolute terms;

   (2) trends in relative abundance;

   (3) population structure, including age/size/spatial structure.

(2) Habitat utilisation –

- (a) movement;
- (b) key habitats and environmental variables (ivers of key population processes);
- (c) foraging areas.

(3) Population growth rates –

- (a) growth of individuals
- (b) reproductive output
- (c) recruitment
- (d) mortality rates
- (e) carrying capacity.

(4) Foraging activities –

- (a) diet
- (b) foraging success
- (c) consumption rate
- (d) competition
- (e) spatial utilisation.

(5) Catch –

- (a) biomass/numbers taken
- (b) size structure in different regions over time.

The degree of detail in taxonomic information remained to be decided but a number of physical and ecological parameters can impact on krill availability and food-web dynamics (Murphy *et al.*, 2007).

Expert groups compiled ecological and environmental data for the following main categories:

(1) exploitation of seals, whales, finfish and krill
(2) cetaceans – toothed, baleen
(3) seals – pack-ice seals, fur seals
(4) seabirds – penguins, flying seabirds
(5) mesopelagic and epipelagic predators – fish and squid
(6) krill
(7) other biological components – primary production and protists, zooplankton
(8) environmental components – sea-ice, sea-surface temperature and atmospheric and ocean processes.

The most important data were considered to be abundance data and particularly the associated information on likely bias, variance and comparability of any time series. These data are available from the literature, a number of general sources, including the IWC, CCAMLR and SCAR-MarBIN, and from works in progress. Depending on the model, these data will need to be subdivided or aggregated in space. In the first instance, abundance data need to be collated by either CCAMLR or IWC statistical/management unit (Fig. 1), converting these into densities and providing a description about the spatial extent to which the densities can be applied. The latter can then be used to determine whether the data collected at one scale, say IWC management units, can be used to provide information at another scale, say a CCAMLR statistical division. Statistical divisions that extend from the Antarctic continent to the CCAMLR boundary (Subarea 48.6, Division 58.4.1) should be further divided into north and south at 60°S. Further subdivision of data into CCAMLR SSMUs in the south Atlantic will be useful (Fig. 2). The degree to which input data can be re-analysed to fit alternative subdivisions to the original analysis is important to be reviewed.

Data on habitat utilisation endeavour to specify the potential spatial overlap between taxa and the spatial variation in productivity that might occur. Two types of data may be needed, the spatial attributes of habitats and the temporal partitioning of habitat and movement between areas.

Typically, population growth is dependent on reproduction, mortality and growth of individuals. Intraspecific competition may result in changes to one or all of these processes. They can be modelled in part or together as functions.

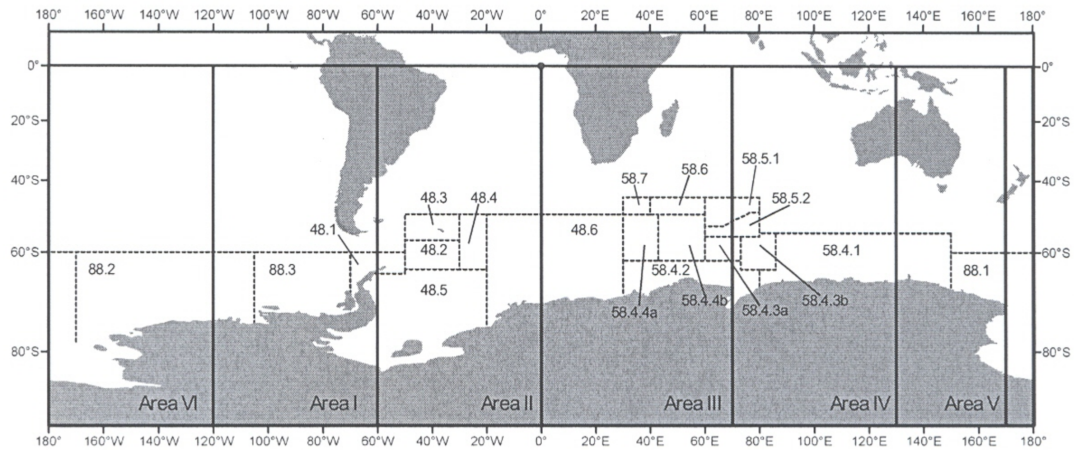

Fig.1. Map showing the area managed by CCAMLR and CCAMLR statistical areas/subareas/divisions along with the IWC management Areas I-VI.

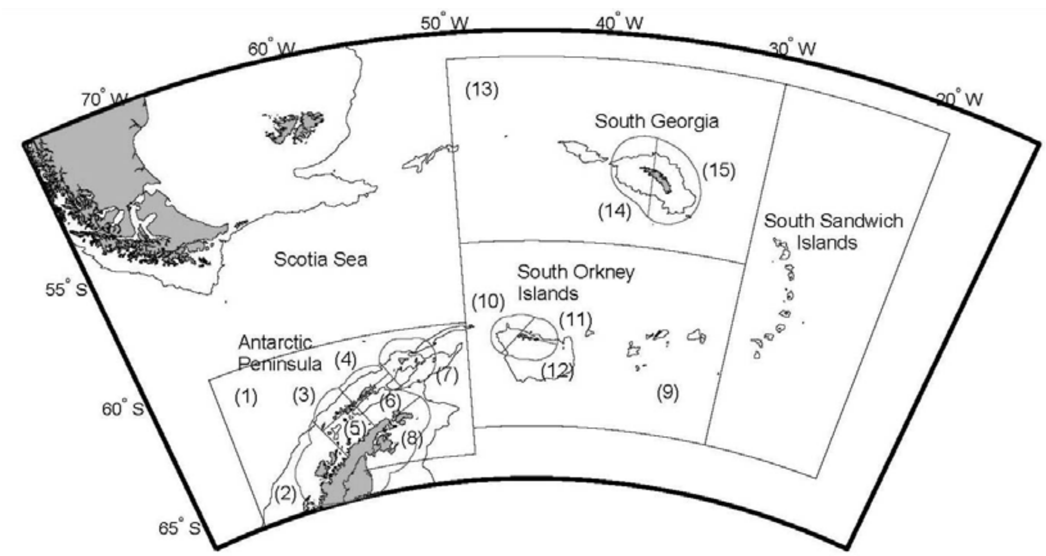

Fig. 2. Small-scale management units adopted by CCAMLR for Area 48.

Models of the foraging dynamics of a taxon utilise diet data and functions for foraging, e.g. Type II and III functions or other dynamic approaches. Although difficult to measure, assumptions are usually made about the nature and extent of inter/intra-specific competition in these models.

Catch data will have been reported at taxon-specific spatial and temporal scales with much catch data being of variable quality, particularly for finfish. It may also be important to consider species for which there is substantial by-catch, such as seabirds. All these data will need to be subdivided into common statistical units across the taxa as appropriate.

Preparation for the Workshop involved expert groups compiling and providing a commentary on metadata. A database was developed and is currently hosted at the AADC with the expectation that the database will be deposited with both the CCAMLR and IWC Secretariats.

With the exception of the flying seabirds, reviews were available from all expert groups. An additional expert group was added early in 2008 under the coordination of Kawaguchi to review the state of the datasets on the exploitation of

Southern Ocean species, including seals, whales, finfish and krill. The compilation of this paper will occur after the Workshop, pending the outcomes of work by the individual expert groups.

The establishment of a metadatabase of data for use in models by CCAMLR and the IWC was considered to be an important outcome of the Workshop. Such a database along with a web-based GUI was established by the AADC and made available to the expert groups for use. It is currently being hosted on a secure site by the AADC. This is only temporary in preparation for the Workshop. The database will be provided to both the CCAMLR and IWC Secretariats for archiving and further development as needed. Information on how to access the database and how to use the GUI is available in CCAMLR-IWC-WS-08/16.

The Workshop was open to members of the SC-CAMLR and IWC SC and their working groups. Furthermore, participants in the expert groups were invited to attend. A number of additional general experts, including those with expertise in statistics and modelling, were also invited to attend.

1.3.1 CCAMLR and IWC modelling requirements

CCAMLR-IWC-WS-08/3 provided a general overview and background to models of Antarctic marine ecosystems being discussed at CCAMLR and the IWC, in particular, summarising the following:

(1) ecosystem models could be developed in CCAMLR and the IWC for the purposes of either –

- (a) evaluating management procedures; or
- (b) in CCAMLR, estimating status of the ecosystem or components thereof;

(2) ecosystem modelling in CCAMLR –

- (a) the development of food-web and ecosystem models in CCAMLR since 1995 and the concerted effort to develop ecosystem models for assisting in evaluating krill management procedures since a workshop in 2004;
- (b) details of the outcomes of the 2004 WG-EMM workshop (SC-CAMLR, 2004) on ecosystem models, including conceptual representation of the ecosystem;
- (c) spatial characterisation of the Southern Ocean, in terms of CCAMLR and IWC statistical units, CCAMLR SSMUs, and the CCAMLR bioregionalisation;

(3) ecosystem modelling in the IWC;

(4) a discussion on model structure, data inputs and where uncertainties in the modelling process arise, including:

- (a) food-web model structure;
- (b) model use and handling uncertainty;
- (c) natural variation and parameter uncertainty;
- (d) model uncertainty arising from how the following are specified –
  - (i) taxonomic specification – guilds and functional groups
  - (ii) prey mortality and predator consumption
  - (iii) relative timing of consumption and biomass accumulation
  - (iv) maintaining appropriate covariation between parameters and model behaviours.

Butterworth presented a summary of the development of food-web models in the IWC:

(1) Issues that have been raised include:

- (a) To what extent might consumption of forage species by top predators impact fisheries?
- (b) To what extent might competition occur between top predators for forage species?
- (c) To what extent might fisheries impact top predators and/or the ecosystem as a whole?

(2) Management advice taking account of species interactions has included:

- (a) a strategy for setting minke whale catches in the early 1980s based on the ‘krill surplus’ hypothesis;
- (b) evaluation of the RMP using variation in MSYR (maximum sustainable yield rate) and K (carrying capacity) as surrogates for species interaction effects.

(3) The manner in which uncertainty can be dealt with has been considered, noting the difficulty that different models can give very different results; the conclusion of the FAO Expert Workshop on Modelling (FAO, in press) was that

ecosystem models could be used as operating models, but have not evolved sufficiently for use as tactical models on which to base quantitative advice.

(4) Examples of food-web modelling have included:

(a) models in northeast Atlantic, northwest Pacific, and northwest Africa, using Ecopath with Ecosim and Multspec, which is an example of a Minimally Realistic Model;

(b) a model for Antarctica considering competition (Mori and Butterworth, 2005).

Butterworth concluded by indicating that improved data are essential for further development of the models and for providing sufficient power to test their predictive reliability, which is one of the core motivations for this Workshop.

Constable presented further clarification of his views of the use of data in CCAMLR and IWC models to assist the discussions on what data are needed for these purposes. In particular, he drew attention to the need to use models to provide a minimal representation required to capture the dynamics of importance (minimal realistic models), i.e. what is essential to be represented in terms of spatial scales, temporal scales and timing of events, biotic detail (species, functional groups, environmental covariates) and population/individual processes? He provided a number of figures to illustrate where he believed data and knowledge can be used to build plausible scenarios (models) of ecosystems (Annex F).

1.3.2 General questions for CCAMLR and IWC ecosystem modelling

The Workshop considered the following as useful general questions guiding the examination of ecosystem effects in conservation and management in the Antarctic:

(1) How might fishing on a species, in particular krill, impact predators of that species?

(2) How might changes in abundances of predators, for example those recovering from prior exploitation, influence other components of the ecosystem?

(3) How might the environment and environmental change impact the abundances of fished species and their predators, and conservation objectives?

In discussion, the Workshop noted the different data types and scales relevant to each question. Issues of timelines for required outcomes were also highlighted with respect to risking unreliable model predictions if timelines are overly constrained. Attempts to model climate related change in particular were noted to require long timelines.

The Workshop noted that these questions were to be considered primarily in relation to krill and krill predators. It noted that each question would naturally be addressed at different scales, ranging from Antarctic-wide, through CCAMLR or IWC management units, to CCAMLR SSMUs.

2 METADATA SUMMARIES

2.1 Physical environment and primary production

2.1.1 Oceanography

2.1.1.1 SUMMARY FROM EXPERT GROUP

CCAMLR-IWC-WS-08/15 discussed how analyses of the dynamics of Southern Ocean ecosystems have highlighted the importance of understanding physical and biological interactions because these are fundamental to predicting the impacts of climate and harvesting in the Southern Ocean and in improving sustainable management strategies. Modelling provides one approach for combining environmental and biological data in a quantitative framework to develop scenarios for system responses to a range of perturbations. However, models typically consider a limited range of space and time scales that are dictated by the questions of interest. Information on processes at smaller scales is included thought parameterisations; information at larger scales is included via boundary conditions. These requirements place important emphasis on availability of datasets that are adequate to meet these modelling needs. Data are also integral to model evaluation and calibration and must encompass the space and time resolution needed to do this. Model-data fusion via data assimilation provides another important use for data in modelling studies.

Numerical ocean circulation models are now relatively mature. Community-based models, such as the Regional Ocean Modelling System (ROMS) (Haidvogel *et al.*, 2008) and the Princeton Ocean Model (POM) (Mellor, 1996), are available and these have extensive user communities. These models are supported and continually updated as new understanding, numerical procedures and research foci evolve. Biological models are not yet as mature and reliable simulations of an ecosystem state are not considered feasible beyond the level of bulk quantities, such as macronutrients or chlorophyll. The limitation of these models comes from insufficient data to parameterise processes, provide initial and boundary conditions, and undertake rigorous model evaluation. An equally important limitation is basic understanding of the coupling between trophic levels, food-web structure and coupling of food webs to environmental conditions and to models of biogeochemical processes. Coupling to these models to those developed for marine resource management remains to be done.

Environmental datasets exist in a variety of forms that include large-scale climatologies, numerous regional programs, Lagrangian measurements (e.g. floats), Eulerian measurements (e.g. moored current meter arrays), and satellite-based observations (e.g. sea-ice, surface winds). The challenge is to combine these data sources to develop characterisations of environmental structure and variability.

Approaches for quantitative evaluation of model output are key to improving model structure and ultimately the ability to predict and evaluate scenarios for altered system states. Simulated distributions should, at a minimum, reproduce observed means and variances with little bias, capture the dynamic range of the observations, match phasing of events, and capture regional differences. How well models meet these criteria is often determined by model-data comparisons, which in many cases are qualitative evaluations. More rigorous quantitative evaluations through statistical comparisons, such as Taylor (Taylor, 2001) and target (Joliff *et al.*, 2007) diagrams, provide estimates of uncertainty in model predictions and highlight areas where model improvements are needed. A diversity of approaches for assessing model skill is needed to identify where model improvements are needed.

Data assimilation is an approach that allows combining models and data in a quantitative manner that yields estimates of associated error and uncertainty. Several of the ocean circulation models that are now available are data assimilative models. Assimilation of data into ecological models has been shown to be feasible. For ecological models, approaches, such as variational adjoint methods, have been used to estimate parameter sets, improve model structure and to investigate model complexity.

A cautionary note is that reduction of uncertainty is not necessarily a desirable goal. It is important to characterise and understand uncertainty in data, models and model predictions. This may actually lead to an increase in uncertainty in estimates. If reduction of uncertainty is a desired goal this it is important to establish the metrics by which progress towards this goal will be assessed.

2.1.1.2 FUTURE RESEARCH PRIORITIES

The Workshop recognised the advances in ocean modelling and the assistance that they can provide in understanding the physical dynamics of key habitats. The Workshop also noted a number of questions that could be useful to address in determining habitat variability and change (see paragraphs 3.3 and 3.4).

The Workshop also recognised the general advances in modelling that integrate food-web and physical system models providing opportunities to better understand the effects of habitat variability and change on food-web dynamics, including:

(1) Multi-species models are being developed for large oceanic pelagic species that are coupled to circulation, biogeochemical and harvesting models. These models represent the integration of ocean and ecosystem processes in a framework that can be used to understand physical and biological controls on important commercial species. An example of such a model is the Apex Predators ECOSystem Model (APECOSM), which represents the spatial dynamics of open ocean pelagic ecosystems in the global ocean (Maury *et al.*, 2007a, 2007b). Physical forcing (winds, temperature and currents from a circulation model), biogeochemical forcing (primary production and oxygen from a biogeochemical model) as well as the effects of fishing are explicitly taken into account in the model. This type of modelling structure allows investigation of the relative effects of environment (bottom-up), species interaction (top-down), and fishing effects on important commercial species. This approach may be useful to CCAMLR and the IWC for some applications.

(2) (ii) Individual-based modelling is an approach that makes good use of many types of data, such a feeding rates or foraging behaviour, which are usually collected at the level of an individual. These models allow detailed investigation of animal responses to environmental, biological, and physiological processes. The results of individual-based models can be scaled to population level using approaches based on statistical distributions that describe the range of variability in key biological or physiological processes. This allows the observed range of variability for a population (e.g. a proxy for genetic variability) to be included, thereby providing a range of possible outcomes for a population in response to particular forcings. Individual-based models may be an approach for inclusion into CCAMLR and IWC modelling activities.

The Workshop also noted two emerging research programmes that may have relevant inputs to CCAMLR and IWC modelling activities:

(1) ICED – Integrating Climate and Ecosystem Dynamics in the Southern Ocean

ICED is a decade-long international multi-disciplinary program that has been established primarily to facilitate the scientific coordination and communication required to produce models of Southern Ocean ecosystems that allow the prediction of future scenarios. ICED is a regional program under GLOBEC and the Integrated Marine Biogeochemistry and Ecosystem Research Programs of the International Geosphere-Biosphere Program.

The long-term goal of ICED is to develop a coordinated circumpolar approach to understand climate interactions in the Southern Ocean, the implications for ecosystem dynamics, the impacts on biogeochemical cycles, and the development of management procedures for the sustainable exploitation of living resources.

ICED has three major scientific objectives:

(1) to understand how climate processes affect the structure and dynamics of ecosystems in the Southern Ocean;

(2) to understand how ecosystem structure and dynamics affect biogeochemical cycles in the Southern Ocean;

(3) to determine how ecosystem structure and dynamics should be incorporated into management approaches to sustainable exploitation of living resources in the Southern Ocean.

Many of the ICED activities, such as analyses of historical datasets, could be relevant to CCAMLR and the IWC. In particular, the emphasis on circumpolar models that combine circulation, food webs and biogeochemistry are intended to be directly linked to many of the modelling efforts relevant to CCAMLR and IWC. The regional observational programs that are planned as part of ICED, will provide integrated dataset that are potentially of interest to CCAMLR and the IWC.

(2) SOOS – Southern Ocean Observing System

The Southern Ocean is vast, remote and logistically difficult to access and as a result is one of the least sampled regions on Earth. SOOS is an attempt to design and implement an observing system that encompasses physical, biogeochemical and ecological processes. SOOS is now in the development stages and should have an implementation plan developed this year. It would be useful if CCAMLR and IWC could provide inputs on needed measurements and regions for measurements.

The Workshop noted that these models will not be used directly in decision making in the short term. They may prove helpful to inform the development of models for evaluating management procedures in the IWC and CCAMLR, but there was insufficient time to discuss them in detail.

2.1.2 Sea-ice

2.1.2.1 SUMMARY FROM EXPERT GROUP

CCAMLR-IWC-WS-08/14 provided a synthesis of data on sea-ice, its dynamics and its role in Southern Ocean marine ecosystems. Sea-ice plays a dominant yet highly variable role in structuring marine ecosystems of the high-latitude Southern Ocean. It forms a nutrient-rich substrate for concentrating microbial communities; a critical food source for pelagic herbivores, which in turn form a key food source for larger predators; and a resting, breeding and protection platform for seals and penguins. Moreover, it strongly impacts pelagic production during ice melt. Different ice types have different ecosystem functions, (e.g. pack-ice versus fast-ice). While sea-ice habitat is highly heterogeneous over small spatial scales, the circumpolar sea-ice cover is characterised by large-scale (seasonal) patterns in its distribution, dynamics and characteristics – given by climatological temperature, wind and ocean current fields. Sea-ice responds to, and modulates, changes/trends in these forcing fields, and as such is highly sensitive to climate change/variability – with ramifications for organisms associated with/dependent on it.

Major large-scale components of the sea-ice habitat include the SSIZ (including the marginal ice zone), the inner pack, regions of perennial sea-ice that persist through summer, and coastal fast-ice, flaw leads and polynyas. A key characteristic of the latter is their annual recurrence and persistence in certain locations, while leads within the pack are essentially short-lived though biologically significant features. The extraordinary annual growth-decay cycle of the ice (from a minimum extent of ~3–4 million km^2 in February to ~19 million km^2 in September–October) moves the sea-ice zone across important physical and biological boundaries/zones in the ocean e.g. the ACC, shelf break, Antarctic Divergence and the SBACC.

Icebergs play a major role in the coastal zone, both when grounded and ifting. They form anchor points for fast-ice formation and boundaries for polynya and localised open water formation, and are a source of meltwater and iron on melting. On the other hand, they can be a 'wildcard' element that can diminish polynya size (and regional primary production) and deleteriously affect penguin breeding success.

Modelling of sea-ice primary production is very important, yet only one model is currently available (although two more are under development). This is specific to Weddell Sea conditions, and not applicable to circumpolar studies. A major current deficiency in terms of model validation is the lack of *in situ* observations quantifying temporal evolution of sea-ice physical habitat and communities, with no measurements of the annual cycle. In fact, current knowledge of the ecological roles of sea-ice based on short and widely-spaced *in situ* 'snapshots'. A particular challenge is to adequately sample and investigate the heterogeneous and multiple ecological niches of sea-ice within the spatio-temporal domain. New technologies such as autonomous underwater vehicles (AUVs) may help acquire large-scale datasets of combined physical-biological parameters, and experiments are planned.

Current needs have been identified for:

(1) more dedicated multi-disciplinary campaigns to measure physical and biochemical ice processes and properties plus associated biological communities, and their temporal evolution;

(2) information on complete annual cycles in the offshore pack;

(3) sustained long-term datasets, e.g. Palmer LTER, to enable detection of trends versus interannual variability, short- to long-term cycles and decadal-scale regime shifts;

(4) development of a better understanding of the impact on, and sensitivity of, sea-ice 'habitat' to variability in modes of climate variability, e.g. Southern Oscillation, ENSO and SAM, and possible teleconnections;

(5) more thorough seasonal understanding of linked sea-ice and water column ecosystem (a campaign is planned off the Adélie Land coast);

(6) establishment of a mechanistic understanding of the linkages between sea-ice, biogeochemical processes, lower to upper trophic levels and climate.

Although an emphasis is placed in the literature on sea-ice extent, ice extent alone is only a partial descriptor of sea-ice habitat. Other key factors include ice concentration, the mode of ice formation, wind-driven ice dynamics as they determine ice transport and the degree of divergence (lead formation) versus convergence (ice compaction and deformation), snowfall/accumulation, wave-ice interaction processes, the timing of annual ice growth and decay (and length of the annual growth season) and ice-surface flooding. An over-riding factor is the strong coupling between ice and snow cover, ocean and atmosphere. Satellites alone can measure/monitor the vast and remote sea-ice zone at a variety of spatial and temporal scales, and in a systematic fashion. *In situ* observations remain essential, however, to both provide information not attainable from satellites and to validate key satellite-derived products. Snow cover plays a key role in sea-ice 'habitat' considerations in terms of its impact on (i) the thermal and optical properties of the sea-ice substrate, and (ii) the spatio-temporal distribution of ice-surface flooding and surface biological communities.

