Annex K1

Report of the Sub-Committee on Ecosystem Modelling

Members: Gales (Convenor), Acquarone, Aguilar, Alter, Apostolaki, Baba, Bejder, Bjørge, Borodin, Bøthun, Butterworth, Campbell, Cañadas, Charrassin, Chilvers, Corkeron, De Decker, de Moor, Donovan, Engel, Ensor, Ferguson, Findlay, Freitas, Gallego, Galletti, Goodman, Grønvik, Gunnlaugsson, Hammond, Hedley, Kaschner, Kelly, Kock, Leaper, Liebschner, Lockyer, Lovell, Mate, Mazzariol, Melton, Miller, Moore, Morishita, Morissette, Muller, Murase, Murphy, Øien, Okada, Okamura, Palka, Panigada, Polacheck, Punt, Ribeiro, Ridoux, Ritter, Robbins, Rogan, Rojas-Bracho, Rose, Rowles, Scordino, Siciliano, Simmonds, Skaug, Stachowitsch, Tamura, Uoya, Urban, Vasquez, Vazquez, Víkingsson, Wade, Walloe, Weinrich, Williams, Yamakage, Yasokawa, Young, Zerbini.

1. CONVENERS OPENING REMARKS
Gales welcomed the participants to the meeting.

2. ELECTION OF CHAIRPERSON AND APPOINTMENT OF RAPPORTEURS
Gales was elected chair. Leaper agreed to act as rapporteur.

3. ADOPTION OF AGENDA
The adopted agenda is given as Appendix 1.

4. REVIEW OF DOCUMENTS
The following documents were relevant to the sub-committee: SC/61/EM1, SC/61/JR2, SC/61/Rep2, ForInfo (FI) 7, 8, 24, 25, 26, 28, 39.

5. ECOSYSTEM MODELLING
5.1 Review report from joint CCAMLR-IWC workshop
A joint CCAMLR-IWC Workshop to review input data for Antarctic marine ecosystem models (SC/61/Rep2) was held at the CCAMLR headquarters in Hobart, Australia in August 2008. The terms of reference for the workshop were to consider the types, relative importance and uncertainties associated with input data for models of the Antarctic marine ecosystem that could be developed for providing management and conservation advice relevant to CCAMLR and IWC. The workshop reviewed the input data that are currently available for such models in order to understand what is needed to reduce uncertainties and errors in their use. Prior to the workshop, expert groups had been assembled to prepare thorough reviews of existing data on the physical and biological components of the ecosystem for a number of taxa (including toothed and baleen whales), sea ice, and ocean processes.

An expected outcome from the workshop was to link whale data with that of other krill consumers to form a consistent set of inputs for modelling which would improve the provision of sound conservation and management advice for the Southern Ocean. In particular, the workshop aimed to identify and prioritise the gaps in knowledge and types of analyses and field research programs that would be needed to reduce important uncertainties in ecosystem models being developed for CCAMLR and IWC.

Early drafts of the toothed and baleen whale papers had been presented and reviewed at IWC60 and most expert group submissions were fairly complete by the workshop. The workshop discussed the reviews in relation to abundance, habitat, life history, food-web linkages and future analytical and research priorities. Due to time constraints there was less in-depth discussion of the physical environment and primary production.

Overall, the workshop made substantial progress toward providing a standardised approach to the use of data for modelling Southern Ocean ecosystems. Improvements in parameterisation in CCAMLR and IWC models, which were in part facilitated by the workshop, are expected to inform ecological relationships between whales, their prey and other parts of the ecosystem, as well as informing models for the sustainable management of krill.

The workshop recognised the importance of appropriate, coordinated, long-term data series of key features of the environment and the predators and their prey. It was noted that major parts of the Southern Ocean ecosystem remain poorly defined (e.g. squid, flighted birds, and salps), and understanding the influence of these knowledge gaps on ecosystem models that focus on the more data-rich components remains a challenge.

The sub-committee welcomed this report and endorsed the recommendations from the workshop. The sub-committee thanked the Joint Steering Group, the participants in the expert groups, the CCAMLR Secretariat for hosting the meeting and the IWC Secretariat for assisting with the coordination of the meeting and in the production of the report.

A key outcome of the workshop was a recommendation that the expert groups should complete their work. The sub-committee recommended that these papers should be developed for publication such that they become available within a reasonable timeframe (and ideally by IWC62), although not necessarily in the same journal (for example the JCRM would be the obvious place to submit the cetacean papers). Co-ordination across the expert groups should attempt to ensure that statements of the extent of uncertainty in the available data are consistent across the groups. Although the idea of shared electronic metadata is probably too ambitious, the compilation of the data reviews by the expert groups would comprise a very useful resource.

Gales drew attention to a joint physical and biological workshop titled 'Monitoring climate change impacts on marine biodiversity: establishing a Southern Ocean Sentinel program' which had been held in Hobart in April 2009 (*www.aad.gov.au/default.asp?casid=35088*). It was noted that physical data have been used extensively in the work of the IPCC but that biological data have been much less prominent. Moore noted initiatives in the northern hemisphere to bring biological data into climate change discussions through bio-response workshops organised by ICES and PICES.