Alternative sources of information are available on large-scale Antarctic sea-ice distribution and its evolution within the ocean–ice–atmosphere system. Coupled models are the key to better understanding factors determining this distribution, and its predicted response to changing and variable climatic conditions. Recent comparison of the output of the 16 coupled models for the fourth assessment report of the IPCC for 1981 to 2000 versus the satellite record of ice extent reveals wide variability in performance, which has been attributed to the performance of their individual atmospheric and ocean components. General recommendations have been made for better expressions of snow cover, ice rheology and ice–ocean interactions. Regarding predictions for the 21st Century, an average extent decrease of ~25% occurs across 15 of the models. Proxy records enable reconstruction of sea-ice extent in the pre-satellite era (effectively pre-1978). Particularly remarkable is the high-resolution reconstruction back over the past 170 years based on the MSA (methanesulphonic acid)[1] record at Law Dome on the continent in eastern Antarctica. Moreover, diatom records from ocean-floor sediment cores indicate a sea-ice cover at the last glacial maximum that was double its current maximum extent, and research is continuing to both supplement and extend these data. The current status of atmospheric observation and modelling is also a key consideration, given that sea-ice habitat is determined by numerous external forces and conditions, including wind speed and direction, air temperature and precipitation.

In terms of ecosystem response, robust prediction rests on an understanding of the various mechanisms and relationships underlying correlations with measures of the environment and environmental change together with an awareness of the non-linearity of ecosystem responses to environmental change. The latter has strongly emerged from Palmer LTER work on the changing Adélie penguin populations in the West Antarctic Peninsula region, for example. Regional sea-ice conditions over the past 30 years in this case have changed to the extent that given locations are no longer experiencing the same frequency of 'optimal' ice conditions (from a penguin perspective) and major ecological change is resulting. This again underlines the key importance of long time-series data not only covering biological but also key environmental parameters (sea-ice, ocean, atmosphere) (i.e. a committed long-term multi-disciplinary approach).

Regarding marine mammals and birds, little information is currently available on species-specific 'optimal' sea-ice conditions. This baseline information is essential if the impacts of environmental change are to be predicted in a realistic fashion. Of particular importance in this regard is the instrumentation and tracking of seals, birds and whales. Initial comparison of data of southern elephant seal tracks from Macquarie Island, for example, suggests that certain polynyas may be preferred habitat. Similarly, king penguins (*A. patagonicus)* appear to show a preference for feeding at and within the marginal ice zone. In all cases, a great deal of information can be gained by comparing and combining the locational and environmental data with satellite-derived information on sea-ice distribution and characteristics. New information is also emerging on the key importance of changeable fast-ice conditions on the breeding success of emperor penguins (*A. forsteri*) at Dumont d'Urville. A major question is: where are seal/whale seabird 'hot spots' within the sea-ice zone, and when and why?

2.1.2.2 FUTURE RESEARCH PRIORITIES

The Workshop **agreed** that, rather than treating sea-ice as a single amorphous 'habitat', which is not the case in reality, a standardised approach across CCAMLR and the IWC to classifying ice habitats is needed. This would aid cross-

[1] Methanesulphonic acid (MSA) is released by phytoplankton living in and around sea ice and is correlated with sea ice extent (Curran *et al.* 2003)

disciplinary comparisons and provide a framework for awing together the biological and physical (environmental) realms. A possible scheme for such a standardised approach could be the following broad-scale zonal elements:

(1) SSIZ;

(2) the marginal ice zone (the outer zone of the SSIZ affected by wave–ice interaction processes);

(3) the inner pack-ice zone;

(4) regions of perennial sea-ice that persist through summer;

(5) coastal and near-coastal fast-ice;

(6) flaw leads and polynyas (persistent and recurrent open water areas).

2.1.3 Primary production

2.1.3.1 SUMMARY FROM EXPERT GROUP

CCAMLR-IWC-WS-08/13 summarised the satellite ocean colour (chlorophyll *a* : Chl-*a*) data that are currently available, from missions beginning with the Coastal Zone Color Scanner in the late 1970s through to the SeaWiFS and MODIS sensors that have collectively been providing data for the last 10 years. The characteristics of these data and limitations such as cloud cover and high solar zenith angle are discussed with regard to their use in the Southern Ocean. A brief history of algorithms linking ocean colour to primary productivity is presented, focusing on the vertically generalised production model (VGPM) and more recent regional carbon-based approaches. Using monthly climatologies of SeaWiFS Chl-*a*, a phenology of phytoplankton blooms is presented for the major provinces surrounding Antarctica. Some of the published information regarding phytoplankton species composition and succession is summarised. Finally, a review of ecosystem and biogeochemical models for the Southern Ocean is presented, with a focus on those models that have been validated using satellite ocean-colour data.

2.1.3.2 FUTURE RESEARCH PRIORITIES

The Workshop noted the following with respect to utilising satellite ocean-colour data in representing primary productivity and algal biomass:

(1) such data provide good spatial coverage at time scales of one month or greater and can be used to discern interannual trends from chlorophyll climatologies;

(2) the data provide only surface (10–20 m) chlorophyll with an accuracy of around 40%;

(3) any chlorophyll maxima are likely to be at depths deeper than the measurements and therefore the surface measurements may not properly reflect the density of chlorophyll in the water column. Work is needed to identify whether the relative densities of surface chlorophyll reflect the true climatologies of chlorophyll in the Southern Ocean;

(4) estimates of chlorophyll *a* from ocean-colour data may not reflect the relative densities of algal biomass. An important issue to address is the degree to which changes in species composition over the Southern Ocean and over time would impact on the calculations of algal biomass and productivity both spatially and temporally;

(5) biogeochemical models are good for characterising regional processes but their outputs do not match satellite data at present;

(6) ocean-colour sensors cannot measure Chl-*a* concentrations in sea-ice. Thus, the question remains whether hot spots of primary production might occur within the sea-ice zone.

2.2 Pelagic species

2.2.1 General

The Workshop considered the spatial resolution at which data for pelagic species would be needed given the types of questions likely to be addressed using ecosystem models for the Antarctic ecosystem. Although the Antarctic pelagic species interact at a variety of spatial scales, the Workshop **agreed** that most ecosystem models would be based on CCAMLR statistical areas or larger areas. As a result, the data summaries for pelagic species are based on CCAMLR statistical subareas/divisions (see Fig. 1).

In considering species other than krill, the Workshop recognised that a desirable feature of CCAMLR and IWC ecosystem models is to provide alternative pathways to the well recognised (and modelled) phytoplankton–krill–top predators pathway. Several Antarctic studies have now shown that secondary production by copepods exceeds that by krill, thus forming a potentially important link between the microbial system and vertebrate predators (CCAMLR-IWC-WS-08/12). Apart from Antarctic krill (*Euphausia superba*), which is a keystone species in the Antarctic ecosystem, it is not straightforward to select the fish, cephalopod and zooplankton species to be included in an ecosystem model, in part because these species may fill various ecological niches during their lives. In addition, considerable uncertainties exist associated with the abundance and dynamics of almost all species.

The Workshop **agreed** that one way to identify the species (or functional groups) to be included in an ecosystem model designed to evaluate the implications of alternative pathways in the ecosystem was to start with the main top predators of krill and identify the prey species that constitute a large proportion of their diets when krill is not abundant, and then identify the prey species of those prey species, continuing this process until phytoplankton as primary prey is reached.

The Workshop **agreed** that zooplankton and squid should be represented as functional groups given data limitations (see paragraphs 2.2.22 to 2.2.35 (zooplankton) and 2.2.36 to 2.2.46 (squid)), while it might be possible to model individual fish species (e.g. mackerel icefish (*Champsocephalus gunnari*)) if this was deemed necessary or appropriate. It also noted that smaller life stages within functional groups may be vulnerable to predation by larger individuals of the same functional group.

The Southern Ocean ecosystems provide a valuable opportunity for the development of understanding of the importance of trophic interactions in the operation of food webs. Southern Ocean ecosystems are vulnerable to change from climate (bottom-up) and harvesting (top-down) driven process. The Workshop **agreed** that some ecosystem models are needed that have a sufficient degree of complexity to allow adjustments in food-web pathways due to these effects to be an emergent property of the models. This will require a new generation of models that include realistic representations of biological processes operating in ecosystems, where these representations encompass the complex physical and biological interaction processes.

The Workshop noted that distribution was likely to be related to a large number of factors. In principle, if relationships between presence (and perhaps density) and such factors could be developed, these relationships could be used to infer presence (or density) in unsampled areas. Although analyses to determine the environmental factors that determine distribution (and abundance) should be undertaken, a first, and key step towards understanding habitat requirements for the pelagic species is to produce presence-absence maps (such as those in the *Squid Atlas*[2]) and to overlay these with maps of key environmental factors.

The Workshop constructed tables for each species/functional group which summarise information on:

(1) abundance (in absolute and relative terms), generation time, catches (where appropriate), and environmental factors determining abundance;

(2) distribution by season (summer and winter) in terms of northern and southern boundaries and whether the following relate to presence: distance from the shelf break and the PFZ, the presence of sea-ice, sea-surface temperature, depth, chlorophyll concentration, water mass and location around Antarctica. The distribution tables should ideally be constructed by life-history stage;

(3) diet composition in quantitative term and feeding rates (e.g. daily consumption rations).

Annex D provides summaries of life-history information for the four pelagic groups.

This section does not follow the format for the other small group sections of this report because many discussions covered aspects related to abundance, habitat, diet and life history at the same time.

2.2.1.1 FUTURE RESEARCH PRIORITIES
Assess alternative model structures to determine the minimum number of functional groups such that alternative pathways arise as emergent behaviour.

2.2.2 Krill
2.2.2.1 SUMMARY FROM EXPERT GROUPS
The krill expert group focused on methods for obtaining information on krill distribution and abundance. Life-history and process data for the krill species are included in CCAMLR-IWC-WS-08/11. Four basic sources of information were identified: net surveys, acoustic surveys, fisheries data and information from krill predators. Each data source leads to biases and has its methodological problems. Overall, there is a lack of long-term systematically collected data on krill distribution and abundance and the time-series data that do exist are from restricted areas of the Southwest Atlantic. Large-scale synoptic surveys have covered areas of the Southwest Atlantic and the Indian Ocean and the most recent acoustic surveys (BROKE, CCAMLR-2000 and BROKE-West; see Table 1) have provided the largely comparable datasets that have been used by CCAMLR to set precautionary catch limits. These datasets also contain a wealth of ancillary information that are of use in examining ecosystem structure and function in key areas of the Antarctic. Future research needs to concentrate on understanding the errors and biases in the data collection methods.

2.2.2.2 SPECIES/FUNCTIONAL GROUPS
The data for krill are summarised for Antarctic krill, ice krill (*Euphausia crystallorophias*) and bigeye krill (*Thysanoessa . macrura*) because these species are caught in krill fisheries or they constitute an important component of the diet of Antarctic predators.

[2] www.nerc-bas.ac.uk/public/mlsd/squid-atlas

2.2.2.3 ISSUES ARISING FROM METADATA SUMMARIES

There remains considerable uncertainty associated with estimates of abundance from acoustic surveys as they pertain to absolute abundance (e.g. in terms of the area of occurrence and the various estimates of abundance from the CCAMLR-2000 Survey). These latter uncertainties relate primarily to target strength but also to analysis methods.

Krill population fluctuations have been linked to a number of features of the physical environment: (i) the position of major frontal systems (Tynan, 1998; Nicol *et al.*, 2000), (ii) the extent of sea-ice both temporally (Loeb *et al.*, 1997; Atkinson *et al.*, 2004, 2008) and spatially (Nicol *et al.*, 2000), (iii) the duration of winter sea-ice (Quetin and Ross, 2003; Quetin *et al.*, 2007), (iv) water mass movements (Priddle *et al.*, 1988), (v) current flows (Hofmann and Murphy, 2004), and (vi) bathymetric features (e.g. shelf break) (Nicol *et al.*, 2006; Atkinson 2008). Several of these relationships have been established for quite restricted regions and may not apply throughout the Antarctic region. For example, the direct effect of sea-ice on production is not likely to be a major iver in the South Georgia region where sea-ice rarely forms in winter. Given the diversity of environments around Antarctica it is unlikely that universal rules can be developed that will describe the distribution of habitats throughout the Southern Ocean (but see the CCAMLR bioregionalisation, SC-CAMLR-XXVI, Annex 9 and spatial modelling procedures being developed there, e.g. Pinkerton *et al.*, 2008). The large-scale survey datasets collected for CCAMLR could be used to examine these relationships further. Additionally, sectoral analysis of the major physical features, such as using the CCAMLR bioregionalisation, could be used to investigate which of these features might be expected to dominate geographically (Nicol *et al.*, 2007; Atkinson *et al.*, 2008).

Table 1

Selected biomass and time series acoustic studies for krill.

Survey type	Survey area	Survey period	Reference
Biomass			
CCAMLR-2000	Area 48 (South Atlantic)	Jan–Feb 2000	Hewitt *et al.*, 2004
BROKE 1996	Division 58.4.1		Nicol *et al.*, 2000
BROKE-West 2006	Division 58.4.2		Nicol *et al.*, 2008
AKES	Subarea 48.6	Jan–Feb 2008	Iversen *et al.*, 2008
FIBEX	South Atlantic Subarea 48.3	Jan–Mar 1981	El-Sayed, 1994
Time-series surveys			
LAKRIS	Subarea 48.6	2005–2008	Siegel *et al.*, 2008
US AMLR	Subarea 48.1	1988–present	Lipsky *et al.*, 2007
US SO-GLOBEC	Subarea 48.1	2001–2006	Hofmann *et al.*, 2004
US LTER	Subarea 48.1	1991–2007	
BAS	Subarea 48.3	1981–present	
US AMLR	Subarea 48.2	1999, 2008, 2009*	Reiss and Cossio, 2008

*Proposed survey in 2009

Table 2 summarises the information on abundance, distribution for the three krill species and Table 3(c) summarises information on diet for these species. Data on *E. superba* are available from both net and acoustic surveys. Large-scale acoustic surveys have been conducted specifically to determine biomass in several CCAMLR statistical areas. Additionally, net and acoustic surveys have been conducted regularly in several areas to examine interannual variability in krill demographics and biomass. Data on the other two species of krill have been collected in a less systematic fashion and no efforts have been made to survey the entire habitat of these species with the aim to determine their biomass in an area.

Ice krill is a species of krill which forms large aggregations and is found in coastal waters. Its aggregating behaviour and size makes it a suitable candidate for acoustic surveys. However, there are no agreed target strength estimates for this species and its ice-covered habitat poses extreme challenges for acoustic surveys.

Bigeye krill is a smaller species and information on distribution and abundance of this species is available from net surveys. It should be possible to obtain estimates of relative biomass of bigeye krill from the large CCAMLR-related surveys.

2.2.2.4 FEEDBACK FOR EXPERT GROUP

The report of the expert group on krill should be expanded to include ice and bigeye krill. Data on krill abundance in the Ross Sea are available from Italian surveys and JARPA, and the report should be extended to discuss these sources of data. The estimates of abundance should be annotated by CVs (CIs) where these are available. There is a need to update the report of the expert group with information on habitat, life history and diet (some of this information is available in CCAMLR-IWC-WS-08/12). The report should be expanded to include trends in relative abundance from AMLR, LTER and South Georgia time series.

2.2.2.5 FUTURE RESEARCH PRIORITIES

2.2.2.5.1 KEY GAPS

The major knowledge gap for krill remains the lack of accurate estimates of absolute abundance, and the lack of information on krill distribution and abundance in large regions of the Southern Ocean. The lack of time series of estimates of krill abundance is a major limitation for the conditioning of ecosystem models, and stock structure uncertainty is also a major limitation. In addition, it is still unclear how krill abundance and life history vary among regions within basins (e.g. West Antarctic and South Georgia within the South Atlantic) (but see paragraph 2.2.18).

2.2.2.5.2 FURTHER ANALYSES

(1) Collate and summarise studies which have been undertaken or are currently under way to develop conceptual models of the relationship between krill and environmental covariates.

(2) Conduct a quantitative analysis which compares krill abundance with phytoplankton distribution, sea-surface temperature, chlorophyll concentration, and other covariates, based on broad-scale studies.

(3) Estimate time series of relative abundances using data from the AMLR, LTER and South Georgia surveys in light of identified correlations, after correcting the data to ensure that like is being compared with like.

Table 2

Summary of available information on krill.

(a) Distribution. Y – information available; N – no information available.

CCAMLR subarea/ division	Total abundance	Trends in abundance	Relative abundance	Catch history	Environmental correlates	Life history
E. superba						
48.1	N	Y	Y	Y	Y	Y
48.2	N	Y	Y	Y	Y	Y
48.3	N	Y	Y	Y	Y	Y
48.4	N	N	Y	N	Y	Y
48.6**	N	Y	Y	N	Y	Y
58.4.1	N	N	Y	Y+	Y	Y
58.4.2	N	N	Y	Y+	Y	Y
88.1	N	N	N*	Y+	Y	Y
E. crystallorophias						
48.1	N	Y	N	N	Y	Y
48.2	N	N	N	N	Y	Y
48.3	N	N	N	N	Y	Y
48.4	N	N	N	N	Y	Y
48.6	N	N	N	N	Y	Y
58.4.1	N	N	N	N	Y	Y
58.4.2	N	N	N	N	Y	Y
88.1	N	N	Y?	N	N	N
T. macrura						
48.1	N	N	N	N	Y	Y
48.2	N	N	N	N	Y	Y
48.3	N	N	N	N	Y	Y
48.4	N	N	N	N	Y	Y
48.6	N	N	Y	N	Y	Y
58.4.1	N	N	N	N	Y	Y
58.4.2	N	N	N	N	Y	Y
88.1	N	N	Y	N	N	N

* Non-standard acoustic and net survey results available.
** Only net data available.
\+ Data available pre-1990s.

(b) Habitat considerations for the three major species of krill. Y – some relationships have been reported; N – a relationship has not been established; ? – variable relationships have been indicated.

Species	Shelf break	PFZ	Other frontal zones (SBACC, SACCF, slope current)	Water temper-ature	Depth zone	Chl-*a*	Geography (embayments, island groups)	Water-mass structure	Sea-ice
E. superba	Y	Y	Y	Y	Y	?	Y	Y	Y
E. crystallorophias	Y	N	Y	Y	Y	N	Y	Y	Y
T. macrura	Y	Y	N	N	N	N	N	N	N

2.2.2.5.3 RESEARCH PROGRAMMES

(1) Continue to refine methods for analysing data from acoustic surveys so that these surveys are capable of providing reliable estimates of absolute abundance, with known statistical properties.

(2) Develop approaches for scaling information (e.g. on feeding functional relationships) from the individual level to the population level.

(3) Develop conceptual models and then investigate the effect of food quality/ quantity on egg quality and reproductive output.

(4) Conduct further studies to examine the relationship between the winter behaviour of krill and local environmental conditions.

(5) Conduct studies to determine the residence time of krill populations, in relation to physical and geographic features; these results, in addition to those from other (e.g. genetics) studies should also assist in determining krill stock structure.

2.2.3 Zooplankton

2.2.3.1 SUMMARY FROM EXPERT GROUPS

CCAMLR-IWC-WS-08/12 provided a critical evaluation of the strengths and weaknesses of zooplankton data that may be used in Southern Ocean food-web models. There is a plethora of data on Southern Ocean zooplankton, but most is on abundance and biomass, with very little on feeding responses. Most of the data are not in any central database, and CCAMLR-IWC-WS-08/12 provided pointers to where some of the data can be found.

CCAMLR-IWC-WS-08/12 emphasised the dominant role of copepods, with the relative importance of other zooplankton groups varying regionally. A recurring theme in CCAMLR-IWC-WS-08/12 is that straightforward-sounding issues can make compilations of data at best confusing and at worst totally misleading if appropriate allowances are not made. Some of these issues are general to any assimilation of zooplankton datasets, such as the sensitivity of abundance estimates to the variable identification of larval stages. Likewise the time of year, depth of sampling and mesh size of net used have great influence on recorded abundance, since the populations can make seasonal vertical migrations and their pulsed reproduction causes great seasonal changes in size structure and abundance. Other issues are specific to the polar environments. For example, lipid storage leads to appreciably different relationships between vital rates and body mass than are found elsewhere. Likewise stenothermy (narrow temperature tolerance) means that more general literature compilations of metabolic rates with temperature and Q_{10}-type relationships must be applied with great caution in Antarctica. CCAMLR-IWC-WS-08/12 identified datasets and approaches to combat these issues, and suggested four simple functional groups based on biomass and ecology (mesozooplankton, salps, Antarctic krill and remaining macrozooplankton).

CCAMLR-IWC-WS-08/12 also highlighted some of the strengths and weaknesses in methodology and data coverage in feeding studies. The zooplankton show a wide range of feeding behaviour from omnivory to carnivory – there are no true herbivores. The range of food chain types is examined with the conclusion that protozoans/micrometazoa (<200 μm) must indeed be the main grazers in the Southern Ocean, since larger zooplankton typically remove <30% of primary production. This emphasises the dominant role of microbial food chains relative to the classical diatom–krill–top-predator type food chains. Overall, the great diversity in zooplankton size and ecology, combined with their specific adaptations to Antarctica, requires care both in assembling comparable datasets and in modelling their rate processes.

2.2.3.2 SPECIES/FUNCTIONAL GROUP RESOLUTION

The Workshop noted that zooplankton would need to be treated as a set of functional groups rather than individual species in any ecosystem model. It **agreed** that best choice of zooplankton functional groups would depend on the question to be addressed by the ecosystem model, but that the following functional groups might be appropriate given the data available: salps, large (>2 mm) copepods, small (<2 mm) copepods, and amphipods (specifically *Themisto gaudichaudii*), and the discussion at the Workshop focused around these groups. Life-cycle models are available for several key species (e.g. *Calanoides acutus* and *Rhincalanus gigas*) and possibly these could be used as generic models to represent the respective groups (in this case the large copepods).

Microzooplankton are important grazers of primary production (consuming 60–70%) as well as prey for larger zooplankton (Annex D), but there were no microzooplankton specialists at the Workshop. It was noted that some information on the microbial loop was available from studies that had concentrated on biogeochemistry and efforts should be made to access this information. Grouping species into functional groups is an approach when constructing ecosystem models, but the Workshop cautioned that productivity will vary among the species within each functional group, although there is a general relationship between size and generation time (and hence productivity).

2.2.3.3 ISSUES ARISING FROM METADATA SUMMARIES

Mesozooplankton biomass was identified as one quantity for which there are substantial amounts of data available and collected in a consistent manner at circumpolar scales. General data compilation for model input is a much more tractable proposition for mesozooplankton biomass than that for the abundance of individual taxa. Information on life history/diet is obviously more limited, but mesozooplankton impact on primary production is well quantified. Mesozooplankton could be a functional group represented as a forcing function in ecosystem models.

Estimates of zooplankton and krill abundance, numbers and biomass, have been collected in all CCAMLR/IWC statistical areas on a number of scales over the last 80 years. However, these have been gathered by various methods with great variation in sampling intensity and these must to be taken into account. Standardisation is required before spatial and temporal comparisons can be made (CCAMLR-IWC-WS-08/12). The CPR is the one system that has provided a consistent sampling method in the region, being most intensive in eastern Antarctica. The Southern Ocean CPR Survey has been in operation since 1991 and can provide surface distribution maps by species in the southern Indian Ocean to supplement net data using standardised abundance estimates (CCAMLR-IWC-WS-08/12).

While there is substantial information on copepod life cycles and factors affecting distribution, oceanic time-series data are still scarce (CCAMLR-IWC-WS-08/12). Long-term monitoring (>10 years) is being conducted in Subarea 48.1 by LTER and AMLR programs, and in Subarea 58.4 from the CPR data and the JARE annual NORPAC net sampling. These can provide trend data, although many of the JARE samples are still being processed. Trend data are available for copepods for Subarea 48.3 from BAS studies. Correlations between abundance and distribution and environmental data exist in Subareas 48.1, 48.2 and 48.3 for copepods and salps. Correlations could be examined for other areas using the CPR data. There is much less information on trends, life history and information on correlations for *T. gaudichaudii* by area.

The Workshop also recognised that studies used different sampling techniques and that this could make between-study comparisons and hence evaluation of trends difficult (CCAMLR-IWC-WS-08/12). This is further complicated by a general inability to distinguish changes in availability to the sampling gear from those in abundance as well as the high seasonal variation of many zooplankton species.

Table 3 summarises the information on abundance, distribution and diet for salps, large and small copepods and amphipods.

2.2.3.4 FEEDBACK FOR EXPERT GROUPS

The report of the expert group should highlight the various long-term datasets more clearly and identify what would be needed to develop time series of indices of abundance for key functional groups. A table should be added to the paper that lists the major sources of data which, if analysed, could be used for model parameterisation.

2.2.3.5 PRIORITIES FOR FUTURE WORK

2.2.3.5.1 KEY GAPS

There is a large amount of information at the species level. However, this information has yet to be assembled into a format that could be used in ecosystem models. There needs to be a more comprehensive effort to evaluate existing published information.

2.2.3.5.2 FURTHER ANALYSES

(1) More comprehensive effort in compiling existing data including past and current datasets and deposition of the resultant data in an appropriate database (e.g. SCAR-MarBIN and/or databases arising from this Workshop).

(2) Synthesise the relationships between key species and environmental features based on data from multiple surveys (e.g. CCAMLR-2000, BROKE and BROKE-West).

(3) There needs to be a more comprehensive effort to evaluate existing published information for its suitability to identify feeding functional relationships and parameterise them.

2.2.3.5.3 FUTURE RESEARCH PROGRAMMES

(1) Examine, analyse and synthesise existing microzooplankton data to develop parameterisations for incorporation of these into food-web models and to assess the relative importance of this linkage to biogeochemical cycles.

(2) Collect and analyse additional information on diet and feeding rates for key species and functional groups, and use these to estimate functional responses.

(3) Evaluate whether data which are relatively easy to collect (e.g. from satellites) could be used as proxies for the abundance of some of the zooplankton groups.

(4) Use inverse models to obtain first-order estimates of biological rates and interactions.

Table 3a (continued on next page)

Summary of available data for zooplankton: abundance and abundance-environmental correlations. C – Can be calculated from CPR data for individual species, some work at community level, ? – possibly.

CCAMLR subarea/ division	Abundance	Trends	Life history	Corre-lations	>10 yrs monitoring data	Abundance	Trends	Life history	Corre-lations	>10 years monitoring data
Large copepods (>2 mm)						Small copepods (<2 mm)				
48.1	Y	Y		Y	Y	Y	Y		Y	Y
48.2	Y		Y	Y		Y		Y	Y	
48.3	Y	Y	Y	Y		Y	Y	Y	Y	
48.4	Y					Y				
48.5	Y					Y				

48.6	Y			C		Y			C	
CCAMLR subarea/ division	Abundance	Trends	Life history	Corre- lations	>10 yrs monitoring data	Abundance	Trends	Life history	Corre- lations	>10 years monitoring data
58.4	Y	Y	?	C	Y	Y	Y		C	Y
58.5	Y			C		Y			C	
58.6	Y					Y				
58.7	Y					Y				
88.1	Y			C		Y			C	
88.2	Y					Y				
88.3	Y			C		Y			C	
Salps						*T. gaudichaudii*				
48.1	Y	Y	Y	Y	Y	Y	Y			Y
48.2	Y			Y		Y				
48.3	Y			Y		Y				
48.4	Y					Y				
48.5	Y					Y				
48.6	Y					-		Y		
58.4	Y	Y	Y			Y				
58.5	Y					Y				
58.6	Y					Y	Y	Y		
58.7	Y					Y				
88.1	Y					Y				
88.2	Y					?				
88.3	Y					?				
Mesozooplankton biomass										
48.1	Y	Y								
48.2	Y									
48.3	Y									
48.4	Y									
48.5	Y									
48.6	Y									
58.4	Y									
58.5	Y									
58.6	Y									
58.7	Y									
88.1	Y									
88.2	Y									
88.3	Y									

Table 3b

Summary of available data for zooplankton: Environmental factors that affect the distribution of salps and the amphipod *Themisto gaudichaudii*. Large copepods comprise five species, most with fairly well known habitats (i.e. factors affecting distribution). - – no major affect; ? – insufficient data to determine whether there is an effect.

Taxon	Distance from shelf break	Water depth	Sea-ice	Fronts	Temperature	Chl-*a*	Sector
Salps	Yes	Yes	Yes	-	Yes	Yes (prefers moderate Chl-*a*)	-
T. gaudichaudii	?	?	?	-	Yes	-	-
Large copepods	-	-	?	-	Yes	Yes	?
Small copepods	-	-	?	-	Yes	?	?

Table 3c

Summary of available data for zooplankton: Diet and feeding rates (source: section 5 and Tables 6 and 7 of CCAMLR-IWC-SC-08/12).

Taxon	Diet (and variability)	Feeding rate (and variability)
E. superba	Yes	Yes, no info on variation
T. macrura	Yes, but poor info on variation	-
E. crystallorophias	Yes, but poor info on variation	-
Salps	Yes	Limited, variation data only in relation to size
T. gaudichaudii	Yes, but poor info on variation	Limited, no info on variation
Large copepods	Yes	Limited, no info on variation
Small copepods	Yes	Limited, no info on variation

2.2.4 Squid

2.2.4.1 SUMMARY FROM EXPERT GROUPS

CCAMLR-IWC-WS-08/10 provided information about populations, habitat utilisation, population growth rates, foraging activities and catch. Squid are notoriously difficult to sample because they possess excellent eyesight and sound and vibration sensors which, coupled to a jet-propelled escape mechanism, enable all but small specimens to easily avoid scientific sampling gear. Commercial fisheries catch adults, but provide unrepresentative data and there have only been limited exploratory fisheries in Antarctic waters. Most population data that exist have been derived from remains, especially beaks, in the gut contents of higher predators. Total consumption of squid in the Antarctic by seabirds, seals and whales has been estimated from these data to be some 34.2 million tonnes per year, and in the Scotia Sea it is estimated to be is some 3.7 million tonnes. Some 15 to 20 species of squid occur in the diet of predators. These range in size from a mantle length of a few millimetres to >2 m. Consumption of one species of commercial interest, seven star flying squid (*Martialia hyadesi)*, in the Scotia Sea is conservatively estimated to be 0.25 million tonnes per year and possibly up to 0.55 million tonnes.

There are sufficient data from net-caught specimens to enable the distribution of most species to be characterised in relation to oceanic frontal systems, bathymetry and sea-ice extent as well as their general vertical distribution, which is related to time of day. Concentrations of seven star flying squid , and probably other species, are related to the presence of mesoscale oceanographic features in the vicinity of the Antarctic PFZ.

There are no data on population growth rates of Antarctic squid, but it is likely that they are slower growing than temperate species, relatively short-lived and semelparous, have relatively low fecundity and large eggs, pelagic eggs and paralarvae, and slow development. Pelagic squid are all predators and opportunistic foragers, usually feeding on crustaceans in early life and shifting to fish, mostly mesopelagics such as myctophids, as they grow larger. It is unlikely that any pelagic squid are specialist krill feeders, but some, or all, can be expected to feed on krill opportunistically when available. Catch data are limited to experimental fisheries for seven star flying squid that took place on five occasions between 1989 and 2001. Catch rates were at the low end of commercial viability. The so-called colossal squid (*Mesonychoteuthis hamiltoni)* is taken as an occasional by-catch in the longline fisheries for Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*).

2.2.4.2 SPECIES/FUNCTIONAL GROUPS

The Workshop discussed information on squid species for which data are available, but recognised that squid would likely have to be a single functional group in any Antarctic ecosystem model.

2.2.4.3 ISSUES ARISING FROM METADATA SUMMARIES

The most reliable source of data on abundance for squid species in the Antarctic are analyses of stomach content data, although estimates of squid consumption may be biased owing to squid beaks potentially being retained in predator stomachs longer than other prey items as well as being subject to uncertainty due to the imprecision and bias associated with predator numbers and diet.

Consideration could be given to modelling squid as a constant mortality rate on their prey species in ecosystem models given (i) the lack of data on abundance of squid and the inability in the short- to medium-term to develop methods to index the abundance of squid, and (ii) the fact that squid populations are likely to respond quickly to changes in prey abundance.

The Workshop noted that the *Squid Atlas*[3] provided a useful way for modellers to assess likely overlap in species distributions and also indicate relationships between squid abundance and some environmental covariates (ice extent, bathymetry and fronts), but noted that the lack of observations of squid species in the atlas did not imply absence, but could reflect a lack of sampling. Annotating the atlas by locations where sampling was conducted but squid had not been found would help address this issue.

Table 4 summarises the information on distribution and diet for squid. No information on abundance is provided in Table 4 owing to lack of data on abundance for squid.

2.2.4.4 FEEDBACK FOR EXPERT GROUP(S)

The report of the expert panel should be extended to reflect information of life-history strategy.

2.2.4.5 PRIORITIES FOR FUTURE WORK

2.2.4.5.1 KEY GAPS

The lack of information on absolute and relative abundance for squid severely limits the ability to include this component in ecosystem models.

2.2.4.5.2 FUTURE RESEARCH PROGRAMMES

(1) Future distribution maps for squid should include locations where sampling was conducted but squid had not been found.

(2) Continued examination of potential methods to assess absolute and relative abundance for squid species.

[3] www.nerc-bas.ac.uk/public/mlsd/squid-atlas

Table 4a

Summary of available data for squid: relationship between squid species and various covariates.

Family	Species	Geographic distribution	Sources
Onychoteuthidae	*Kondakovia longimana* (Filippova, 1972)	Circumpolar Antarctic	Filippova, 1972; Lu and Williams, 1994; Vacchi *et al.*, 1994; Lynnes and Rodhouse, 2002
	Moroteuthis ingens (Smith, 1881)	Circumpolar Sub-Antarctic	Massy, 1916; Filippova, 1972; Filippova and Yukhov, 1979; Alexeyev, 1994
	Moroteuthis knipovitchi (Filippova, 1972)	Circumpolar Antarctic	Fillipova, 1972; Filippova and Yukhov, 1979; Rodhouse, 1989; Rodhouse *et al.*, 1996; Piatkowski *et al.*, 1998
	Moroteuthis robsoni (Adam, 1962)	Occasional Sub-Antarctic	Rodhouse, 1990
	Notonykia atricanae (Nesis *et al.*, 1998)	Sub-Antarctic	Nesis *et al.*, 1998b
Gonatidae	*Gonatus antarcticus* (Lönnberg, 1898)	Circumpolar Sub-Antarctic	Kubodera and Okutani, 1986; Rodhouse *et al.*, 1996; Nesis, 1999; Anderson and Rodhouse, 2002
Histioteuthidae	*Histioteuthis atlantica* (Hoyle, 1885)	Sub-Antarctic	Kubodera, 1989; Alexeyev, 1994
	Histioteuthis eltaninae (Voss, 1969)	Circumpolar Sub-Antarctic	Lu and Mangold, 1978; Alexeyev, 1994; Piatkowski *et al.*, 1994; Rodhouse *et al.*, 1996
Batoteuthidae	*Batoteuthis skolops* (Young and Roper, 1968)	Circumpolar Antarctic	Young, 1968; Filippova and Yukhov, 1979; Rodhouse *et al.*, 1992b; Rodhouse *et al.*, 1996; Anderson and Rodhouse, 2002; Collins *et al.*, 2004
Psychroteuthidae	*Psychroteuthis glacialis* (Thiele, 1920)	Circumpolar Antarctic	Filippova, 1972; Filippova and Yukhov, 1979; Kubodera, 1989; Rodhouse, 1989; Piatkowski *et al.*, 1990, 1994, 1998; Lu and Williams, 1994; Anderson and Rodhouse, 2002; Collins *et al.*, 2004
Neoteuthidae	*Alluroteuthis antarcticus* (Odhner, 1923)	Circumpolar Antarctic	Odhner, 1923; Dell, 1959; Filippova and Yukhov, 1979; Filippova and Yukhov, 1982; Kubodera, 1989; Rodhouse, 1988; Anderson and Rodhouse, 2002
Bathyteuthidae	*Bathyteuthis abyssicola* (Hoyle, 1885)	Circumpolar Antarctic	Hoyle, 1886, 1912; Odhner, 1923; Roper, 1969; Lu and Mangold, 1978; Lu and Williams, 1994; Rodhouse *et al.*, 1996
Brachioteuthidae	*Slosarczykovia circumantarctica* (Lipinski, 2001)	Circumpolar Antarctic	Kubodera, 1989; Lipinski, 2001; Rodhouse, 1989; Rodhouse *et al.*, 1996; Piatkowski *et al.*, 1994; Anderson and Rodhouse, 2002; Collins *et al.*, 2004
	Brachioteuthis linkovski (Lipinski, 2001)	Occasional Sub-Antarctic	Lipinski, 2001; Cherel *et al.*, 2004
Ommastrephidae	*Martialia hyadesi* (Rochebrune and Mabille, 1887)	Circumpolar Sub-Antarctic	O'Sullivan *et al.*, 1983; Rodhouse and Yeatman, 1990; Rodhouse, 1991; Piatkowski *et al.*, 1991; Uozomi *et al.*, 1991; Alexeyev, 1994; Rodhouse *et al.*, 1996; Gonzalez and Rodhouse; 1998; Anderson and Rodhouse, 2001
	Todarodes filippovae (Adam, 1975)	Circumpolar Sub-Antarctic	Piatkowski *et al.*, 1991; Dunning, 1993; Alexeyev, 1994
Chiroteuthidae	*Chiroteuthis veranyi* (Ferussac, 1825)	Occasional Sub-Antarctic	Alexeyev, 1994; Rodhouse and Lu, 1998
Mastigoteuthidae	*Mastigoteuthis psychrophila* (Nesis, 1977)	Circumpolar Antarctic	Jackson and Lu, 1994; Lu and Williams, 1994; Piatkowski *et al.*, 1994; Rodhouse *et al.*, 1996; Cherel *et al.*, 2004
Cranchiidae	*Galiteuthis glacialis* (Chun, 1906)	Circumpolar Antarctic	Chun, 1910; Dell, 1959; Filippova, 1972; Lu and Mangold, 1978; McSweeney, 1978; Kubodera and Okutani, 1986; Rodhouse and Clarke, 1986; Rodhouse, 1989; Lu and Williams, 1994; Piatkowski and Hagen, 1994; Rodhouse *et al.*, 1996; Nesis *et al.*, 1998a; Piatkowski *et al.*, 1998; Anderson and Rodhouse, 2002
	Taonius sp. (cf. *pavo*)	Occasional Sub-Antarctic	Rodhouse, 1990b
	Mesonychoteuthis hamiltoni (Robson, 1925)	Circumpolar Antarctic	McSweeney, 1970; Filippova and Yukhov, 1979; Rodhouse and Clarke, 1985
Lepidoteuthidae	*Pholidoteuthis boschmai* (Adam, 1950)	Scotia Sea	Nemoto *et al.*, 1985; Offredo *et al.*, 1985

Table 4b

Summary of available data for squid: diet information. All from visual/gut contents apart from *Martialia hyadesi* in the Scotia Sea where the methods were serology +visual/gut contents

Species/location	Size range in mm (*n*)	Prey types	Main prey species	Source
Martialia hyadesi				
South Georgia	278–370	Myctophids, crustacea, cephalopods	*Krefftichthys anderssoni, Protomyctophum choriodon, P. bolini, Gymnoscopelus nicholsi, Euphausia superba, Gonatus antarcticus*	Gonzalez and Rodhouse, 1998
South Georgia	190–310 (61)	Myctophids, euphausids, amphipods	*K. andersoni, Electrona carlsbergi, E. superba*	Rodhouse *et al.*, 1992a
Patagonian Shelf	190–350 (336)	Myctophids, euphausids, amphipods, cephalopods	*K. anderssoni, G. nicholsi, Themisto gaudichaudii, Martialia hyadesi*	Gonzalez *et al.*, 1997
Patagonian Shelf	220–370	Myctophids, euphausids, amphipods, cephalopods	*Protomyctophum tensioni, G. nicholsi, M. hyadesi*	Ivanovic *et al.*, 1998
Scotia Sea	216–260 (25)	Fish, cephalopods	*K. anderssoni, G. nicholsi, Electrona antarctica*	Kear, 1992
South Georgia	225–312 (40)	Amphipods, myctophid fish and cephalopods	*T. gaudichaudii, K. anderssoni, P. choriodon*	Dickson *et al.*, 2004
Moroteuthis ingens				
New Zealand	264–445 (37)	Principally fish >90%; 9% squid	*Stomias boa/Chauliodus sloani, Lampanyctodes hectoris*	Jackson *et al.*, 1998
Macquarie and Heard	150–432 (54)	96% fish myctophids Bathylagus	*Electrona* spp., *Gymnoscopelus* spp., *P. bolini, K. anderssoni*	Phillips *et al.*, 2001
New Zealand, Macquarie, Patagonian Shelf	200–500 (316)	Primarily myctophid fish	*L. hectoris, E. carlsbergi*	Phillips *et al.*, 2003a
Patagonian Shelf	75–375 (100)	Crustacea, myctophids, cephalopods	*G. nicholsi, Loligo gahi, Moroteutis ingens*	Phillips *et al.*, 2003b
South Shetlands	(1)	Krill	*E. superba*	Nemoto *et al.*, 1988
Kerguelen	112–286 (72)	Principally fish, with squid and crustacea	*Arctozenus risso, Paradiplospinosus gracilis, M. ingens*	Cherel and Duhamel, 2003
Kondakovia longimana				
South Shetlands	60–360 (121)	Macroplankton	*E. superba, T. gaudichaudii, T. macrura*, amphipods, chaetognaths, fish, squid	Nemoto *et al.*, 1985, 1988
Moroteuthis knipovitchi				
South Shetlands	140–360 (23)	Krill, fish	Myctophids, *E. superba*	Nemoto *et al.*, 1985, 1988
South Georgia	212–321(8)	Krill, fish	*E. superba, G. nicholsi*	Collins *et al.*, 2004
Moroteuthis robsoni				
South Shetlands	60–100 (5)	Euphausids	*E. superba*	Nemoto *et al.*, 1988
Alluroteuthis antarcticus				
South Shetlands	40–140 (7)	Macroplankton	*E. superba, T. gaudichaudii*, fish, squid	Nemoto *et al.*, 1985, 1988
Scotia Sea	221 (1)	Euphausids, fish	*E. superba*	Kear, 1992
Prydz Bay	(2)	Squid, fish	*Psychroteuthis glacialis, Pleuragramma*	Lu and Williams, 1994
Galiteuthis glacialis				
South Shetlands	100–240 (19)	Macroplankton	*E. superba, T. gaudichaudii,* chaetognaths	Nemoto *et al.*, 1985, 1988
		Macroplankton	Euphausids, amphipods, copepods, chaetognaths	McSweeney, 1978
Prydz Bay	74–493 (3)	Crustacea, fish	*E. superba*	Lu and Williams, 1994
Slosarczykovia circumantarctica				
South Shetlands	40–160 (75)	Krill	*E. superba*	Nemoto *et al.*, 1985, 1988
Scotia Sea	67–113 (3)	Crustacea		Kear, 1992
Gonatus antarcticus				
South Shetlands	40–160 (48)	Krill	*E. superba*	Nemoto *et al.*, 1988
Scotia Sea	57–375 (2)	Unidentified fish		Kear, 1992
Psychroteuthis glacialis				
Scotia Sea	114–360 (13)	Euphausids, fish	*E. superba, Chionodraco, Chaenodraco*	Kear, 1992
Prydz Bay	121–201 (53)	Krill and fish	*Pleuragramma, E. superba*	Lu and Williams, 1994
South Georgia	(4)	Krill	*E. superba*	Collins *et al.*, 2004

2.2.5 *Fish*

2.2.5.1 SUMMARY FROM EXPERT GROUPS

CCAMLR-IWC-WS-08/9 noted that the first attempts to estimate the krill and pelagic food consumption by Antarctic demersal fish were made in the early 1980s based on a few biomass estimates, and mostly qualitative and a few quantitative food studies. These estimates were extended to the mesopelagic realm and the high-Antarctic Zone in the late 1980s and early 1990s when these areas were exploited commercially and a larger number of feeding studies were conducted concomitant with the fishery. Currently, the best estimates of krill consumption by fish are 23–29 × 10^6 tonnes of krill and other pelagic prey taken annually by demersal fish and 7–44 × 10^6 tonnes taken by mesopelagic fish in the Atlantic Ocean sector only. No estimates of consumption by mesopelagic fish can yet be provided for the Indian and Pacific Ocean sectors. Due to the commercial fishery substantially reducing abundant krill predators such as marbled rockcod (*Notothenia rossii*) and mackerel icefish, the importance of demersal fish as predators of krill has been substantially reduced in the last three decades.

Estimates of pelagic prey consumption still have wide confidence limits. Major shortcomings of the consumption estimates for mesopelagic fish are the validity of hydroacoustic biomass estimates conducted in the late 1980s and the scarcity of quantitative food consumption data for some abundant myctophid species. Major shortcomings of the consumption estimates of demersal fish are the inaccuracy of biomass estimates for most abundant fish species, the shortness of most food studies which do not adequately reflect the opportunistic feeding habits of many demersal fish, and the scarcity of quantitative feeding studies during winter. There is evidence from CCAMLR-IWC-WS-08/9 that the importance of krill in fish diets varies substantially with time and location on various scales, and with the suite of prey types available in the different regions in the Southern Ocean.

The imprecise nature of abundance estimates, coupled with a wide range of estimates for daily food consumption in summer and a scarcity of such data for the winter season, means that it is unlikely that fish will be an important component in ecosystem and food-web models in the Southern Ocean in the near future. As a first step in a modelling approach which includes fish, mackerel icefish might be included in modelling approaches currently being undertaken in CCAMLR. Mackerel icefish plays an important role as a predator of krill and as prey for seals and birds for which, at least at South Georgia, sufficiently precise parameter estimates could be developed to serve as input for models. Furthermore, the effects of large changes in abundance and community structure of fish brought about by industrial fishing needs to be considered.

Table 5 summarises the information on abundance, distribution and diet for fish.

2.2.5.2 SPECIES/FUNCTIONAL GROUPS

The Workshop discussed data availability for myctophids and considered them as a single group (owing primarily to the lack of quantitative information and stomach evacuation rates in some of the important krill predators). The Workshop noted that ecosystem models might need to represent fish species using size-, age- or stage-structured models.

2.2.5.3 ISSUES ARISING FROM METADATA SUMMARIES

CCAMLR-IWC-WS-08/9 contained information on the abundance of fish in sections 4.1.1 for mesopelagic fish and sections 4.4.1.1, 4.4.2.1, 4.5., 4.6, 4.7.2 and 4.8.2 for demersal fish. Estimates of abundance of mesopelagic species (myctophids) in the South Atlantic are available from Russian acoustic surveys from 1987 to 1989. However, these estimates should not be used as the basis for ecosystem models owing to uncertainty associated with their calculation and the changes and improvements in both methodology and target strength estimation since the surveys were conducted. The Workshop **agreed** that more was known about the distribution of mesopelagic fish than their abundance, at least for some of the myctophid species.

In contrast to the situation for mesopelagic fish, survey estimates of abundance are available for demersal fish in some CCAMLR statistical areas (see Table 5). These surveys are unlikely to provide absolute estimates of abundance owing to catchability differing from unity for most species. Rather, these data should be included in ecosystem models as a source of information on trends in relative abundance.

Table 5 (continued on next page)

Summary of available data for fish. Rows are only included in this table if the species concerned is found in the subarea/division. Y – data are available; L – little data available; N – no data available.

CCAMLR subarea/ division	Relative abundance	Trends in relative abundance	Catch history	Habitat	Life history	Quantity food composition	Daily food consumption	Environment
Notothenia rossii								
48.3	Y	Y	Y	L	Y	Y	Y	L
48.2	N	L	Y	N	N	N	N	N
48.1	Y	Y	Y	L	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
58.5.1	Y	N	Y	N	Y	N	N	N

CCAMLR subarea/ division	Relative abundance	Trends in relative abundance	Catch history	Habitat	Life history	Quantity food composition	Daily food consumption	Environment
58.5.2	Y	N	N	N	N	N	N	N
58.4.4	N	N	N	N	N	N	N	N
Champsocephalus gunnari								
48.3	Y	Y	Y	L	Y	Y	Y	Y
48.2	Y	N	Y	N	Y	N	N	N
48.1	Y	Y	Y	L	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
58.5.1	Y	N	Y	N	Y	N	N	L
58.5.2	Y	Y	Y	N	Y	N	N	L
Gobionotothen gibberifrons								
48.3	Y	Y	Y	N	Y	Y	Y	N
48.2	Y	Y	Y	N	Y	N	N	N
48.1	Y	Y	Y	N	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
Chaenocephalus aceratus								
48.3	Y	Y	Y	N	Y	Y	Y	L
48.2	Y	Y	Y	N	Y	N	N	N
48.1	Y	Y	Y	N	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
Pseudochaenichthys georgianus								
48.3	Y	Y	Y	N	Y	Y	Y	L
48.2	Y	Y	Y	N	N	N	N	N
48.1	Y	Y	Y	N	N	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
Lepidonotothen larseni								
48.3	Y	Y	N	L	Y	Y	Y	L
48.2	Y	N	N	N	Y	N	N	N
48.1	Y	Y	N	L	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
58.6 and 58.7	Y	N	N	N	N	N	N	N
58.5.1	N	N	N	N	N	N	N	N
58.5.2	N	N	N	N	N	N	N	N
58.4.4	N	N	N	N	N	Y	Y	N
Lepidonotothen squamifrons								
48.3	Y	Y	Y	N	Y	Y	Y	N
48.2	N	N	N	N	N	N	N	N
48.1	Y	Y	N	N	Y	Y	Y	L
48.4 and 48.6	N	N	N	N	N	N	N	N
58.6 and 58.7	N	N	N	N	N	N	N	N
58.5.1	Y	Y	Y	N	Y	N	N	N
58.5.2	Y	N	N	N	Y	N	N	N
58.4.4	N	N	Y	N	Y	N	N	N
88.1 and 88.2	N	N	N	N	N	N	N	N
Dissostichus eleginoides								
48.3	Y	Y	Y	N	Y	Y	Y	N
48.2	N	N	N	N	N	N	N	N
48.1	N	N	N	N	N	N	N	N
48.4 and 48.6	N	N	Y	N	Y	N	N	N
58.6 and 58.7	Y	Y	Y	N	Y	N	N	N
58.5.1	Y	Y	Y	N	Y	N	N	N
58.5.2	Y	Y	Y	N	Y	N	N	N
58.4.4	N	N	Y	N	N	N	N	N
58.4.3	N	N	Y	N	N	N	N	N
58.4.2	N	N	Y	N	N	N	N	N
58.4.1	N	N	Y	N	N	N	N	N
Dissostichus mawsoni								
48.2	Y	N	N	N	N	N	N	N
48.1	Y	N	N	N	N	Y	Y	N
48.4 and 48.6 southern part	N	N	Y	N	N	N	N	N
58.4.3	N	Y	Y	N	N	N	N	N
58.4.2	N	Y	Y	N	N	N	N	N
58.4.1	N	N	Y	N	N	N	N	N
88.1 and 88.2	Y	Y	Y	N	Y	N	N	Y

2.2.5.4 FEEDBACK FOR EXPERT GROUP(S)

The report of the expert group needs to be extended to include information on habitat, and a brief outline of the major biological characteristics of mesopelagic and demersal fish.

2.2.5.5 PRIORITIES FOR FUTURE WORK

2.2.5.5.1 KEY GAPS

The paucity of data for a group of key fish predators (mesopelagic fish) is a major uncertainty for parameterising ecosystem models for the Antarctic region. Data on diet, abundance and habitat are more complete for demersal fish, but the inability to express abundance in absolute terms restricts the use of abundance data in ecosystem models.

2.2.5.5.2 FURTHER ANALYSES

(1) Examine whether it is possible to re-analyse past myctophid surveys to develop estimates of abundance.

(2) Compare net-based and acoustics-based indices of relative abundance for mesopelagic fish.

Produce maps for each fish species (e.g. using the fish distribution maps in Gon and Heemstra, 1990) which show where they are found and where sampling has been conducted but the species was not found, and overlay these with maps of key environmental covariates.

2.2.5.5.3 FUTURE RESEARCH PROGRAMMES

Research on mesopelagic fish should focus on:

(1) reliable estimation of the target strength of myctophids and other mesopelagic fish;

(2) reliable estimation of biomass and its changes over time (month, year);

(3) estimation of daily food intake for the most abundant myctophid species;

(4) estimation of daily food consumption by abundant mesopelagic fish other than myctophids (e.g. Antarctic Jonas fish (*Notolepis coatsi*) and common name? (*Paradiplospinus gracilis*)).

Studies on demersal and mesopelagic fish in the future need to focus on:

(1) use of an ROV (in combination with trawling to allow the question of how trawls integrate over multiple mesoscale habitats to be addressed);

(2) use of properly designed surveys to estimate biomass and its trends;

(3) estimation of prey availability;

(4) winter feeding studies;

(5) estimation of daily food intake and food requirements of fish.

2.3 Seals and seabirds

2.3.1 Summary of expert group reports

2.3.1.1 PACK-ICE SEALS

CCAMLR-IWC-WS-08/6 reviewed population surveys and abundance estimates for the four seal species that breed in the sea-ice (crabeater seal (*Lobodon carcinophagus*), leopard seal (*Hyurga leptonyx*), Ross seal (*Ommatophoca rossii)*, Weddell seal (*Leptonychotes weddellii*). The spatial scope covers the circumpolar extent of pack-ice, and the temporal scope spans a period of more than 50 years from when pack-ice seal surveys were first undertaken and reported in the 1950s to the present day. The review was presented chronologically, and in doing so tried to provide a sense of the evolution and development of methodologies over a 50-year period of application. The methodologies employed in individual survey efforts were described, and likely biases and uncertainties in resulting abundance estimates discussed. It was concluded that estimating trends in abundance was difficult because there have been few repeat surveys in the same regions, methodologies have evolved over time, and uncertainty around abundance estimates is substantial.

2.3.1.2 ANTARCTIC FUR SEALS

CCAMLR-IWC-WS-08/7 reviewed data on abundance, habitat utilisation, population growth and foraging for the Antarctic fur seal (*Arctocephalus gazella*). Abundance data are available for the major known breeding localities, although recent surveys of the largest part of the population breeding at South Georgia are relatively old (1991) and a recent survey is still in progress. Data on habitat utilisation are available from several sites from remote tracking. Diet and foraging behaviour are well described during the lactation period. Catch was not considered.

2.3.1.3 PENGUINS

CCAMLR-IWC-WS-08/8 reviewed the availability of data for deriving breeding abundance estimates for the four krill-consuming penguins (macaroni (*Eudyptes chrysolophus*), Adélie (*Pygoscelis adeliae)*, chinstrap (*P. antarctica*), gentoo (*P. papua*)) in the CCAMLR Convention area and the uncertainties in deriving regional abundance estimates from these counts. The available count data comes from a variety of sources and survey efforts, and when combined, was thought to be reasonably comprehensive for some regions but less complete for others. Key problems identified in the paper were variety and variability in the demographic units counted, and the variable age of count data across sites. It was recommended that modelling approaches may be useful in addressing biases and uncertainties when deriving abundance estimates from these count data.

2.3.1.4 FLYING BIRDS

CCAMLR-IWC-WS-08/18 reviewed information relevant to estimation of food consumption for 34 species of flying seabirds in the Southern Ocean. The paper collated information on population size, diet and energetic requirements for each of the species and derived estimates of overall consumption.

2.3.2 Species/functional groups

The Workshop reviewed the species that were included in the expert group reports.

It was considered that the southern elephant seal (*Mirounga leonina*), which breeds in areas both inside and outside the CAMLR Convention Area, but spends a considerable amount of their time, outside the breeding season, foraging in the CAMLR Convention Area where they acquire a significant component of their annual energy budget, should be considered in future work.

It was **agreed** that the four penguin species reviewed in CCAMLR-IWC-WS-08/8 were relevant but that considering only krill consumers may be restrictive for the purposes of the Workshop. It was therefore **recommended** that two additional species, the emperor penguin and king penguin, be considered in future work.

It was noted that the flying seabird species considered in CCAMLR-IWC-WS-08/18 included all species whose distribution overlapped the CAMLR Convention Area, and **recommended** that a reduced list of species include only those breeding in the CAMLR Convention Area, and visitors to the CCAMLR area that were considered to be present in appreciable numbers. A reduced list based on these criteria is provided in Table 6. It was suggested that the flying birds could be grouped into functional categories such as large albatrosses, small albatrosses and giant petrels, large procellariformes, small procellariformes (Pteroomas etc.), diving and storm petrels, and coastal species. The Workshop also recognised this was still a substantial number of species, and **recommended** the expert group consider whether further prioritising of species is appropriate in future work.

Table 6

Revised list of penguin and flying seabird species for consideration in future work. Future consideration of visitors needs to take into account the difficulty of determining the timing and distribution of visitation. Vagrants are not included.

	Breeding		
Aptenodytes forsteri	Emperor penguin	*Fulmarus glacialoides*	Southern fulmar
Aptenodytes patagonicus	King penguin	*Thalassoica antarctica*	Antarctic petrel
Pygoscelis papua	Gentoo penguin	*Daption capense*	Cape petrel
Pygoscelis adeliae	Adélie penguin	*Pagodroma nivea*	Snow petrel
Pygoscelis antarctica	Chinstrap penguin	*Procellaria aequinoctialis*	White-chinned petrel
Eudyptes chrysolophus	Macaroni penguin	*Sterna vittata*	Antarctic tern
		Halobaena caerulea	Blue petrel
Diomedea exulans	Wandering albatross		
Thalassarche melanophrys	Black-browed albatross	*Pachyptila desolata*	Antarctic prion
Thalassarche chrysostoma	Grey-headed albatross	*Pachyptila crasirostris*	Fairy prion
Phoebetria palpebrata	Light-mantled sooty albatross	*Oceanites oceanicus*	Wilson's storm-petrel
		Fregetta tropica	Black-bellied storm-petrel
Macronectes giganteus	Southern giant petrel	*Pelecanoides georgicus*	South Georgia diving petrel
Macronectes halli	Northern giant petrel	*Pelecanoides urinatrix*	Common diving petrel
Catharacta lonnbergi	Brown skua	*Phalacrocorax atriceps*	Imperial shag
Catharacta maccormicki	South polar skua		
Larus dominicanus	Kelp gull		
	Visitors		
Diomedea sanfordi	Northern royal albatross	*Pterodroma lessonii*	White-headed petrel
Diomedea epomophora	Southern royal albatross	*Pterodroma mollis*	Soft-plumaged petrel
Thalassarche impavida	Campbell albatross		
Pterodroma brevirostris	Kerguelen petrel	*Pachyptila belcheri*	Slender-billed prion
Pterodroma inexpectata	Mottled petrel	*Puffinus griseus*	Sooty shearwater
		Puffinus tenuirostris	Short-tailed shearwater

The Workshop **recommended** that, given the commonality in issues related to habitat utilisation, life history and foraging, that future work may be efficiently considered within two broad groups: seals and seabirds.

2.3.3 Spatial stratification

The Workshop **agreed** that the following broad spatial stratification for summarising parameter data for all seals and seabirds would be useful.

Ross Sea	Subareas 88.1 and 88.2
Amundsen Sea	Subarea 88.3
Antarctic Peninsula/Scotia Sea	Subareas 48.1, 48.2, 48.3 and 48.4
Weddell Sea	Subarea 48.5 and 48.6
East Antarctica	Divisions 58.4.1 and 58.4.2
Indian Ocean sub-Antarctic islands	Subareas 58.5, 58.6, 58.7.

Having considered these general issues, the Workshop then reflected on the current work of the expert groups and **recommended** priorities and directions for future work. These recommendations are addressed below by parameter, and by broad species groups (seals and seabirds) within parameters.

2.3.4 Issues related to metadata summaries and feedback for the expert groups

2.3.4.1 ABUNDANCE

2.3.4.1.1 SEALS

Considerable progress has been made in summarising information on abundance and trends in abundance for pack-ice seals and the Antarctic fur seal. As neither of the seal expert groups was originally tasked with summarising abundance information on the southern elephant seal, but the Workshop **recommended** this species now be considered, this species is **recommended** to be considered in future work. The Workshop recognised that substantially different methods are required for estimating abundance for pack-ice seals, which are widely dispersed over large areas, compared to Antarctic fur seals and the southern elephant seal, which are surveyed when aggregated into dense colonies at their breeding sites. This fundamental difference in life history also means that different components of the population are available to surveys for the ice-breeding and land-breeding species, and that methods for estimating abundance need to account for these differences. For example, surveys of pack-ice seals are thought to include most or all population components (adults, juveniles, breeders, non-breeders) if conducted at an appropriate time, but surveys of Antarctic fur seals and southern elephant seals at breeding sites only include breeding adults and/or pups. Therefore, colony-based population counts must incorporate some method to incorporate non-breeding individuals in the population assessment.

With regard to pack-ice seals, the subgroup welcomed the recent completion of analyses of APIS surveys, and indicated that completion of analysis of APIS data from the eastern Weddell Sea would be valuable for the development ecosystem models. It was noted that trends are of similar importance to status in ecosystem modelling, and indicated that the expert group's conclusion that trend estimation from APIS and earlier surveys is difficult has important implications for ecosystem modelling efforts. It was **recommended** that, wherever possible, new surveys employing new methodologies ensure that some linkage to past surveys is possible by including essential comparable elements of methodology.

Pack-ice seal abundance estimates are summarised in CCAMLR-IWC-WS-08/6 for the scale at which surveys were conducted, which varied substantially between surveys. Development of abundance estimates for areas of specific interest to CCAMLR or the IWC may require re-analysis, splitting or merging of data from different survey efforts. Alternatively, as abundance estimates for the most recent APIS surveys were derived from spatial predictive models, the models might be used to predict abundance over different areas to those from which they were developed.

In addition to a summary of abundance estimates and a discussion of the potential biases in abundance estimates for Antarctic fur seals, CCAMLR-IWC-WS-08/7 included a list of publications pertaining to abundance estimation for the Antarctic fur seal that can form the basis of a metadata summary. The subgroup noted that a survey currently in progress at the major fur seal colony at South Georgia, if completed in 2008/09, will substantially improve knowledge of fur seal abundance. The Workshop also noted that estimation of the non-breeding population is not addressed by the survey efforts and would need to be addressed through demographic modelling. A survey of Antarctic fur seal abundance at the South Shetland Islands has recently been completed and results should be available in the near future. As for pack-ice seals, knowledge of trends in Antarctic fur seals will facilitate ecosystem modelling efforts, and in this regard it was felt that further consideration of long term trends in Antarctic fur seal abundance is important.

Known breeding colonies of Antarctic fur seals are restricted to a few localities (primarily South Georgia and the South Shetland Islands), so scaling-up estimates is simply a matter of merging estimates across localities.

The Workshop **recommended** that an overview summary of availability of abundance and trend information be compiled for all seal and seabird species in a single table structure. This table was populated for the four pack-ice species during the Workshop (Tables 7 to 10).

Table 7

Overview summary of availability of abundance and trends data for the crabeater seal. RS=Ross |Sea; AS=Amundsen Sea; APSS=Antarctic Peninsula Scotia Sea; WS=Weddell Sea; EA=East Antarctica. Y – yes; N – no; 1999/2000 – austral summer; B – breeding; NB – non-breeding. No data for the sub-Antarctic Islands

	RS	AS	APSS	WS	EA
Is there a population estimate?	Y	Y	Y	N	Y
Confidence/uncertainty in estimate	Y	Y	Y	N	Y
Is there trend data (population or other parameter)?	N	N	N	N	N
Confidence/uncertainty in trend	N	N	N	N	N
Number of sites (spatial cover of count effort)	-	-	-	-	-
Year of most recent count	1999/2000	1999/2000	1999/2000	-	1999/2000
Component of population estimated? (B, NB, All)	All	All	All	-	All

Table 8

Overview summary of availability of abundance and trends data for the Ross seal. RS=Ross |Sea; AS=Amundsen Sea; APSS=Antarctic Peninsula Scotia Sea; WS=Weddell Sea; EA=East Antarctica. Y – yes; N – no; 1999/2000 – austral summer; B – breeding; NB – non-breeding. No data for the sub-Antarctic Islands

	RS	AS	APSS	WS	EA
Is there a population estimate?	Y	Y	N	N	Y
Confidence/uncertainty in estimate	Y	Y	N	N	Y
Is there trend data (population or other parameter)?	N	N	N	N	N
Confidence/uncertainty in trend	N	N	N	N	N
Number of sites (spatial cover of count effort)	-	-	-	-	-
Year of most recent count	1999/2000	1999/2000	1999/2000	-	1999/2000
Component of population estimated? (B, NB, All)	All	All	All	-	All

Table 9

Overview summary of availability of abundance and trends data for the leopard seal. RS=Ross |Sea; AS=Amundsen Sea; APSS=Antarctic Peninsula Scotia Sea; WS=Weddell Sea; EA=East Antarctica. Y – yes; N – no; 1999/2000 – austral summer; B – breeding; NB – non-breeding. No data for the sub-Antarctic Islands

	RS	AS	APSS	WS	EA
Is there a population estimate?	Y	Y	Y	N	Y
Confidence/uncertainty in estimate	Y	Y	Y	N	Y
Is there trend data (population or other parameter)?	N	N	N	N	N
Confidence/uncertainty in trend	N	N	N	N	N
Number of sites (spatial cover of count effort)	-	-	-	-	-
Year of most recent count	1999/2000	1999/2000	1999/2000	-	1999/2000
Component of population estimated? (B, NB, All)	All	All	All	-	All

Table 10

Overview summary of availability of abundance and trends data for the Weddell seal. RS=Ross |Sea; AS=Amundsen Sea; APSS=Antarctic Peninsula Scotia Sea; WS=Weddell Sea; EA=East Antarctica. Y – yes; N – no; 1999/2000 – austral summer; B – breeding; NB – non-breeding. No data for the sub-Antarctic Islands

	RS	AS	APSS	WS	EA
Is there a population estimate?	Y	Y	Y	N	N
Confidence/uncertainty in estimate	Y	Y	Y	N	N
Is there trend data (population or other parameter)?	N	N	N	N	N
Confidence/uncertainty in trend	N	N	N	N	N
Number of sites (spatial cover of count effort)	-	-	-	-	-
Year of most recent count	1999/2000	1999/2000	1999/2000	-	-
Component of population estimated? (B, NB, All)	All	All	All	-	-

2.3.4.1.2 BIRDS

The Workshop recognised that knowledge of abundance for penguins and flying seabirds could, in principle, be derived from surveys of breeding populations at breeding sites, and at-sea surveys. As with land-breeding seals, abundance estimates derived from colony counts must include corrections and or assessments of non-breeding individuals that are not observed on the colony. At-sea surveys, in contrast, include both breeding and non-breeding birds.

CCAMLR-IWC-WS-08/8 reviewed issues involved in estimating penguin breeding population abundance from land-based survey methods. The report included a very useful discussion of the general issues involved in estimating the abundance and its uncertainty. It was **recommended** that future work include, where possible, specific information on abundance data and estimates, even if preliminary and not yet accounting for known biases and uncertainties but that the attendant potential uncertainties and biases be described. It was noted that extending the estimates of breeding abundance to total abundance to enable total prey consumption may also be necessary for ecosystem modelling. The Workshop **recommended** that future work on abundance by the expert group could focus on both these issues.

Penguin count data have been collected at the scale of the breeding colony. Given this scale of data collection, the Workshop recognised it would be possible to combine data across colonies to any desired level for regional abundance estimation, and **recommended** that future work in abundance estimation should build in flexibility in the scale of estimation to estimation procedures in order to satisfy any scale requirements of future ecosystem models.

CCAMLR-IWC-WS-08/18 indicated that the knowledge of flying seabird abundance was poor and errors were impossible to estimate from cited sources, which were not the original reports. The Workshop **recommended** that it would be desirable for future work on flying seabird abundance, if feasible; to review the original sources of abundance data in order to better understand the biases and uncertainties inherent in abundance estimates. This would require a substantial effort, and a larger expert group, to complete.

2.3.4.2 HABITAT

2.3.4.2.1 GENERAL CONSIDERATIONS

Apex predators occur in areas where oceanographic features such as currents, sea-ice, frontal systems, thermal layers, sea mounts and continental shelf breaks increase the availability or predictability of prey. All these oceanographic features and processes are thought to impact marine predator distributions by physically forcing prey aggregations and, thus, creating areas where foraging efficiency can be increased. Indeed, for many marine predators, regions of highly localised productivity may be essential for reproduction and survival. In the Antarctic there is also the role of sea-ice in directly affecting the foraging ability of seals and birds.

Many of these studies use ship or aerial surveys to assess abundance and then correlated the observed distribution with oceanography. Although these studies have been and continue to be quite informative, they do not provide insights into the strategies employed by individual animals to locate prime habitats (or is this food), nor can they provide insights into the spatial or temporal course of these interactions. Advances in satellite telemetry, electronic tags, and remote sensing methods provide tools that allow us to follow the movements and behaviour of individual animals. These approaches are making it possible to extend our understanding beyond simple linkages of prey and predator distributions with environmental features to the identification of specific behaviours with specific environmental conditions. A comparison of the advantages and disadvantages of the two approaches of studying top marine predators can be seen in Table 11.

Table 11

Comparison of survey and tagging methods to determine the distribution of marine animals.

Survey	Electronic tags
Advantages Can sample hard to study species Environmental Data Physical Environment CTD, chlorophyll	Advantages Long time series Animal behaviour Dive pattern Animal movements Home range Habitat utilisation Environnemental data Physical environnent CTD, chlorophyll
Disadvantages Snapshot Only know about area surveyed Biased measure of range Sample bias Animal behaviour	Disadvantages Must be able to tag animal. No direct measure of abundance. Environmental and habitat data primarily relate to where the animals have been. Other data are needed to identify environmental attributes of where the animals did not spend sufficient time to estimate those attributes.

The Workshop **recommended** that future work on habitat utilisation could include consideration of both tagging and at-sea survey data in order to provide the most complete assessment of habitat utilisation.

The Workshop considered that a consistent format for developing habitat metadata summaries across seal and bird groups would facilitate a coherent approach to this issue, and designed a template for summarising habitat utilisation data (Table 12). The **recommended** approach identifies a temporal and spatial (horizontal and vertical) stratification.

2.3.4.2.2 SEALS

The expert group on pack-ice seals has not yet been able to review the state of knowledge on seal habitat utilisation. The template (Table 12 developed by the Workshop is **recommended** to structure and standardise future work by the expert groups).

Table 12

Template for habitat utilisation summary

		Summer (21 Dec–20 Mar)	Autumn (21 Mar–20 June)	Winter (21 June–20 Sep)	Spring (21 Sep–20 Dec)
Species 1	Horizontal distribution				
	Vertical distribution				
Species 2	Horizontal distribution				
	Vertical distribution				

Vertical distribution categories: Surface (S); Lunge diver (L); Epipelagic diver (E); Mesopelagic diver (M); Benthic-demersal diver (BD)
Horizontal distribution categories: Polar Frontal Zone (PFZ); Marginal ice zone (MIZ); Interior annual pack-ice (IAPI); Interior perennial pack-ice (IPPI); Fast-ice (FI); Coastal polynya (CP); Continental shelf break (CSB); Continental shelf CS).

2.3.4.2.3 BIRDS

As for seals, the penguin and flying seabird expert groups have not yet been able to review information on habitat utilisation. The Workshop **recommended** that future work on habitat by the penguin expert group should include the development of metadata using the habitat table template provided in Table 12.

2.3.4.3 DIET, FORAGING AND LIFE HISTORY

2.3.4.3.1 GENERAL CONSIDERATIONS

Many of the issues relating to the trophic linkages/diet are common to seabirds and seals as data are generally restricted to the period when adults are provisioning offspring and this causes a limitation to both the spatial and temporal coverage. The restriction in the availability of diet data outside the period of offspring provisioning was recognised as a substantial limitation in characterising the trophic linkages.

A common suite of techniques are available for determining the diet for seals and seabirds, including direct regurgitates (from birds), stomach lavage (seals), scats (seals, especially fur seals) and serological methods and fatty acid profile analysis, stable isotope analysis and prey DNA identification. All these methods provide different data on the diet of individual species and have limitations and advantages with respect to other methods. The most productive approach to understanding diet will come from the use of an ensemble of techniques. This will be especially important where there are known biases in one of the methods (e.g. over-representation of squid beaks in stomachs due to retention of beaks). The Workshop **recommended** that a standardised approach to summarising diet information would facilitate a coherent approach across species groups in future work. A template for summarising diet information is provided in Table 13.

Table 13

Template for diet summary

Key: techniques - Regurgitate, Lavage, Scat, Fasa, Isotope, DNA; region - Ross Sea/Amundsen Sea/Antarctic Peninsula-Scotia Sea/Weddell Sea/East Antarctica/Indian Ocean sub-Antarctic Islands; season - 1 – spring, 2 – summer, 3 – autumn, 4 – winter (use actual dates)

	Data	Technique	Region (data available)	Season (region, data available)
Crabeater seals	Y	R, S	-/y/-/-/y/-	-/1,3/-/-/2,3,4/-
Antarctic prion	Y	R	-/-/y/-/-/y	-/-/2/-/-/2

Diet data for seabirds and seals are recognised to exist in summary databases, including CEMP and other compilations. The Workshop recognised that where diet data are presented it is important to present the range of data in order to represent uncertainty/variability rather than to decide on a representative/best study. The compilation of such a summary metadata table is a priority.

The Workshop recognised that there was a paucity of data on what seabirds and seals eat outside the period when diet have been sampled; both as a function of where they go and what they eat when they are in the regions they inhabit outside the breeding season.

There are generally very few data that provide information on the concurrent measurement of prey consumption and independent measures of prey availability at comparable scales of the predator foraging event. If obtained across the foraging area of the population as a whole, these measurements are essential for constructing the functional relationships required for modelling. The Workshop considered this further under general issues.

Estimation of feeding rates from diet requires knowledge of the energy requirements of the predator, the energy content of the diet and the efficiency by which prey are converted to energy. With respect to seals and seabirds there is considerable information on the Field Metabolic Rate (FMR) of many species during the breeding season. There is substantial information on the overall energetic costs associated with rearing the young. For example, data exists on rates of prey delivery to some species of penguins and albatross chicks and to reproduction in Weddell, elephant and fur seals. However, there is minimal data on the energetic costs associated with reproduction in Ross, crabeater and leopard seals. For species where direct data are not available, rates of prey intake can be derived from the information currently available for the other species of birds and seals.

Marine environments are quite dynamic with resource availability varying amatically in both space and time. Reliably finding resources in such a variable environment is limited to a range of foraging patterns where temporal and spatial variation match. Consequently, some marine vertebrates are thought to have evolved a suite of life history traits that allow species to match the spatio-temporal variability in resource acquisition (i.e. foraging) with the demands of reproduction and self-maintenance. For land-breeding bird and seal species, reproduction is further constrained by the need to breed on land but feed at sea. The separation between breeding and feeding habitats can be characterised by two general life-history patterns: (i) income breeders (most seabirds, and fur seals), where the young are provisioned from resources that are acquired as they are needed; and (ii) capital breeders (true seals and baleen whales) where resources are acquired and stored over a long period of time prior to the reproductive event. As capital breeders obtain all of the resources necessary to provision their offspring after one very long trip to sea prior to parturition, they are able to forage over spatial scales exceeding 1 000s km from their breeding site. In contrast, most income breeders return to provision their offspring frequently and are therefore limited to trips lasting a few hours to a few days. Income breeders are thus limited to foraging at distances of 10s to 100s km from the colony. Albatrosses represent an extreme form of income breeder and can forage over large spatial scales, often covering 1 000s km in a matter of days.

The Workshop considered the attributes of life history that may be important in developing ecosystem models. Important attributes included age at first breeding, frequency of breeding, adult and juvenile survival, maximum clutch size, the duration and timing of the breeding season, and whether moult is continuous or distinct. A template for summarising this information is provided in Table 14.

Table 14

Template for life-history summary. Where appropriate information on confidence intervals around point estimates, potential biases and interannual variability are highly desirable

By Species	Parameter estimate or description
Age-at-first breeding	
Breeding frequency	
Juvenile survival	
Adult survival	
Maximum clutch size	
Breeding season: timing	
Breeding season: duration	
Moult (continuous or distinct)	

2.3.4.3.2 SEALS

The Workshop noted that the pack-ice seal expert group has not yet been able to review information on diet, foraging and life history. CCAMLR-IWC-WS-08/7 indicated that diet data for Antarctic fur seals are available from breeding sites (some year-round, some during the breeding season only), and provided a list of papers relating to diet and foraging. Information on life history has not yet been reviewed. It was **recommended** that future work should include the development of metadata using the templates described above.

2.3.4.3.3 SEABIRDS

The Workshop noted that the penguin expert group had not yet been able to review diet, foraging and life history information for penguins. The flying seabird report included information on diet, but the group has not yet been able to review life-history parameters.

The Workshop recognised that the tasks originally assigned to all expert groups were very substantial, and that it was a very difficult task for the expert groups to address all the issues prior to the Workshop.

2.3.5 Future work

The Workshop considered future work for seals and birds under this item and this is reported in paragraphs 4.13 to 4.19.

2.4 Whales

2.4.1 Summary from expert groups

CCAMLR-IWC-WS-08/4 addressed the abundance, trends, exploitation history, and foraging parameters of six baleen whales; humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), fin (*B. physalus*), sei (*B. borealis*), Antarctic minke (*B. bonaerensis*), and southern right whales (*Eubalaena australis*) in the southern hemisphere. The majority of survey data have come from the area of open-ocean south of 60°S to the ice edge. The review focused on: (i) population abundance, trend and stock structure; (ii) habitat utilisation including migration, spatial structure at peak concentrations and foraging areas; (iii) foraging activities including diet and consumption; and (iv) catch as annual summaries by species and broad-scale areas or breeding populations. Consideration has also been given to possible biases and uncertainty in the data. In the review, emphasis has been given to information obtained in the high latitudes (feeding grounds), but in some cases data from low latitudes (winter/breeding) grounds have been included to complement or contrast what is known from feeding grounds and to include information on whales throughout their range. In some instances, parameters are either estimated across IWC management units or as parts of management units and are scaled accordingly. Data have been sourced from international research programmes such as those conducted by the IWC and CCAMLR (e.g. IDCR SOWER, CCAMLR-2000 Survey) and national programs (SOCEP, BROKE, JARPA).

For the six species considered here, data range from comprehensive to extremely sparse, differ greatly in quality, in terms of spatial and temporal resolution, where these differences are dependent on both the species and area concerned. Information on diet and large-scale spatial distribution are relatively good, but understanding the complex spatial structuring of baleen whales in relation to their prey and environment at scales relevant to the individual or regions is only in its infancy; there is considerable uncertainty in estimates for consumption. Finally, there is a fairly comprehensive understanding of biases for certain data types (mainly abundance and trend), although these involve often complex issues to do with survey design, and changing statistical analytical methodologies. This means that bias can be very specific to whale datasets and should be addressed in each case.

There is generally less information on the odontocetes of the Southern Ocean than the baleen whales. Abundance estimation is often complicated by long dive times and inconspicuous surface behaviour or by responsive movement towards or away from survey vessels. In a systematic review of odontocetes of the Southern Ocean, Van Waerebeek *et al.* (2004) identified 28 species as occurring with 22 species showing a regular, apparently year-round, presence. Based on this review and the frequencies of sightings, a list of species that appear potentially ecologically important south of the CCAMLR boundary (between 45°S and 60°S depending on longitude) was identified as sperm whale (*Physeter macrocephalus*), killer whale (*Orcinus orca*), southern long-finned pilot whale (*Globicephala melas edwardii*), hourglass dolphin (*Lagenorhynchus cruciger*), southern bottlenose whale (*Hyperoodon planifrons*), Arnoux's beaked whale (*Berardius arnuxii*), *s*trap-toothed beaked whale (*Mesoplodon layardii*), Gray's beaked whale (*Mesoplodon grayi*). Of these species, biomass is dominated by sperm whales and southern bottlenose whales, other species may be locally important but have had few sightings due to being difficult to see and more northerly distribution. CCAMLR-IWC-WS-08/5 reviewed data on abundance, distribution, feeding ecology, exploitation and life-history parameters for these species, noting that in many cases data are extremely limited or non-existent. The diet of sperm whales and beaked whales appears dominated by squid whereas three ecotypes have been described for killer whales with different diets that are either dominated by marine mammals or fish.

2.4.2 Species/functional groups

In addressing the terms of reference of the Workshop, baleen whales were given the highest priority because of the dominance of krill in the diet. Of the baleen whale species, sei whales were considered of lower priority because of their generally more northerly distribution. The IWC SC is preparing for an in-depth assessment of North Pacific sei whales (IWC, 2008) which includes reviewing available data on the species, including the Southern Ocean.

Toothed whales, which have a more varied diet, dominated by squid for some species, were given lower priority. However, the most abundant toothed whales were also considered important because of the interactions between their prey species and krill. In terms of biomass, sperm whales and southern bottlenose whales are the most important odontocete consumers, but killer whales also have important interactions as predators of marine mammals.

2.4.3 Abundance

2.4.3.1 STATE OF METADATA SUMMARIES

Table 15 shows the Workshop summary of relevant abundance estimates by known populations. Where population sub-structure is not known, abundance estimates are given by species. The table attempts to distinguish between estimates made on the breeding grounds, estimates on the feeding grounds that are believed to include the whole population, and regional estimates that do not cover the whole range of the population range. If the combined regional snapshots are believed to encompass the complete (or nearly complete) range of a single population then these can be taken as estimates of the population. If the snapshots are believed to include more than one population, then estimates need to be partitioned according to what is known about spatial population structure and uncertainty. For some species such as fin whales, abundance estimates cover only the southern portion of the known range and thus cannot be considered as reliable estimates of the total population.

2.4.3.2 ISSUES ARISING FROM METADATA SUMMARIES

Most estimates of whale abundance are snapshot surveys of numbers of individuals within a specified region at a particular time. The IWC SC has devoted large amounts of time to trying to obtain the best possible snapshots and associated variances from design based surveys. It also has an **agreed** methodology for combining different snapshots from different times to generate a combined abundance estimate and variance. Although in some instances there are unresolved issues (e.g. related to the proportion of animals directly on the trackline that are detected and to group size) these have been discussed in detail by the IWC SC and were not considered further at the Workshop.

Abundance estimates and time series may include (1) estimates that are believed to be unbiased, (2) biased estimates where the likely direction of bias has been identified, or (3) estimates that represent a relative index of abundance. In general, abundance estimates need to be interpreted with other data. For example, abundance estimates need to be reconciled with historic catch series and any observed trends. Combining such data will need a population model which will likely incorporate life-history and/or habitat parameters. Whale populations typically show some degree of segregation of population components, both on winter breeding grounds and in summer feeding grounds. The main population components are mothers with calves (or who have recently weaned a calf), pregnant females, resting females, males, and juvenile animals. These components are typically represented to differing extents in different areas at different times of year. In interpreting abundance data, it is important to determine which components are included, and to take account of the 'missing' components. For example, of southern right whales surveyed in their Southwest Atlantic breeding area, about 30% of the observed population are mothers with calves (Rowntree *et al.*, 2001), but demographic analyses reveal that this group makes up only 8% of the total population (Cooke *et al.*, 2001). Segregation of adult and juvenile animals into different feeding areas appears to be the norm rather than the exception at least for *Balaenoptera* spp. (Leaper *et al.*, 2000).

Table 15

Matrix for conditioning whale population dynamics component of models. Annotated fields data are available (and presented in the expert review) for which any model should be consistent with – these data might either be used to develop the model or to validate it. N – no data are currently available.

Species/species population	Estimates for breeding population: Total abundance	Estimates for breeding population: Trend in total abundance	Regional snapshots of abundance in Antarctic waters	Trend from regional estimates of abundance	Some data on stock boundaries within surveyed region in Antarctic	Long-term history of substantial catches
Humpback whale (A)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Humpback whale (B)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables, 4, 5[2]
Humpback whale (C)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Humpback whale (D)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Humpback whale (E)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Humpback whale (F)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Humpback whale (G)[1]	Table 2[2]	Table 3[2]	Table 2[2]	Table 3[2]	Table 1[2]	Tables 4, 5[2]
Blue whale	Table 6[2]	Branch *et al.*, 2004	Table 6[2]	Matsuoka *et al.*, 2006	N	Table 7[2]
Fin whale	N	N	Table 8[2]	Table 8[2]	N	Tables 9, 10[2]
Sei whale	N	N	N	N	N	Tables 11, 12[2]
Antarctic minke whale	Tables 13, 14[2,3]	N	N	N	Pastene *et al.*, 2006; and see IWC, 2008b, p. 422	Tables 15, 16[2]
Southern right whale (Eastern South America)	Cooke *et al.*, 2001	Cooke *et al.*, 2001	Hedley *et al.*, 2001	N	N	Section 4.6.1.3[2]
Southern right whale (Australia/NZ)	Bannister, 2008	Bannister, 2008	N	N	N	Section 4.6.3.3[2]
Southern right whale (South Africa)	Best *et al.*, 2006	Best *et al.*, 2006	N	N	N	Section 4.6.2.3[2]
Southern right whale (Western South America)	IUCN, 2008	N	N	N	N	Section 4.6.4.3[2]
Sperm whale	N	N	Table 1[4]	N	N	Smith *et al.*, 2005
Southern bottlenose whale	N	N	Table 1[4]	N	N	N
Killer whale	Table 1[4]	N	Table 1[4]	N	N	N
Hourglass dolphin	N	N	Table 1[4]	N	N	N

1 See CCAMLR-IWC-WS-08/4, Table 1
2 See CCAMLR-IWC-WS-08/4
3 The status of Antarctic minke whales is still currently under review within the IWC, although the IWC is nearing the end of a comprehensive review of their status. There are currently no agreed estimates.
4 See CCAMLR-IWC-WS-08/5

Table 15 indicates where data are available but some indication of data quality (for example whether estimates have been accepted by the IWC SC as suitable for particular purposes) is also required. The expert groups were **recommended** to develop categories to indicate the status of the abundance estimates listed in the table. An example of the type of categories that have been developed for general classification of data quality is given in (Kucera *et al.*, 2005).

2.4.3.3 SCALING ISSUES

The need for information on population structure within ecosystem models will depend on the nature of the model and the spatial scale in particular. Estimates of prey consumption do not rely on information on population structure except for killer whales where diet differs between ecotypes. However, it may be important to understand population structure at spatial scales for which localised changes in prey abundance might occur (e.g. such as might occur as a result of a krill fishery). Stock structure and feeding locations for the populations of humpback whales are the best understood of all the baleen whales and have been the subject of considerable discussion within the IWC SC (IWC, 2008). Minke whale stock structure has been studied intensively in some regions of the Southern Ocean (from JARPA in Areas III–VI), but there are almost no data elsewhere. There are very few data on stock structure for blue, fin, and sei whales or odontocetes.

2.4.3.4 RECOMMENDATIONS FOR FURTHER WORK

It was noted that resolving issues with abundance and trends of minke whales was important, and that this is being addressed by the IWC SC. Addressing the lack of abundance data for fin whales is a key priority due to the high historic abundance of this species and the current lack of data. Surveys for these species on the breeding grounds (which are largely unknown) are unlikely to be feasible.

Data from the Southern Ocean, north of 60°S are limited and could be addressed by surveys between 60°S and CCAMLR boundary which could also help generate estimates for other species (particularly sei and right whales). However, surveys in this area are frequently made difficult by weather conditions. Complete new circumpolar surveys are unlikely in the future, so there is a need for a regional focus to detect trends at smaller spatial scales. Surveys to identify regional trends may also help identify variables driving these trends.

Examining recovery of small well-studied populations may be informative in an ecosystem modelling context. For example, there are considerable data on population dynamics of southern right whales in the Southwest Atlantic (Cooke *et al.*, 2001) which are believed to feed around South Georgia (Rowntree *et al.*, 2008). This is a well-studied area for other species and data such as estimates of whale density from these feeding grounds would be valuable. The longitudinal sector south of South Africa was also identified as an area where estimates of fin whale abundance could be particularly important (in combination with detailed feeding studies; paragraph 2.4.36). IDCR SOWER cruises in this area have also noted high densities of minke, blue and humpback whales (Ensor *et al.*, 2007).

2.4.4 Habitat

For the purposes of the discussion, habitat was considered in terms of the physical and biological covariates that determine whale distribution patterns. It was noted that there was a need for models that relate whale density to spatial and temporal covariates to support ecosystem models.

The majority of data on habitat use and whale distribution patterns in the Southern Ocean have come from visual surveys with some data from passive acoustics and a very small amount of data from telemetry studies. Most observations relate to whales at the surface and there is very little information on use of the water column in terms of depth. Multi-disciplinary, large-scale, surveys with the specific objective of collecting whale data concurrently with habitat data include the CCAMLR-2000, SO-GLOBEC and BROKE surveys. It was noted that there were data from these surveys (including data that could be used for abundance estimation) that could be analysed further and it was **recommended** that these analyses should be undertaken as soon as possible. Habitat related data have also been collected during the JARPA and JARPAII surveys.

2.4.4.1 STATE OF METADATA SUMMARIES

The expert group papers described patterns of habitat use in general qualitative terms. Table 16 develops on the qualitative descriptions by identifying parameters that have been related to whale distribution.

2.4.4.2 ISSUES ARISING FROM METADATA SUMMARIES

In addition to the parameters that have been used in previous studies (suggested template in Table 16), the Workshop identified additional spatial and temporal covariates that could be considered in trying to estimate whale abundances from density data (Table 17).

Table 16

Suggested format for the expert group to summarise studies where spatial/temporal covariates have been used in models of whale density.

Species abundance estimate	Covariates included in model	Reference
Humpback whale		
Blue whale		
Fin whale		
Sei whale		
Antarctic minke whale		
Southern right whale		
Sperm whale		
Southern bottlenose whale		
Killer whale		
Hourglass dolphin		

Changes in sea-ice dynamics and concentration have been identified as particularly important in understanding differences in minke whale abundance estimates. Sea-ice dynamics were also identified as important predictors of habitat including formation of polynyas and primary productivity associated with ice. Changes in grounded iceberg, fast-ice distribution and coastal configuration are likely to impact on whale habitat by modification of coastal polynyas. In many cases there will be time lags between changes in sea-ice and resulting changes that are likely to affect whales. Several interactions between sea-ice and other permanent features such as the shelf break or grounded icebergs have been identified.

In discussion of primary productivity it was noted that two types of data are available from satellites which measure the amount of light absorbed by chlorophyll which is a function of chlorophyll concentration. Algorithms have been developed to derive the rate of primary production from remotely sensed chlorophyll concentration and other environmental variables. Both chlorophyll concentration and primary production rate are readily available from providers of remotely sensed data. However, satellite-derived measures of these data should be used with caution because there is often a subsurface chlorophyll maximum layer that is too deep in the water column to be sensed remotely and this may impact on the value of these data as covariates.

Table 17

Potential covariates discussed in relation to developing models of whale density.

Temporal covariates	
	Timing within a season
	Variability and time lags in relation to physical or biological processes
Fixed physical covariates	
	Lat/Long
	Depth
	Distance from shelf break
	Shelf slope
Dynamic physical covariates	
	SST
	Upwelling intensity and mixed layer depth
	Frontal systems
	Seasonal sea-ice dynamics
	Short term (days/weeks) changes in ice concentration
Biological covariates	
	Primary productivity (rate and quantity)
	Krill concentration (spatial scale)
	Krill swarm type and vertical distribution
	Interspecific interactions between whales
	Intraspecific factors including segregation by age, sex, reproductive status

2.4.4.3 SCALING ISSUES

It was noted that choice of spatial scale is particularly important when relating whale density to habitat covariates. For example, although krill distribution will inevitably be a major factor determining the distribution of baleen whales, there is not always a clear correlation between krill concentration and whale density. It was noted however that this lack of correlation may be solely a function of analytical resolution and that a simple correlation might not necessarily be expected.

Data on the movements of individual whales on their feeding grounds is limited to some Discovery mark data and more recently, a few brief satellite-tracking studies. Satellite telemetry has advanced to the point where more widespread application of tags to cetaceans in the Southern Ocean is now possible. Such studies are likely to inform our understanding of the scale and heterogeneity of their foraging patterns. The Workshop encouraged such studies, particularly where they might coincide with studies that provide data on other aspects of the marine environment.

2.4.4.4 FURTHER RESEARCH

In addition, to habitat covariate data collected on multi-disciplinary surveys, remote sensing can provide data including SST, sea-ice and primary productivity. In many cases there are time sequences of these data over several years which could be used in further analyses of whale surveys.

Considerable data on habitat use by other predators have been gained from telemetry studies and the Workshop discussed the importance of such data for whales. In particular, telemetry devices that include data loggers can provide three-dimensional information on the use and characteristics of the water column. There is a need to address issues surrounding the number of animals that need to be tagged in order to make inferences at a population level.

Studies of habitat use by individual animals may also use photo-identification or genetic mark recapture. For example, the ongoing analysis of re-sightings of individually identified blue whales using IDCR SOWER data (Olson, 2008) has provided valuable insights on the residency and fidelity within and between seasons of blue whales near the pack-ice south of South Africa; the continued collection of such data and comparison with other Antarctic areas, will yield more information on these patterns.

Long-term passive acoustic monitoring, such as bottom-mounted Acoustic Recording Package (ARP)devices which can record continuously for over a year, have the potential for monitoring seasonal variation in vocalisations at a particular location. These can be used to generate a relative index of density based on assumptions about variations in calling rates.

2.4.5 Life histories and food-web linkages

The expert review for baleen whales did not consider life-history parameters because the group determined that reviewing data on abundance, trends, distribution and foraging were of primary importance in the context of current CCAMLR and IWC models. However, based on discussions at the Workshop, it was **recommended** that the group should review these. The parameters of interest are pregnancy rates, calf production, age-at-first reproduction and survival. In some cases these data are available for specific populations, in other cases these are just available for the species within Antarctic waters as a whole, and in other cases there are data for the species in the northern hemisphere. These parameters cannot be considered as static values and the time period over which estimates were made needs to be specified.

Life-history parameters have proven difficult to measure but estimates have been made from lethal sampling on the feeding grounds and photo-identification studies (mainly on the breeding grounds). Estimates derived from lethal sampling for minke whales were discussed extensively in the JARPA review conducted by the IWC in 2006 (IWC, 2007).

The Workshop discussed food-web linkages in the context of:

(i) diet by species (noting that for baleen whale diet is limited to krill species within the area of interest), population or ecotype, including the ability to switch diet in response to changes in prey availability;

(ii) where prey are consumed;

(iii) when are prey consumed;

(iv) how much prey is consumed.

2.4.5.1 STATE OF METADATA SUMMARIES

Basic data on diet composition were reviewed by the expert groups. Key uncertainties relate to the length of the feeding period within Antarctic waters and the spatial patterns of prey consumption. In addition, there is considerable uncertainty in estimating energy requirements of large whales and the relationship between energy requirements and body mass (Leaper and Lavigne, 2007).

2.4.5.2 ISSUES ARISING FROM METADATA SUMMARIES

Much of the data on diet in the metadata summaries had been derived from analyses of stomach contents. Recently developed techniques include genetic analyses of faeces and fatty acids/isotopes to identify prey species. These techniques have the potential to provide estimates of prey consumption integrated over longer time periods. The advantages and disadvantages of the different methods have been discussed in detail by the IWC SC (IWC, 2003).

Ecosystem models require functional relationships between predators and prey. These relationships will depend upon an interaction between the availability of the prey to the predator and the selectivity of the prey by the predator. The Workshop noted previous discussions on functional response in relation to whales including the 2002 IWC SC workshop in La Jolla, USA, on whales and fisheries (IWC, 2004a) and the JARPA review (IWC, 2007b). The La Jolla workshop had identified functional response as one of the key uncertainties in ecosystem models. Empirical measurements of both sets of parameters are difficult, and perhaps impossible to acquire, especially in a manner that can be applied over varying temporal scales and at the level of the population. Nonetheless, researchers have used a variety of data to inform estimates of functional responses (e.g. in a study of minke whales in the northeast Atlantic based on stomach content data, Smout and Lindstrom (2007)). As these estimates are likely to be influential in model function and output, the Workshop **recommended** that where such estimates are used, the basis for that estimate and the uncertainties, including biases, are provided.

In addition, recent studies of southern right whales based on isotope analysis have shown different feeding patterns between individuals apparently passed on by mothers to their calves.

2.4.5.3 SCALING ISSUES

In discussion of scaling issues within the IWC SC, one suggestion for three categories of scale that describe feeding ecology and the spatial-temporal distribution of cetaceans was: (i) cetaceans migrate seasonally between feeding and breeding grounds; (ii) cetaceans move over days and weeks in search of preferred local abundance of food; and (iii) whales dive and search for food within localised areas.

These issues of spatial scale are relevant to methods used to estimate consumption rates due to the considerable uncertainty in the period for which whales feed within the area of interest. New analytical techniques based on isotope analysis may be able to identify whether feeding occurred outside of the Southern Ocean.

2.4.5.4 FURTHER RESEARCH

The relationship between distribution patters of Antarctic minke whales and krill was investigated in the Ross Sea using a multi-disciplinary dataset collected by the *Kaiyo Maru*-JARPA joint survey (Murase *et al.*, 2007). Two species of krill, Antarctic and ice krill were distributed in the Ross Sea. The scale of interactions between Antarctic minke whales and the environmental factors were investigated at a segment length of 5 n miles using GAM. The results indicated that the abundance of Antarctic minke whales could relate to the biomass of Antarctic krill.

The Workshop also received details of a recent study (pers. comm. Gerard Santora) study from the western Antarctic Peninsula which combined biological and physical sampling of the water column including qualification of the length-frequency distribution of krill, with observations of feeding whales. It was noted that this type of study helped to elucidate niche separation and localised prey utilisation. Further similar studies in other areas should be encouraged. Other areas identified with particular potential for feeding ecology studies include the Kerguelen plateau and the longitudinal sector south of South Africa. The Kerguelen plateau (from Kerguelen Islands to Prydz Bay) area has been studied during multi-disciplinary and multiple predator studies by France and Australia, and strong linkages along the plateau have been demonstrated. Recent IDCR SOWER cruises have operated in the area south of South Africa where observations included large feeding aggregations of fin whales around Bouvet Island and made observations of blue whales (including successful photo-identification). It was noted that in this longitudinal sector, minke and humpback whales were abundant and blue whales were also frequently encountered. The three ecotypes of killer whales also occur in this area.

These type of small-scale studies need to be considered along with synoptic surveys and large-scale tracking in order to provide the necessary range of data likely required for ecosystem models.

An increased understanding of changes in life-history parameters related to environmental effects and density dependent responses is also important. Such studies will require long-term datasets. For example, a study of southern right whale breeding success for the population in the Southwest Atlantic (Leaper *et al.*, 2006) used a 30-year time series of photo-identification data to investigate relationships between calf production and environmental variables. In this study, calving success appeared to be affected by environmental variables even though the population was still at a low level.

It was noted that further review of historical whaling data and resulting literature may be informative on a number of relevant issues. It was **recommended** that the expert group review these sources for information on life history parameters including for example, age-at-first reproduction. Whaling data may also be informative on spatial and temporal patterns of habitat utilisation, particularly in areas that have not been covered by recent surveys.

2.5 Exploitation

2.5.1 Cetaceans

Catch data have and do play an important part in the assessment work of the IWC SC. The IWC Secretariat maintains the definitive series of catch data for the 'modern whaling' period: some two million records. Considerable effort has been expended to code and verify the catch data, including documentation of uncertainties in the record. For some operations in the early years of the 20th century, only total catch data are available (this represents about 20% of the total catch record for modern whaling). For the remaining 80% of the catch, individual catch records are available; in the 'best instance', for each whale the following information is available: species, date of catch, position of catch (latitude and longitude to the nearest minute), length (to the nearest foot or 0.1 m), sex, reproductive status, stomach contents, and fishery operation (nation, vessel). The resolution of the reported data varies by operation and time period (e.g. position may vary from exact position of the catch, through noon position of the factory ship or position of the land station); the reliability of the various types of reported information by nation, operation and time period (including the major falsification of data reported by the USSR) has been extensively discussed within the IWC SC and in a number of published papers.

For open-boat whaling (pre-modern whaling period), the catch history has been reconstructed using various methods including examination of logbooks and records of whale products; this applies particularly to southern right whales (IWC, 2001).

Appropriate ways to incorporate satisfactorily the various levels of uncertainty in the catch records (ranging from uncertainty in the records themselves to methods of allocating catches from breeding stocks to Antarctic feeding areas) for modelling purposes has been thoroughly considered by the IWC SC, and is often based on alternative plausible hypotheses. Such an approach should also be applicable to any ecosystem modelling work.

In addition to the catch data, effort data are available. The resolution and reliability of these data vary with operation and time period. The IWC SC has reviewed the utility or otherwise of the use of CPUE data for assessments and modelling and has recognised the limitations of using such information in anything but a crude manner (IWC, 1989).

The catch records (and to some extent the effort data) are relevant to ecosystem modelling at a number of different levels, from simple catch series to population dynamics modelling, including spatial and temporal distribution, to estimation and interpretation of life history parameters and even making inferences on ice edge data (e.g. de La Mare, 2002).

Although there are some published summaries of catch data, it is most appropriate to obtain the most recent validated catch series from the IWC catch database, available from the IWC Secretariat.

2.5.2 Seals

The Workshop noted that the UK is the depository for the Convention on the Conservation of Antarctic Seals (CCAS) and, as part of this role, the UK receives data on catches of seals. The Workshop **agreed** to investigate possibilities of gaining access to historical sealing record from the Convention and from other published and unpublished sources.

2.5.3 Penguins

In the 19th century and early 20th century, king (and probably other species) penguins were exploited by sealing gangs on sub-Antarctic islands. The birds were used for several purposes, such as fuelling the boilers used in the processing of seals, and fuelling lamps and cooking stoves. Penguin skins were turned into clothing and flesh and eggs were consumed by the sealers. Accurate records of the number of birds killed were not kept and available information is largely anecdotal. Some king penguin populations were drastically reduced in size on most islands while king penguins completely disappeared from others islands for several decades. In recent decades, king penguin populations have made a remarkable recovery throughout their range. Most of the recoveries have been documented (e.g. Macquarie Island: Rounsevell and Copson, 1982; Heard Island: Gales and Pemberton, 1988; Kerguelen Archipelago: Weimerskirch *et al.*, 1989).

2.5.4 Albatross

Historic records indicate that albatross eggs (Cott, 1953) were extensively harvested for food during the whaling era.

2.5.5 Fish

The CCAMLR Secretariat holds various databases related to fish exploitation. Catch statistics cover the complete history of fish exploitation. Detailed data such as catch and effort by species, area, and CCAMLR seasons are incomplete for the first years of the fishery. Available statistical data can be accessed in the public domain. Other data are subject to the Rules for Access and Use of CCAMLR Data, and include haul-by-haul data from longline and trawl fisheries, detailed biological data collected as part of CCAMLR's Scheme for International Scientific Observation, and fishery research and acoustic data collected during research surveys.

The Workshop acknowledged that there were some uncertainties associated with early catch records reported to CCAMLR, and that the extent of these uncertainties has not been resolved. In particular, the accuracy of the catch data from the early years of the fishing history (e.g. for the first 7–10 years in the 1970s) is under question, and therefore usage of data from these period should be dealt with caution. The Workshop **agreed** that the analysis of such uncertainty would be a matter of priority.

2.5.6 Squid

The Workshop noted that experimental squid fisheries have taken place in Subarea 48.3 between 1989 and 2001 when a total of five jigging vessels fished for seven star flying squid at the PFZ to the north of South Georgia. The catch rate was about 8 to 10 tonnes per night per vessel.

This species is caught by the jigging fleet targeting Argentine shortfin squid (*Illex argentinus*) on the Patagonian shelf and is also caught south of New Zealand. A mass stranding has been reported at Macquarie Island. This species is also taken as by-catch in the slender tuna fishery in the Southern Pacific. No interest for fishing on this species in Subarea 48.3 has been expressed over the past 7 to 8 years.

The Workshop also noted that Argentine shortfin squid is taken on the Patagonian shelf, and annual catches were highly variable (10 000–300 000 tonnes). Interest in a targeted fishery for seven star flying squid has been highest when Argentine shortfin squid catches have been at their lowest levels.

2.5.7 Krill

Four types of data submissions are required from krill fishing countries fishing within the CAMLR Convention Area:

(i) monthly summaries of catch and effort (STATLANT) data aggregated into FAO statistical areas;

(ii) in-season catch and effort reports;

(iii) fine-scale, haul-by-haul data;

(iv) scientific observer data and reports including biological data and technical information o the fishery.

STATLANT data are in the public domain (CCAMLR *Statistical Bulletin*; e.g. CCAMLR, 2006). Haul-by-haul data and observer data include details of time, date, positions of fishing, and general information of the vessel and conversion factors of the products (CCAMLR, 2006). With the exception of STATLANT data, the data are subject to the Rules for Access and Use of CCAMLR Data, and originators/owners of data retain control over the use of their unpublished data outside CCAMLR.

The STATLANT database contains all reported krill catches at FAO statistical area/subarea resolution. Fine-scale catch and effort data consist of data which are finer than STATLANT statistics. Most of the fine-scale data are reported on a haul-by-haul basis with accurate positional information; this is the current requirement in krill fisheries (CCAMLR, 2005). Some historic data are reported as catch and effort aggregated by approximately 10 n miles x 10 n miles rectangle and 10-day period, and some data were aggregated by approximately 30 n miles x 30 n miles (0.5° latitude by 1° longitude) rectangle and monthly period. Also, fine-scale data coverage of the krill fisheries was incomplete, especially in the earlier days until the mid-1980s (CCAMLR, 2005).

Various sources of uncertainties were highlighted for the commercial catch records. Firstly, the accuracy itself of catch and effort data and position data, especially for those reported in the earlier periods. Secondly, large uncertainties surround the conversion factors used to estimate the landed catch from the final products. Thirdly, uncertainties surrounding the total amount of krill removed from the system by the fishing activities, which result from krill that are killed by the fishing gear but are not retained in the codend when it is landed on the vessel.

2.5.8 Fishery by-catch

2.5.8.1 FISH BY-CATCH

Although information on records of fish by-catch taken in krill fisheries are held in the CCAMLR databases, no quantitative data are available due to lack of systematic coverage by the scientific observers in the krill fishery. It was stressed that 100% systematic coverage is the only way to obtain quantitative data on fish by-catch.

Information on the distribution of larval fish in relation to krill aggregation is unknown. This is an important information which is currently lacking when interpreting the by-catch data from the krill fishery.

2.5.8.2 INCIDENTAL MORTALITY OF MARINE MAMMALS AND SEABIRDS ASSOCIATED WITH FISHING IN THE CAMLR CONVENTION AREA

Over the period 1997–2007, the number of observed seabird mortalities decreased from 6,589 (1997) to 2 (2006) and to 0 in 2007. Over the same period, the estimated median total potential seabird by-catch in unregulated longline fishing was 193,927 (157,917–565,245).

Reports of incidental mortality of Antarctic fur seals in the krill fishery in Area 48 were first reported to CCAMLR in 2002/03 when 27 seals were recorded dead. Incidental mortality increased to 142 seals in 2003/04 and, following the introduction of by-catch mitigation measures including seal excluder devices, the incidental mortality was reduced to 16 seals in 2004/05, one in the following season and 2006/07.

Incidental mortality of marine mammals and seabirds associated with fishing in the CAMLR Convention Area is reviewed annually by the *ad hoc* Working Group on Incidental Mortality Associated with Fishing (WG-IMAF) and reported to SC-CAMLR (e.g. SC-CAMLR, 2007c).

2.5.9 Future work

The Workshop **agreed** that it would be useful for CCAMLR to undertake work to quantify the uncertainties in catch records for krill and finfish.

3 GENERAL ISSUES AND PRIORITIES

The Workshop generally discussed the issues, questions and priorities for collating and acquiring data for use in the development of multi-species/ecosystem models relevant to CCAMLR and the IWC. It noted that the questions of importance could be grouped into those pertaining to predators, prey and habitat variability and change. There were also some general modelling-based questions that would be useful to address.

The Workshop noted that the general questions surrounding predators and prey were well articulated from the work of each subgroup.

The Workshop noted that there had not been an opportunity for a similar depth of discussion on the physical environment and primary production that might give rise to environmental and habitat variability and change. The Workshop **agreed** that habitat variability and change are important ivers of food-web dynamics in the Southern Ocean. It noted that the analyses listed below, which use existing environmental datasets and circulation models, could contribute to understanding the relationships between biota and habitats, how habitats may vary in space and time and to what extent climate change could impact on habitats:

(1) Establish baselines that could be used to evaluate change in habitats: combine and analyse historical hyographic, sea-ice, atmospheric and satellite datasets to develop a characterisation of environmental structure and its variability at circumpolar and regional scales with a focus on:

> (a) determine variability associated with locations of ACC fronts, such as latitudinal range, sea-ice distribution and characteristics, and responses to large-scale climate forcing (e.g. ENSO, SAM), and changes in ACC transport;
>
> (b) determine basic circulation patterns and sea-ice dynamics for regions (e.g. Ross Sea, WAP, Weddell Sea) including seasonal changes (e.g. from buoyancy forcing) and extent of coupling to large-scale circumpolar circulation;
>
> (c) correlating biological distributions with habitat structure;

(2) estimate potential biotic linkages between different regions using simulated circulation distributions to:

(a) evaluate large-scale and regional transport of krill and zooplankton, including residence times;

(b) estimate exchange rates;

(c) provide insights into potential areas with distinct stocks;

(d) identify potential metapopulation structure, including source and sink local populations;

(3) improve the predictability of frontal locations, characteristics of the sea-ice zone, the ability to identify processes that lead to changes in habitat, as well as evaluate the effect of frontal variability on the transport of biota through the continued development of circulation models (circumpolar and regional scale) so that they capture patterns and variability seen in large-scale and regional data analyses.

The Workshop developed a set of key integrated questions that emerged from the various discussions of the three subgroups along with the discussion above on habitats and the physical environment. These questions attempted to specify the overarching issues that characterise the data and methodologies that would be needed to support a variety of ecosystem models relevant to CCAMLR and the IWC. The questions considered predators, prey, habitat variability and change, which would be correlates of the physical and biological environment of the key taxa, and general food-web modelling issues. It was once again noted that the relevance of the different questions about data will vary with the particular model being developed or the objective that a model may be attempting to address. Discussions were framed around the three **agreed** ecosystem issues identified earlier (see Item 1.3.2). The questions are outlined below.

Predators:

(1) Spatial overlap: How well can we define the foraging space by taxa/population?

(a) What are the priority taxa?

(b) What are the defining features of feeding habitats?

(c) What are the priority methodologies?

(2) Temporal overlap: How well can we define the foraging season by taxa/population?

(a) What are the taxa with influential seasonal dynamics?

(b) What are the priority methodologies?

(3) Resulting consumption: How well can we define the diet (foraging success) by taxa/population?

(a) What are the influential consumers and their food requirements?

(b) What is the species composition in the diet of the influential consumers?

(c) What are the key population dynamics (e.g. reproductive rate, stage-specific predation) that influence the strength of the predator–prey relationship?

(d) When would predators be expected to feed in the Southern Ocean?

(e) What are the priority methodologies?

Prey:

(4) Spatial issues: How well can we define the spatial extent and variability by taxa/population?

(a) What are the priority taxa?

(b) What are the priority methodologies?

(5) Temporal overlap: How well can we define the availability of prey to predators by season?

(a) What are the priority taxa?

(b) What are the priority methodologies?

(6) Productivity: How well can we characterise the forcing functions that reflect bottom up influences?

(a) What are the priority taxa?

(b) What are the priority methodologies?

(7) Non-predation effects on dynamics: How well can we characterise the forcing functions that reflect general mortality?

(a) What are the priority taxa?

(b) What are the priority methodologies?

Habitat variability and change:

(8) How can we quantify the three dimensional habitat of predator and prey populations based on oceanographic, sea-ice, atmospheric and productivity data?

(9) How can variability in habitats be quantified in spatial and temporal scales relevant to the key taxa and ecological processes?

(10) How can we establish the effect of environmental variability and change on the productivity and dynamics of food webs?

Workshop participants were reminded of the conclusions of an IWC workshop on modelling interactions between cetaceans and fisheries (IWC, 2004a). At that meeting the participants concluded the following: 'The reality is that for no system at present are we in a position, in terms of data availability and model development, to be able to provide quantitatively predictive management advice on the impacts of cetaceans on fisheries or fisheries on cetaceans'. At a more recent ecosystem modelling workshop run by the FAO in July 2007, a similar conclusion was reached.

In order to distil a shared view of the relative priority that each or all of the integrated questions should be given in relation to particular ecosystem models, eleven of the workshop participants were asked to provide a brief summary of their view of research priorities and needs, based on the relevant ecosystem questions (see above) and the categories above (predators, prey, habitat variability and change, general model-based questions). These summaries attributed to their authors are provided unedited in Annex F; individual summaries were not discussed by the Workshop although they contributed to the discussions below.

The range of views presented to the Workshop reflected the substantial challenge that building informative ecosystem models represents for CCAMLR and the IWC. These challenges were characterised as the difficulty of developing sufficiently refined model inputs, as well as in the development of appropriate model structure and in the manner in which uncertainty is bounded. Importantly, in relation to defining data needs and approaches, some strong common threads emerged. These are expanded upon below and form the basis for recommendations from this Workshop.

The differences in views of approaches to the model environment itself, and the timeline for which these models will become relevant to management are perhaps not surprising and reflect both the relatively embryonic phase of this discipline as well as the diversity of questions the models are designed to address, the timelines in which they strive to provide outputs and the scales at which they are designed to operate. In general terms, two approaches to ecosystem models were presented:

(1) parsimonious models being built from a relatively well understood core (perhaps a central species), branching out into the ecosystem (in components and scale) only as far as the data would reasonably allow inference; or

(2) inherent complexity and dynamics of ecosystems would be a focus with models being developed, starting from a broader, more complex structure, applying parsimony during the course of development by trimming the model down to a more practical core that aimed to retain the influential components and dynamics of the system.

Both approaches include inherent advantages and challenges. The Workshop noted that there are broader modelling issues, such as model and data validation that are important, but that these lay beyond the scope of this Workshop.

The primary aim of this Workshop was to attempt to develop some prioritisation of data needs for ecosystem models which focus on krill and krill-based predators. Notwithstanding the need for different types of data for different models and questions, the common views expressed in an approach to data collection, integration and analysis provide a cogent guide for future work relevant to CCAMLR and the IWC. In essence, these approaches fell into three broad categories:

(1) Characterisation, linkages and influences of environmental and seasonal features on the distribution and density of predators and their prey.

A strong emphasis was given to improved characterisation of the physical and biological environment in which animals move. In particular, identification of relevant sampling and analytical scales, quantification of environmental variability, and identification of the persistent or ephemeral nature of major features were highlighted. The elucidation of linkages within food webs, including alternate pathways was also highlighted as a priority. It was noted that such data are increasingly being generated from remote sensed data series, as well as animal-borne sensors and transmitters. Improvements in the prioritised collection and integrated analysis of these data would likely enhance modelling efforts.

(2) The value of further, integrated analyses of existing datasets and series to explore the relationships of predators, prey and environmental correlates.

The particular value of large-scale, integrated studies that collect synoptic assessments of the distribution of predators, their prey and key aspects of the environment was highlighted. The relevance and utility of historical data series, such as 20th century whaling data and the *Discovery Reports*, were also highlighted as providing possible 'baseline' measures of seasonal and spatial distribution of predators and prey.

(3) The importance of appropriate, coordinated, long-term data series of key features of the environment (e.g. remote-sensed data) and the predators and their prey (e.g. time series of relative abundance).

All three core ecosystem modelling issues considered by the Workshop require time-series of data. Questions relevant to climate change perhaps needing the most extensive trophic level range. The maintenance of such time series are expensive and consistent funding is a perennial challenge. The development of new, and the maintenance of existing data series for modelling should focus on core and influential components of the physical and biological environment in which predators and prey exist.

The Workshop **endorsed** the general data and research prioritisation detailed above.

Throughout the discussions in plenary and within the subgroups, two general modelling-based questions arose:

(i) How well, and with what methods, can we define functional feeding relationships?

(ii) How much abundance data (by taxon, location, and temporal resolution) do we need?

There was insufficient time for a focused discussion on these issues at the Workshop, but a few general conclusions and recommendations can be noted. Firstly, in relation to functional feeding relationships in ecosystem models, it was stressed that these can only be estimated through inference. The difficulty of scaling measurements and resultant inferences made at fine temporal and spatial scales was noted to be problematic (IWC, 2004).

In relation to data on abundance, the Workshop **agreed** that such data are core to ecosystem models, but their relative importance differs for different types of models.

The Workshop **agreed** that a more comprehensive discussion on these modelling issues, and their relative importance and influence for different models would be valuable.

4 PRODUCTS AND FUTURE WORK

4.1 Metadatabase and other tools

CCAMLR-IWC-08/16 provided an overview of the CCAMLR-IWC metadatabase and web-based GUI developed by the AADC and instructions on its use. The Workshop was supportive of the aims of the development of the metadatabase and GUI and **agreed** that it was an important component of the work program identified in preparation for the Workshop. To date, the expert groups have primarily been responsible for managing content for the tool.

The Workshop noted that the metadatabase and GUI are still in an early stage of development and to date, the database has not been well populated with data. The Workshop **agreed** that this is a useful development and encouraged users to provide content and to identify issues in capturing the metadata in order to improve the tool. Members of the expert groups were invited to provide comments on the metadatabase and GUI and their experience with its use.

Southwell (coordinator of the pack-ice seals group) and Leaper (member of the baleen whales group) noted that standardising metadata in tabular form as a first step prior to working directly with the metadatabase increased the efficiency of metadata entry for these groups. Other methodologies in building content, particularly for more complex taxonomic groups (e.g. zooplankton), should be explored with the developers to improve the metadatabase and GUI.

The workshop noted that a number of steps could be taken to ensure that the metadatabase and GUI becomes a useful and well-utilised repository of metadata. It was noted that currently all Antarctic metadata records are already, or soon will be, online at the Global Change Master Directory (GCMD). Ramm noted that CCAMLR is currently in the process of developing GCMD metadata records and considers the CCAMLR-IWC metadatabase and GUI as a contribution to this process. Using the GCMD keywords within the metadatabase would provide a consistent approach to discovery of data and metadata records.

Providing direct links from the metadatabase to relevant datasets at SCAR-MarBIN was proposed. The Workshop encourages data to be made available via SCAR-MarBIN either by direct hosting by SCAR-MarBIN or publication through other data providers such as AADC, CCAMLR and the IWC. Direct delivery of data should be considered as a next step, using SCAR-MarBIN as the first example.

The Workshop also noted that SCAR-MarBIN has a funding cycle only to 2009. CCAMLR and the IWC could act as key ivers, both in terms of end-users of data and in recommending data portal developments of SCAR-MarBIN, with the aim of improving the long-term sustainability of SCAR-MarBIN. Similar considerations could be given to other common data repositories that are required for the metadata tool.

The Workshop noted that further content development of the CCAMLR-IWC metadatabase and GUI would require substantial resources and the process would benefit from achieving a higher profile within CCAMLR and the IWC.

The Workshop **agreed** that the metadatabase and GUI should continue to be available after the Workshop to support further work by the expert groups. The manner in which the metadatabase and the metadata tool will be developed and managed will need to be considered by the Joint Steering Group, in particular when and how this work will be migrated from the AADC to the CCAMLR and IWC Secretariats.

4.2 Publications

CCAMLR-IWC-WS-08/2 discussed the publication of the results from the work of the expert groups. There was insufficient time to consider this in detail and was referred to future work by the Joint Steering Group (see Item 4.3.6 below).

4.3 Future work

4.3.1 Physical environment and primary production

Future work on oceanography, sea-ice and primary production was considered in the following paragraphs:

(1) oceanography (see Item 2.1.1.2)

(2) sea-ice (see Item 2.1.2.2)

(3) primary production (see Item 2.1.3.2).

4.3.2 Pelagic species

The Workshop noted the future work identified by the pelagic species group in the following paragraphs:

(1) defining functional groups of pelagic species (see Item 2.2.1);

(2) krill –
- (a) feedback to the expert group (see Item 2.2.2.4)
- (b) key gaps (see Item 2.2.2.5.1)
- (c) further analyses (see Item 2.2.2.5.2)
- (d) research programmes (see Item 2.2.2.5.3);

(3) zooplankton –
- (a) feedback to the expert group (see Item 2.2.3.4)
- (b) key gaps (see Item 2.2.3.5.1))
- (c) further analyses (see Item 2.2.3.5.2))
- (d) future research programmes (see Item 2.2.3.5.3);

(4) squid –
- (a) feedback to the expert group (see Item 2.2.4.3))
- (b) key gaps (see Item 2.2.4.5.1)
- (c) future research programmes (see Item 2.2.4.5.2));

(5) fish –
- (a) feedback to the expert group (see Item 2.2.5.4)
- (b) key gaps (see Item 2.2.5.5.1)
- (c) further analyses (see Item 2.2.5.5.2)
- (d) future research programmes (see Item 2.2.5.5.3).

4.3.3 Seals and birds

The Workshop considered the question of future work in two categories: the first concerned the work required to complete the ‘inventory’ work of the expert groups; the second concerned necessary field and analytical work required to fill ‘key’ information gaps. Clearly, there is an interaction between these two categories (completing the inventory work is required to identify the key gaps).

4.3.3.1 COMPLETION OF THE EXPERT GROUP REPORTS

The Workshop noted that the expert groups within this category be reformed either taxonomically (perhaps seals and birds) or issue-based (e.g. abundance, diet, habitat etc.) that would cut across taxa . It was also noted that, whichever approach is adopted, a convenor and steering committee for these groups needs to be finalised as soon as possible to ensure that the necessary expertise is available and that the workload for individuals is manageable; the *modus operandii* for the expert groups will be discussed by the Joint Steering Group. Templates for the information to be covered by the expert groups are provided in the text and tables (see Item 2.3.4 and Tables 7 - 14).

The Workshop noted that the critical evaluation of existing analyses/datasets is important for the reports to be of value for conservation and management. The initial examination of the available information for seals and birds revealed that there are considerable gaps in information for some species/spatial scales/temporal scales/parameters. In some cases, obtaining and analysing such data may be feasible in the short-to-medium term, but that this may take some time and resourcing. In other cases the difficulty of the task may make this unfeasible, at least using present methods; it is important that expert groups identify clearly which is the case for identified 'key gaps' because this is valuable information for modellers as it will prevent the development of models for which necessary information may never become available (at least at the level of resolution required to make them useful).

Given this, the Workshop **recommended** that the expert groups provide, at the end of their reports, an indication of what they believe is the timeframe, methods, resource level and feasibility to compile the available data for what they consider to be 'key gaps' taking into the account discussions under Item 3.

Completion of expert group reports will require a considerable amount of work. The Workshop noted that timely completion of this work is important both in terms of valuable publications and in the development of a coordinated integrated set of research recommendations that will greatly assist conservation and management. The manner in which this work will be completed will need to be considered by the Joint Steering Group and the expert groups that are formed. It was suggested that resources be made available to assist collation of the available published and unpublished information and that short (3–4 day) workshops may be necessary to complete the reports.

4.3.3.2 AN INITIAL CONSIDERATION OF ISSUES RELATED TO FIELD/ANALYTICAL WORK TO FILL KEY INFORMATION GAPS

The Workshop noted that determination of 'key gaps' cannot be seen in isolation from modelling exercises themselves and their objectives; in a number of cases, for example, the need to refine (or even perhaps do more than best-guess a range for) parameter estimates will depend on initial modelling exercises to determine sensitivity to those parameters. It may be necessary to develop mechanisms to facilitate this collaboration after the completion of the expert group reports.

The following priorities were identified by the subgroup:

(i) to undertake analyses of information (available from many sources) relating animal distribution and density with environmental variables;

(ii) to extend the collection of distribution, abundance and diet data to the whole year as they are at present almost exclusively limited to the breeding season;

(iii) to carefully investigate existing data to determine whether reliable qualitative or quantitative information on trends in demography can be identified (e.g. abundance of penguins, flying seabirds, crabeater and fur seals);

(iv) to develop a common set of tools for addressing these issues including the identification/development of a central data archive.

4.3.4 Whales

4.3.4.1 FURTHER WORK REQUESTED FROM EXPERT GROUPS

It was **recommended** that the expert group for baleen whales should review life-history parameters including information from historical whaling data and resulting literature. Whaling data may also be informative on spatial and temporal patterns of habitat utilisation, particularly in areas that have not been covered by recent surveys (see Item 2.4.5.4).

The expert groups were **recommended** to develop categories to indicate the status of the abundance estimates listed in Table 15 (see Item 2.4.3.2)

4.3.4.2 FURTHER ANALYSES OF EXISTING DATA

It was noted that resolving issues with abundance and trends of minke whales was important, and that this is being addressed by IWC SC.

It was noted that multi-disciplinary, large-scale, surveys with the specific objective of collecting whale data concurrently with habitat data (including data that could be used for abundance estimation) could be analysed further and it was **recommended** that these analyses should be undertaken as soon as possible (see Item 2.4.4).

4.3.4.3 FURTHER LONG-TERM RESEARCH PROJECTS

Addressing the lack of abundance data for fin whales is a key priority due to the high historic abundance of this species and the current lack of data. Data from the Southern Ocean, north of 60°S are limited and could be addressed by surveys between 60°S and CCAMLR boundary. Complete new circumpolar surveys are unlikely in the future, and in the absence of such surveys the Workshop **recommended** a regional focus to detect trends at smaller spatial scales (see Item 2.4.3.4)). The Workshop also noted that examining recovery of small well-studied populations may be informative in an ecosystem modelling context (see Item 2.4.4).

In addition to habitat covariate data collected on multi-disciplinary surveys, remote sensing can provide data including SST, sea-ice and ocean colour. The Workshop **recommended** investigating historical sources of such data which could be used in further analyses of existing whale survey data (see Item 2.4.4.4).

Considerable data on habitat use by other predators have been gained from telemetry studies and the Workshop recognised the importance of such data for whales (see Item 2.4.4.4). Studies of habitat use by individual animals may also use photo-identification or genetic mark recapture (see Item 2.4.4.4). The Workshop noted the value of studies which combined biological and physical sampling of the water column including qualification of the length, frequency distribution of krill, with observations of feeding whales and encouraged further such studies (see Item 2.4.4.4).

To address the question of seasonal abundance of whales in the Southern Ocean, long-term passive acoustic data can be used for monitoring seasonal variations in vocalisations at a particular location. These can be used to generate a relative index of density based on assumptions about variations in calling rates (see Item 2.4.4.4).

4.3.5 Exploitation

Future work **recommended** for the exploitation expert group is given under Item 2.5.1.

4.3.6 General

The Workshop **agreed** that the Joint Steering Group should continue its work beyond the Workshop in order to help coordinate the future work. It also **agreed** that others, who are able to assist the Joint Steering Group to achieve its work, should be encouraged to be involved in the Joint Steering Group as ad hoc members, and that the Joint Steering Group should seek to have its membership endorsed by the relevant Scientific Committee.

The Workshop noted that it would be useful to retain the existing expert groups for collating the metadata on the different taxa. It also noted that some issues could be usefully considered across all taxa because of the similarities of the estimation issues, biases and uncertainties. In that sense, the Workshop encouraged the Joint Steering Group to consider whether three additional small groups could be assembled to help expert groups consider some of the general issues in estimating parameters and collating data, and to provide a synthesis of advice on the general issues, where appropriate. The suggested additional groups are:

- (i) habitats
- (ii) life history characteristics
- (iii) food-web linkages.

The Workshop **agreed** that the Joint Steering Group should be asked to progress the work under the terms of reference according to the following tasks and timeline:

(i) Submit the report of the Workshop to the respective Scientific Committees, noting that:

- (a) an executive summary will be prepared by the Workshop convenors for submission to SC-CAMLR for translation in order that the key points of the report are highlighted to all Members of SC-CAMLR, as there is insufficient time to have the report translated in full in time for its meeting in October 2008;
- (b) the CCAMLR and IWC Secretariats would correspond to determine the publication timetable of the report.

(ii) Consult with Workshop participants and expert groups to determine the manner in which the work could be concluded and how the expert groups might progress this, in line with the discussion above. Where needed, the Joint Steering Group will need to find convenors and membership of expert groups to facilitate this work. The Joint Steering Group should consider the following when developing a work plan:

- (a) resources required to complete the tasks;
- (b) the possibility of Workshops to help progress the collation and synthesis of data and to complete the papers.

(iii) Develop a proposal for publishing the consolidated reports from the expert groups and associated syntheses, including consideration of publication as a book, special volume or a sequence of papers as the work is completed.

(iv) Continue supervising the development of the metadatabase.

(v) Provide a proposal advancing all of these actions by September 2008 in time for consideration by SC-CAMLR in 2008 and IWC SC in 2009.

The Workshop **agreed** that it remained desirable to complete this work program within 12 months in order to maintain the momentum and to achieve a coherent whole.

5. ADOPTION OF THE REPORT AND CLOSE OF THE MEETING

The Report of the Joint CCAMLR-IWC Workshop to Review Input Data for Antarctic Marine Ecosystem Models was adopted. It was noted that the report would be formatted separately by the two organisations in accordance with their house styles.

In closing the meeting, Constable and Gales noted the substantial progress made by the expert groups and the Workshop towards providing a standardised approach to the use of data from Southern Ocean ecosystems in modelling by CCAMLR and the IWC. They thanked the participants of the Workshop for their active contributions and desire for progressing this work. They also noted and thanked the many contributors to this success including the SC-CAMLR and IWC SC and the secretariats of CCAMLR and IWC, the Joint Steering Group, the expert groups and their coordinators, the Workshop small groups coordinators and rapporteurs along with other rapporteurs, the support of the CCAMLR Secretariat in hosting the meeting, and Doust for providing administrative support to the Workshop.

The participants joined Donovan in thanking Constable and Gales for their work with the Joint Steering Group in preparing for and convening the Workshop.

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Annex A
Agenda

1. Introduction
    1.1 Terms of reference
    1.2 Agenda and organisation of the meeting
    1.3 Background

2. Metadata summaries
    2.1 Physical environment and primary production
        2.1.1 Oceanography
        2.1.2 Sea-ice
        2.1.3 Primary production
    2.2 Pelagic species
    2.3 Seals and seabirds
    2.4 Whales
    2.5 Exploitation

3. General issues surrounding metadata and priorities for future research

4. Products and future work
    4.1 Metadatabase and other tools
    4.2 Publications
    4.3 Future work

5. Report adoption

6. Close of the meeting.

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Annex C
List of Documents

CCAMLR-IWC-WS-08/	Title
1	Draft Agenda. Coordinators – A. Constable and N. Gales
2	CCAMLR-IWC Workshop to review input data for Antarctic marine ecosystem models. Coordinators – A. Constable and N. Gales
3	Models of Antarctic marine ecosystems in support of CCAMLR and IWC: background. Coordinator – A. Constable
4	A review of abundance, trends and foraging parameters of baleen whales in the southern hemisphere. Coordinator – A. Zerbini
5	Report of review group of data sources on odontocetes in the Southern Ocean in preparation for IWC/CCAMLR workshop in August 2008. Coordinator – R. Leaper
6	A review of bias and uncertainty in Antarctic pack-ice seal abundance estimates. Coordinator – C. Southwell
7	Report of the review group on sources of data on Antarctic fur seals *Arctocephalus gazella* in the Southern Ocean in preparation for the CCAMLR-IWC workshop, August 2008. Coordinator – K. Reid
8	A review of the uncertainties associated with penguin population and abundance estimates for the CCAMLR region. Coordinator – P. Trathan
9	The role of fish as predators of krill (*Euphausia superba*) and other pelagic resources in the Southern Ocean. Coordinator – K.-H. Kock
10	Review of input data for Antarctic ecosystem models: pelagic cephalopods. Coordinator – P. Rodhouse
11	Krill population trends. Coordinator – S. Nicol
12	Zooplankton in Southern Ocean food web models: a critique of available data. Coordinator – A. Atkinson
13	CCAMLR-IWC Export Group Report: Primary Productivity and Phytoplankton Coordinator – P. Strutton
14	Observing and modelling Antarctic sea ice habitats – Sea Ice Expert Group Report to the CCAMLR-IWC Workshop to Review Input Data for Marine Ecosystem Models. Coordinator – R. Masson
15	An overview of data and models for Southern Ocean studies. Coordinator – E. Hofmann
16	CCAMLR-IWC Workshop metadatabase. Coordinator – S. Doust
17	Conveners' guide to generating a synopsis of papers from expert groups to assist with general discussions. Coordinators – A. Constable and N. Gales
18	Food consumption by flying seabirds in the Southern Ocean Coordinator – B. Wienecke

Annex D
Summaries of life history for krill, zooplankton and squid

KRILL

CCAMLR-IWC-WS-08/11 concentrated on studies that examined distribution and abundance. There is a wealth of studies into krill life history from both field and laboratory studies (most recent review by Siegel, 2005). These have resulted in the development of conceptual models at the individual level (Nicol et al., 2006) and at the population level (Atkinson, 2008) which aim to describe the observed patterns of distribution. Most of the background information relating to population dynamics of krill is summarised in Siegel and Nicol (2000) and Siegel (2005). These papers provide reviews of estimates of growth, mortality, fecundity, recruitment and longevity. Probably the key bottleneck in the life history of krill is the survival of larvae from the point of hatching through the first winter. At this point in their life cycle the animals have little ability to resist food shortage and the survival of the larvae through to their first spring is probably key to subsequent recruitment (Quetin et al., 2007).

There is little information on the effect of quality of food on krill growth and reproduction. Growth has been linked to food availability (see below) and there is field information on the effects of food quality on the growth of young krill. Growth rates of krill, including larvae, during the austral spring and early summer (November to mid-January) is a function of the abundance and composition of the phytoplankton community in the water column (Ross et al., 2000). Sea-ice microbial communities are also thought to be a better nutritional source in the under-ice habitat for larvae than open-water source. Krill rely on springtime primary production (ice-associated and open-water primary production) to fuel ovarian development and the timing of the spring bloom is thought to be critical (Kawaguchi et al., 2007, Ross and Quetin, 2000; Hagen et al., 1996; Quetin and Ross, 2001).

Krill have a number of overwintering strategies: (i) reduced metabolism, (ii) increased carnivory or detritivory, (iii) starvation and shrinkage, (iv) migration inshore or to deep water, and (v) feeding under the ice. The circumstances under which each of these strategies is employed are not well defined and populations of krill may utilise all of these strategies (Siegel, 2005).

The various life-history stages (and seasonally the reproductive stages) of krill can show distinct spatial separation, both vertically and horizontally. Krill are broadcast spawners and they lay their eggs in deep water where they can sink to 1 000 m. The developing larvae swim upwards and return to the surface to feed in autumn. Eggs spawned by krill in one area may therefore recruit as juveniles to another area, thus the population structure of a krill population may reflect both endogenous as well as exogenous effects. The extent to which krill exist as populations in an area and their capacity to self-recruit is a subject of active modelling and research.

Several models of krill growth have been produced. The most recent are Atkinson et al. (2006), Candy and Kawaguchi (2006), Hofmann and Lascara (2000), Kawaguchi et al. (2006), Rosenberg et al. (1986) and Tarling et al. (2006).

ZOOPLANKTON

Copepods

Life-cycles information is available in CCAMLR-IWC-WS-08/12, in particular sections 2 and 4. In brief, three species are known to have two-year life spans, *Rhincalanus gigas, Calanus propinquus* and *C. acutus.* They exhibit deep-water seasonal migration (~1 000 m) to diapause over winter before returning to the surface waters in spring to mature or reproduce. Most of the other copepod species are assumed to live one year with generally pulse spawning. The small cyclopoid copepod *Oithona similis* lives a few months and breeds continuously.

All major species are now considered omnivore, feeding on phytoplankton, microzooplankton and particulate matter such as marine snow and possibly faecal matter. Genuine carnivorous copepods are low in number. Very little is known on food quality, recruitment and mortality for copepods.

Salps

Basic information is available on their unusual life cycle of alternating sexual/asexual generations, including their seasonal vertical distribution. Growth rates are available but fundamental questions remain over mortality rates, factors affecting ‘recruitment’ (i.e. causes of salp blooms) and metapopulation structure.

THEMISTO GAUDCHAUDII

Only very basic information is available on the life cycle, with absence of detailed data on reproduction, recruitment, separation of age classes and mortality rates etc.

All species have circumpolar distributions and pronounced latitudinal zonation. The distribution of abundance is highly variable, and can be transient. Sub-Antarctic islands, gyres and polynyas may have more persistent localised high abundances.

Squid

Pelagic squid, in common with most other cephalopods, are fast-growing, short-lived and semelparous. Although there is no reason to suppose that Antarctic squid are not semelparous, low temperature is a major factor controlling growth in polar organisms and the few Antarctic cephalopods in which growth has been examined have slower growth rates than species from warmers waters. Rates of growth as well as fecundity, egg size and development in Antarctic cephalopods are reviewed by Collins and Rodhouse (2006). The Antarctic octopuses have very large eggs compared with lower latitude species. The pelagic squids also have larger eggs than lower latitude species, but the difference is less marked than in the octopuses. As expected, larger egg size does appear to be related to lower fecundity although there are few data. Egg development time has not been measured, but on the basis of their size and prevailing temperatures it has been suggested to be about 30 months for the Antarctic pelagic cranchiid squid *Galiteuthis glacialis*. There are no estimates for recruitment, mortality rates or carrying capacity for Antarctic pelagic squid. On the basis of comparisons with lower latitude species it is probably safe to assume that: (i) recruitment of most species is annual following an extended egg and paralarval phase; (ii) recruitment is probably variable and driven by environmental variability; (iii) mortality is relatively low; and (iv) carrying capacity will vary with availability of prey. Populations of ecologically opportunistic squid will increase and that when prey is abundant, but over time they will be variable. This is supported by evidence of variability of interannual variability in species of squid in the diet of seabird predators.

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Annex E
Unedited views of some participants on relative priorities for ecosystem modelling

MARK BRAVINGTON

The range of possible structures for an ecosystem model is too big to allow a purely empirical approach to building them (e.g. based purely on cross-correlations in time-series). It is necessary to develop some basic physical and biological understanding of the system in order to constrain the space of *a priori* plausible models; otherwise, the task is statistically hopeless. But it also seems hopeless to try to deduce the population dynamics responses of major predators from first principle, so some notion of time series data and model fitting seems unavoidable. The comments below relate to what the priorities might be for further data on large spatial-scale krill-centric models in the Antarctic.

Species-level information

In deciding whether the model should specifically incorporate a particular taxon, and what, if any, priority there should be for further work on the species (in an ecosystem-model-building context), I would ask three questions:

- does the species eat enough to matter—is it a 'player'? This can be very rough: some idea of abundance, and some idea of consumption rates, e.g. from allometry.
- if yes to 1, then: is our current or medium-term future information on the species good enough that explicitly including the species in the model would substantially improve our certainty about overall predictions?
- if yes to 1 and 2, then: what is the population structure / site fidelity (e.g. do individuals range the whole Antarctic, across ocean basins, or across smaller scales such as gyres? are they there all year or..?). Knowing this is crucial to building sensible models, given that management and conservation decisions are typically linked to particular spatial scales.

In the Antarctic, examples of species that would likely 'fail' question 1 are a number of seabird species. Examples of taxa that would likely 'fail' question 2 are fish, squid and non-krill zooplankton. With respect to question 3, a best guess may be necessary to begin with; but there are big uncertainties with respect to krill and many baleen whales, and this is surely a priority for future work. At least for krill, this is linked to a decent level of understanding of basic physics and primary production; how much is 'decent' is a whole other story.

Even if a taxon 'fails' question 2 and therefore does not warrant explicit inclusion, we cannot ignore its existence if we know it has a big impact on krill. The corollary is that the model would need to have black-box components reflecting unknown predation on krill, which we cannot expect to be bridged by process studies in the medium term. And the corollary of *that* is: in order to estimate how the black-box works, surely we will need time-series data on the explicitly included species.

Historical data

Fitting statistical models to data, ecosystem models or otherwise, requires more than just *quantity* of data; it also requires *contrast* in the data. For example, if abundance of species X varies very little over the time series, then we have no direct data on what the implications of *changes* in species X might mean. For species which have been heavily exploited, the historical record is the obvious place to look (e.g. for how life-history parameters of whales changed over exploitation).

Should we build models?

Ecosystem models are much trickier than single-species models, in part because there are more dimensions to our ignorance about how the system works, not just parameter values, but also in terms of alternative model structures. It is healthier to think about developing a *suite* of models that try to capture parametric and structural uncertainty (subject to all the models being consistent with the data, not just in terms of time series but also in terms of plausibility of mechanism). If the model-suite is too narrow and leads to spuriously precise predictions, it will be worse than useless for management. So we need to be able to move beyond 'best guesses' at phenomena, to figuring out plausible ranges. Although the Antarctic is easier than many other parts of the globe in terms of simplicity of food webs and clarity about physical drivers, the job of building and fitting a model-suite is immense.

Ecosystem management *necessarily* requires some level of qualitative and quantitative understanding of the ecosystem, but it does not *necessarily* require an underlying quantitative ecosystem model. Building a decent ecosystem model-suite, i.e. one that honestly captures our ignorance about structure and parameters, is a huge amount of work. The question to ask *before* starting, is this: is it obvious in advance that the model's predictions will provide more certainty than we can already get from our fundamental understanding? I do not know enough to answer that for the Antarctic, but hopefully others can. And if the answer is 'no, the predictions will be no more precise', then the time and effort required to build models would better be spent doing something else.

DOUG BUTTERWORTH

Note: The use of the word 'progressing' in the title is particularly deliberate; what follows is not intended to describe a comprehensive long-term approach, but rather necessary initial steps in a long-term process.

Questions 1 and 2

- The spatial scale pertinent to the points below is the scale at which the question is directed: Management Unit or SSMU; the temporal scale is annual, or biannual where relevant to encompass important seasonal differences (e.g. in production or presence within the spatial unit).

- Conduct an approximate accounting of estimates of consumption of krill by the top predator/predator groups in the spatial unit to provide an order of relative importance ('importance index').

- Institute (where not already available) approaches to provide comparable indices over time of the relative abundance of krill and top predators/predator groups in the spatial unit. The priorities for the latter are to be determined by joint consideration of the 'important index' and practical considerations. The frequency of index determination (annual or longer intervals) is to be based on typical species life spans (e.g. inverse natural mortality rates) (i.e. less frequent for species with slower dynamics) and practical considerations.

- To the extent possible, convert indices of relative to estimates of absolute abundance.

- Sample the diet of the top predators/predator groups on an annual basis if possible, with priority guided by the 'importance index', and with a view towards estimating the parameters of a range of plausible feeding functional relationships.

- Estimate the period of the year that each predator/predator group spends feeding within the spatial unit.

- For SSMUs (in particular), develop approaches to estimate the transport of krill into and out of the spatial unit.

- Develop a range of MRMs (minimally realistic models), incorporating predator–prey interaction terms, to serve as operating models for testing catch limit algorithms, conditioning these models on the available abundance, life history and diet data.

- Select a catch(es) (or efforts) limit algorithm to provide scientific management recommendations, based on performance in simulation testing under the operating models developed. The algorithm's computations would most likely give particular weight to recent trends in indices of abundance to incorporate the robustness provided by feedback control into the overall management approach.

4.4 Question 3

The following points are added to those above:

- Request biologists and oceanographers with knowledge of the potential major environmental drivers of the ecosystem at the spatial level under consideration to select a maximum of three annual environmental indices (e.g. extent of sea-ice cover) hypothesised to be those most likely to impact the dynamics. There need to be time series of these indices available for some past years, and the capability of monitoring them into the future.

- Incorporate such indices as external inputs to the dynamics of the operating models being used to simulation test alternative catch limit algorithms; this would be to the extent that plausible relationships can be determined by conditioning against past data (even if only on a more qualitative than quantitative basis).

JUSTIN COOKE

Of the three main management questions (paragraph 1.35) questions of type 1 – how does fishing on a prey species impact predators of that species – might well be answerable (and in several cases have been answered) using models of the local system, incorporating just a few components and little in the way of environmental factors, that do not need to explicitly include a model of the large-scale and multi-year dynamics of the prey.

Addressing questions of type 2 and 3 requires an understanding of the system at larger scales and longer time scales, and potentially consideration of the full system, from the physical environment, through primary production, through to prey species and finally to predators.

While some of the interaction between predators (questions of type 2) can be quite local and immediate, and addressable using relatively simple modelling approaches as for questions of type 1, it may be wrong to ignore the wider-scale interactions (e.g. depletion of common prey populations, even where predators do not overlap in time or space). Addressing these wider-scale interactions will tend to lead into consideration of models of the more comprehensive kind required to address questions of type 3.

For example, in the case of krill, the apparent absence of genetic differentiation between areas may be suggestive that instead of there being permanent, self-sustaining populations in each area, populations may tend to be regenerated from a common source, at more or less frequent intervals.

To understand the multi-year dynamics of the ecosystem, it is important to be able to identify those persistent source populations of krill and other prey species, which are primarily responsible for the (periodic or aperiodic) regeneration of prey populations throughout the Southern Ocean, following environmental perturbations.

Conservation of these core populations will likely be important for long-term management of the system, in particular if a management goal is the prevention of 'tipping' of the system semi-permanently into qualitatively different and less desirable states.

The more ephemeral prey populations, that are liable to disappear or reappear following major environmental fluctuations, may be very important in many areas as food for the predators that exploit them, but depletion of these populations may not have the same effects on prey production in subsequent years as depletion of the core populations would have.

Most of the components of an ecosystem model are subject to great uncertainty. Because the sum of all the uncertainties tends to be dominated by the few largest individual uncertainties (expressed simply: CVs add as squares, not linearly), improving understanding of the currently most poorly known components of the system is probably the highest priority. The development of models which qualitatively capture the system well, even if their predictions are subject to large quantitative uncertainty, may be of the greatest value for developing long-term management approaches of the most appropriate qualitative form.

Such management approaches might involve, for example, complete protection of core populations, with exploitation confined to the remainder, rather than having exploitation of all populations subject to quantitative regulation.

DANIEL COSTA

There is a need to develop approaches to derive an understanding of the functional response of top predators from the considerable behavioural data that can and is being collected from them. For example, can we infer something about patch quality from the dive behaviour and or pattern? One approach that has been developed in IPQ (individual patch quality?) and transit time between patches versus patch residence time. The ability to eventually test these models against studies where prey abundance is actually measured while a predator or predators are foraging in that area would be outstanding interaction between models and empirical data collection.

Develop individual-based models (IBMs) or other approaches to allow prediction and or description of movement and foraging behaviour of top predators. Such models are critical to link the demography (at the population level, as populations are made up of individuals) to biophysical processes at the scale appropriate to the predator. This would allow integration of top predators in bottom up nutrient, phytoplankton, zooplankton (NPZ) type models. It could also incorporate models of predation risk (avoidance behaviour) and or competition between other predators or organisms.

Develop a model to assess alternative trophic pathways. For example, what happens to top predators if they derive most of their energy from fish rather than krill. There is evidence that these different food webs have different patterns and can support different predator populations. How is energy flow altered? Is one most stable, is one low energy or better able to sequester energy or carbon?

What are the fundamental measurements that would be most desirable if we had a SOOS? Assuming such a system would be offshore or near your predator study site.

MEGAN FERGUSON

The integrated questions that the Workshop proposed cover the scope of the ecosystem modelling question well. The overarching question is, How do we collect and analyse data to address these questions? I think there are three themes that could help guide future research efforts with the goal of informing ecosystem models. First, the Southern Ocean is so vast that we need to think about **nested field sampling designs** that could be incorporated into **hierarchical models** to integrate information across spatial and temporal scales, and from the individual to the population. Second, in order to determine the appropriate sampling scales for the field and analytical scales and scaling functions for the models, we need to understand the **patch structure and temporal variability** of the biological and physical environment. Third, modellers need to talk to biologists and physical oceanographers to try to understand how the **physical environment** affects the relevant species. This level of understanding is critical for identifying the appropriate sampling scale and for developing models that will have predictive power in a dynamic environment.

TOSHIHIDE KITAKADO

There are several key items at population level for modelling purposes as follows:

(i) Information on prey availability and its dynamics in a certain scale of space and time, which is of course linked to the distribution and abundance of the prey species (perhaps by life stage).

(ii) Information on pattern of habitat utilisation by predators (as well as their abundance and population dynamics), which may depend on their life stages, sex segregation, environment and so on.

(iii) Information on feeding rates or functional responses for predators.

(iv) Information on prey selection.

The bottom lines to resolve these key issues are availability of information on abundance of prey and predators and stomach contents or diet composition against prey availability at population level. Also, monitoring the diet composition is informative to capture the impact of environmental change on the ecosystem. In this sense, work for transforming knowledge on the individual-based behaviour to population-based one is important. Furthermore, the scale of space and time that needs to consider surely depends on research and management objectives of either CCAMLR and IWC or both. These should be clearly described. Handling uncertainties is another key issue. Statistical uncertainties will be handled well by the statistical methods, but it is necessary to develop a management procedure which is robust to ecosystem model uncertainty.

RUSSELL LEAPER

Many ecosystem models have placed an emphasis on parameter estimates rather than model structure. One option in developing a model is to start with a model of the most simple pathway (e.g. diatoms→krill→higher predators) and continue adding additional pathways as needed to generate a MRM. One problem with this is that the basic model structure may effectively determine the model results, and although the sensitivity of results to parameter estimates can be tested, the sensitivity of the results to model structure is not possible to test. An alternative approach is to start with a more complex, multiple pathway model and to try to simplify this by removing pathways on the basis of sensitivity tests. For this type of approach it is more critical to put broad bounds on all the pathways rather than refine parameter estimates for a few.

ANDRE PUNT

The key information needs for ecosystem (or multi-species) models depend critically on the objectives for which they were designed, and whether they are to be used for tactical (e.g. the updating of catch limits) or strategic (e.g. testing of management rules) purposes. The nature and information needs for ecosystem models also depend on the how quickly results are needed (in some cases, and from a management perspective, obtaining an approximate answer quickly may be much more useful than obtaining the right answer long into the future). Ideally, an ecosystem model should be built around a 'core' species or set of 'core' species. 'Core' species are species that can be assessed using conventional single-species approaches and hence for which data on (minimally) indices of relative abundance are available. In principle, ecosystem models constrain species behaviour through the constraints implied by feeding functional relationships. However, this benefit will not be available, and the model will be of limited use (at least for tactical purposes), without a 'core' species, models for which can be reliably parameterised. There is minimally a need for daily ration and diet composition data for the 'core' species and preferably a time series for both. Sampling which is random with respect to predator and prey distribution, and based on consistent methodology, is preferable to detailed high-intensity sampling at limited temporal and spatial scales. The information needs for an ecosystem model designed to evaluate the implications of environmental forcing, including environmental change, will be different from those for ecosystem models designed for other purposes. Specifically, ecosystem models designed to evaluate the implications of environmental forcing are ideally developed based on process-based hypotheses and involve nested sub-models operating at different temporal and spatial scales.

KEITH REID

I preface these comments with the acknowledgement that I am not a modeller.

I see the role of ecosystem models as a component of the ecosystem approach as they provide a means of developing a simulation environment to test assessment models in order to evaluate the likelihood of achieving management objectives. An important consideration of this approach to management strategy evaluation is that potential scenarios should not be ruled out because they do not fit with our observations. The risk that an observation gains a greater weight through repeated reporting, rather than repeated observation, creates the risk of a disproportionate weighting for some scenarios. In the development of ecosystem models the acquisition of large-scale, long time-scale data is obviously a goal (grail), however, there is a recognition that acquiring these data is very difficult if not impractical/impossible. In considering predator–prey interactions, I feel that it is important to provide an understanding of those interactions at the scales that influence the life histories of the species involved. The highly seasonal nature of the Antarctic means that predators and prey respond at sub-annual scales and therefore understanding the short time-scale changes in the krill abundance in the regions where predators feed (especially at times when they are constrained by the need to provision offspring) is especially important as even small changes in distribution and/or timing of periods of krill abundance may have a large impact of reproductive performance. Viewed at an annual time scale, these small changes will be subsumed, however, they may actually have a very large impact of predator populations. The short time-scale data on krill, as collected by moored acoustic arrays, as well as the monitoring of predator performance (including diet and reproductive output) are key data collection priorities for assessing the potential impact of fisheries on predators of krill in the Antarctic.

ANDREW CONSTABLE

The structure and data requirements of ecosystem models is dependent on whether they are to be used as assessment tools or in providing scenarios for testing management procedures (i.e. testing the assessment tools and the decision rules in a management procedure). There is a lesser requirement for time series of population and food-web data in scenario-type models. Importantly, the models should focus on a central species or group of species (e.g. krill and krill predators) and concentrate on primary and secondary interactions and factors that will influence those (species and processes that could directly impact or have a substantial indirect impact on krill and krill predators). Species and interactions further out in the food web can be considered peripheral and likely not to be relevant, at least in the first instance. Scenario-type models are very useful for identifying how we can best learn about the important processes in the ecosystem and the degree to which we can make good management decisions for achieving management and conservation objectives.

The building of an ecosystem model will need to account for all the issues identified in paragraph 3.4. Even though the model may summarise many processes in a single process or parameter, the author of a model needs to ensure that such simplification of the model does not inadvertently and inappropriately bias the outcomes with respect to the management questions being addressed. A key issue is whether the spatial, temporal and biological partitioning in reality is correctly reflected in the model, i.e. that a predator–prey overlap in the model takes appropriate account of the factors that could cause the overlap to occur or not; presence in the Southern Ocean at the same time of year does not mean that a predator will necessarily have access to potential prey. Similarly, the opportunities for alternative energy pathways to give rise to an alternative suite of ecological dynamics in the predator–prey system of interest, e.g. the krill-based food web, needs to be preserved in the model structure, even if those pathways are not represented in full.

As there are many model structures that could give rise to a suite of time series of abundances, most of which are of poor quality in the Southern Ocean, then the focus in the short term for developing ecosystem models for the Southern Ocean needs to be on characterising the processes and interactions that influence the dynamics of the key populations of interest.

Annex F
Some figures to illustrate where data and knowledge might be used to build plausible scenarios (models) of ecosystems

Andrew Constable

NB: The following figures are available in colour on the CCAMLR website.

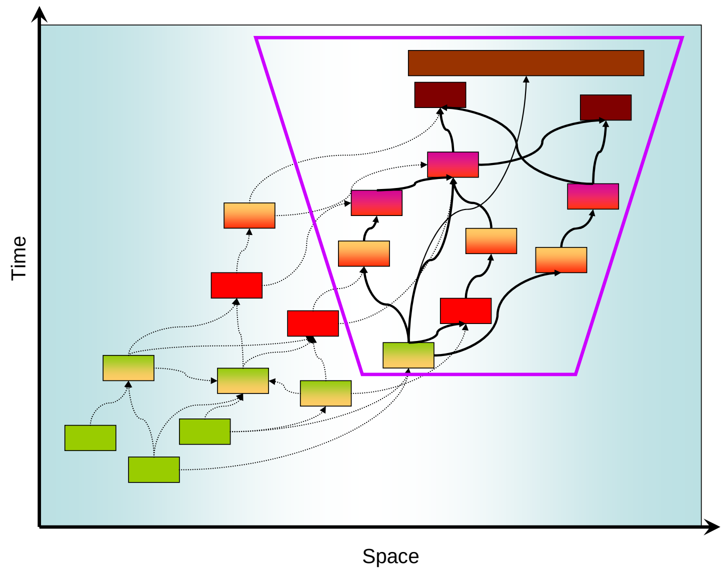

Fig. 1. Schematic representation of different taxa and their relationships, within the physical ocean and sea-ice, arranged according to the spatial and temporal scales within which individuals of the different taxa typically function. The trapezoid shows a typical subset of a minimal realistic model that might be considered by CCAMLR and the IWC with krill at the bottom of the food web operating at smaller scales than larger predators. In this case, some species of whales cover broad spatial scales and are shown at the top of this food web.

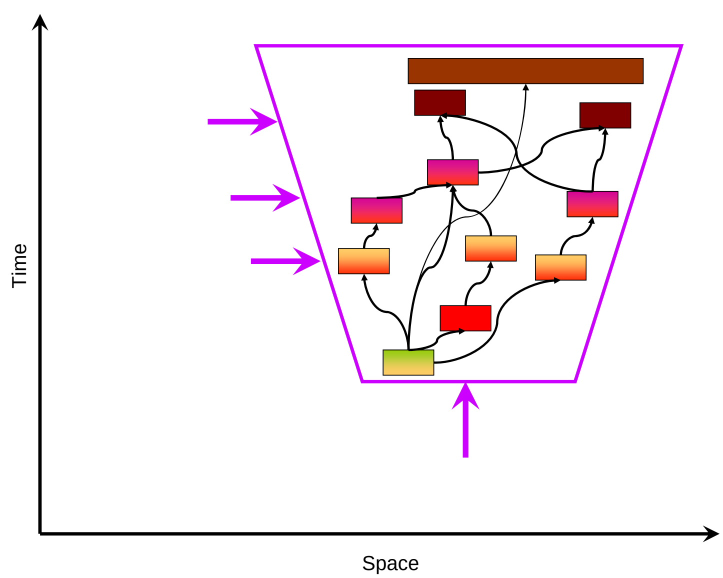

Fig. 2. For simplicity, the food web and physical environment outside the trapezoid is then collapsed into a series of forcing functions indicated by the arrows.

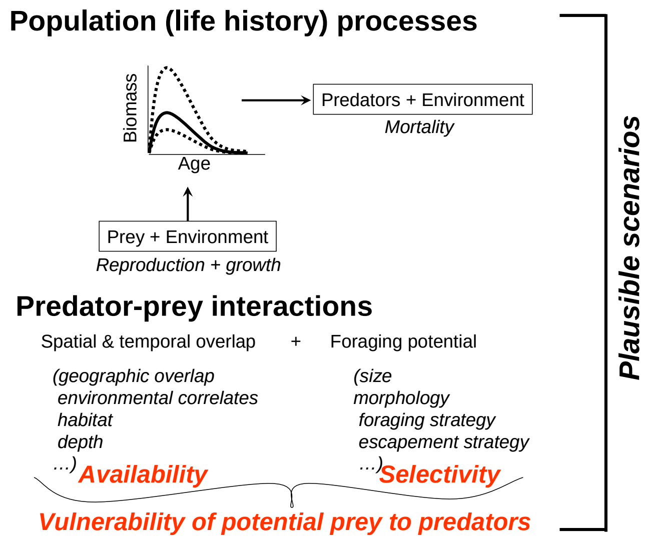

Fig. 3. Plausible scenarios are first built into models by representing population and predator–prey processes at a level of detail appropriate to the purpose of the model. For populations, these processes will influence reproduction, growth and mortality. For predator–prey interactions, the functions will represent the vulnerability of prey to predators given the degree of spatial and temporal overlap (prey availability to predators) combined with the ability for predators to capture prey when they are encountered (selectivity).

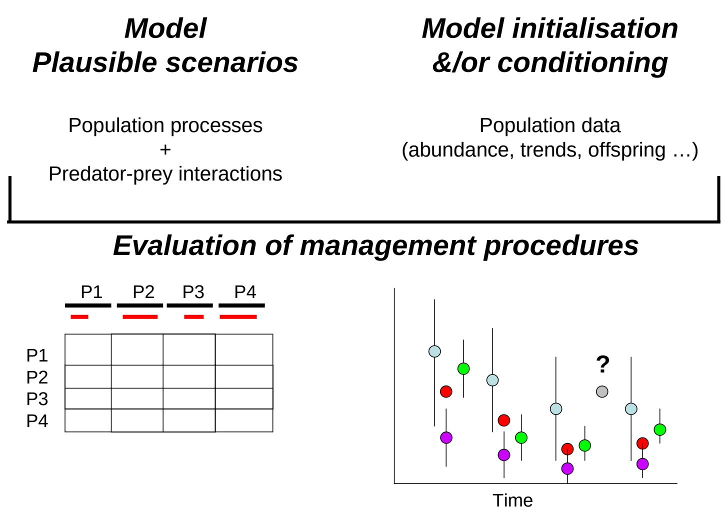

Fig. 4. Plausibility can be improved by the inclusion of population data either for initialising the models or for conditioning the models to a time series. In this case, some parameters in the model structure can be estimated and, individually, represent many ecological processes. Data will have differing relationships to the true state of the population, which is indicated by the red circles. Precision of estimates is indicated by the magnitude of the error bars while biases may be of a consistent relative magnitude (useful as a relative time series) or could be offset by fixed amounts, which could cause problems if those offsets are unknown and the models need to remove fixed quantities.

Annex G
Acronyms and abbreviations

AAD	Australian Government Antarctic Division
AADC	Australian Antarctic Data Centre
ACC	Antarctic Circumpolar Current
AKES	Antarctic Krill and Ecosystem Survey (Norway)
AMLR	Antarctic Marine Living Resources (USA)
APECOSM	Apex Predators Ecosystem Model
APIS	Antarctic Pack-Ice Seals Program (SCAR-GSS)
ARP	Acoustic Recording Package
BAS	British Antarctic Survey
BROKE	Baseline Research on Oceanography, Krill and the Environment (Australia); CCAMLR Division 58.4.1
BROKE-West	as above; CCAMLR Division 58.4.2
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCAMLR-2000 Survey	CCAMLR 2000 Krill Synoptic Survey of Area 48
CCAS	Convention on the Conservation of Seals
CPR	Continuous Plankton Recorder (international) 1991 onwards
CPUE	Catch-per-unit-effort
CI	Confidence Interval
CV	Coefficient of Variation
Ecopath	Software for construction and analysis of mass-balance models and feeding interactions or nutrient flow in ecosystems (see www.ecopath.org)
Ecosim	Software for construction and analysis of mass-balance models and feeding interactions or nutrient flow in ecosystems (see www.ecopath.org)
ENSO	El Niño Southern Oscillation
FIBEX	First International BIOMASS Experiment (Krill survey under auspices of SCAR)
FMR	Field Metabolic Rate
GAM	Generalised Additive Model
GCMD	Global Change Master Directory
GLOBEC	Global Ocean Ecosystems Dynamics Research (USA)
GUI	Graphical User Interface
ICED	Integrating Climate and Ecosystem Dynamics in the Southern Ocean
IDCR SOWER	International Decade of Cetacean Research – Southern Ocean Whale and Ecosystem Research
IPCC	Intergovernmental Panel on Climate Change
IWC	International Whaling Commission
IWC SC	IWC Scientific Committee
JARE	Japanese Antarctic Research Expedition
JARPA	Japanese Whale Research Program under special permit in the Antarctic
K	Carrying Capacity
LAKRIS	Lazarev Krill Study (the German contribution to CCAMLR-IPY 2008)
LTER	Long-term Ecological Research (US National Science Foundation)
MODIS	Moderate Resolution Imaging Spectroradiometer
MRM	Minimally Realistic Models
MSA	Methanesulphonic Acid
MSYR	Maximum Sustainable Yield Rate
Multspec	Multi-species Model for fish and marine mammals
NORPAC	North Pacific
PFZ	Polar Frontal Zone
POM	Princeton Ocean Model
RMP	Revised Management Procedure
ROM	Regional Ocean Modelling Systems
ROV	Remotely-Operated Vehicle
SACCF	Southern Antarctic Circumpolar Front
SAM	Southern Annular Mode
SBACC	Southern Boundary of the Antarctic Circumpolar Current
SC-CAMLR	Scientific Committee of CCAMLR
SCAR	Scientific Committee on Antarctic Research

SCAR-Marbin	SCAR Marine Biodiversity Information Network
SeaWiFS	Sea-viewing Wide field-of-view Sensor
SOCEP	Southern Ocean Cetacean Environment Program (Australia)
SO-GLOBEC	Southern Ocean GLOBEC
SOOS	Southern Ocean Observing System
SSIZ	Seasonal Sea-ice Zone
SSMU	Small-scale Management Unit (CCAMLR)
VGPM	Vertically Generalised Production Model
WAP	Western Antarctic Peninsula
WG-EMM	SC-CAMLR Working Group on Ecosystem Monitoring and Management
WG-IMAF	(ad hoc) Working Group on Incidental Mortality Associated with Fishing