5.2 Review of progress in the development of ecosystem models
Four closely related papers dealing with cetacean *vs.* fisheries interactions in the Caribbean and Northwest African ecosystems (SC/61/FI25, 26, 28 and 39) were presented by Morissette and Kaschner. Study areas were selected to respond to claims made in political fora that fish consumption by large cetaceans are a threat to fisheries resources in these regions, although the authors conceded that the investigation of potential competition

between fisheries and cetaceans would have been more rewarding in polar feeding areas, both in terms of data availability and scientific relevance. Given the lack of local, long-term dedicated surveys to provide reliable cetacean abundance estimates, density estimates had to be derived from a global model (Kaschner, 2004; Kaschner *et al*., 2006). However, comparisons with observed species-specific densities from surveys conducted in similar habitats indicated that predictions from the global model were similar in terms of magnitude (detailed information provided in tables in SC/61/FI26). It was assumed that baleen whales eat 10% of their total annual consumption in tropical breeding areas, even though there is no evidence that some species feed at all in these areas. To address issues of uncertainties and data gaps raised following the presentation of preliminary models at last year's meeting, an extensive uncertainty analysis was conducted, with a particular focus on cetacean model parameterization. Under the wide range of uncertainty assumptions, model results consistently indicated that: (1) cetaceans consume less than fisheries take and are feeding on different prey species; (2) the overlap between cetaceans and fisheries is lower than in other areas; (3) the overall trophic impact of cetaceans is minimal compared to that of fisheries, and (4) the simulated eradication of baleen whales in both ecosystems did not lead to any appreciable increase of commercial fish biomass. The model results are robust to the most extreme assumptions, and uncertainty has been addressed in a way that has not been done before for such global ecosystem models. Acknowledging existing data gaps for some cetacean input parameters which necessitated such assumptions, the authors stressed the existence of good local data available for important non-cetaceans groups in the ecosystem, and the overall above-average quality of input data to the model.

Murase expressed concerns on the conclusions of papers SC/61/FI25, FI28 and FI39. The problems associated with the analysis of marine mammal- fisheries interactions by Morissette *et al.* (2008) resulted in prolonged discussion at SC60 (IWC, 2009). He believed the sequence of similar papers presented to this meeting (SC/61/FI25, FI26, FI28, FI39) have not addressed many of the issues raised during those discussions. One of the major flaws was assumptions made related to input data. Data on abundance of cetaceans were mainly based on a global model rather than sighting surveys in the local areas. Such a global scale model tends to average out the distribution pattern of cetacean which obscures hot spots at small scales. The global model was discussed at the 58th IWC/SC in 2006. It was pointed out that it was necessary to structure spatial models to handle data at smaller scales for management purposes (IWC, 2007). Uncertainty of abundance estimates from a global model makes it difficult to use these estimates because of lack of ground truth data in the targeted areas. The diet compositions of baleen whales were in some cases derived from the results in the North Atlantic. However, the assumption that the diet composition in breeding areas is the same as in feeding grounds is unrealistic. The quality of input data is the most important element to derive meaningful output from ecosystem models. Given such insight, CCAMLR and IWC had the joint workshop to in part review the reliability of input data for ecosystem models (SC/61/Rep2).

Murase continued that he believed data used as input for the Caribbean and Northwest Africa models (SC/61/FI28; SC/61/FI39) in this case would not meet any reasonable criteria required for the above mentioned model output to be considered reliable. Models for the Caribbean and Northwest Africa were based on numerous assumptions that could have compounding effects on the reliability of outputs yet the description of sensitivity analysis referred in SC/61/FI28 and SC/61/FI31 do not make it clear how such possible compounding effects are addressed. Ecosystem modelling work itself can be very useful to understand the marine mammal-fisheries interactions which can lead to ecosystem based fisheries management in the future. However, in his view, because of the lack of data related to all aspects of the ecosystem modelled, no conclusion can be drawn about marine mammal-fisheries interactions in the Caribbean and Northwest African waters from papers SC/61/FI28 and SC/61/FI39 at this stage.

Morissette and Kaschner responded to the claim that they had not addressed many of the issues raised during discussions at SC60, by pointing out that each of the comments had been addressed to the extent possible. They offered to provide a table summarising how this was done. On the issue of sensitivity analysis and addressing possible compounding effects they had conducted a Monte Carlo simulation in Ecosim and found model results to be robust to these uncertainties. They agreed to further elaborate on this in the published version of their submitted work.

During the discussion that followed, it was mentioned that components of model parameterization that are critical to evaluating ecosystem models were not provided directly in SC/61/FI39 and SC/61/FI28, which are currently in review for publication by scientific journals. Examples of relevant information include relative feeding time, feeding time adjustment rates, prey switching vulnerability, and assumed functional forms, such as that used for feeding relationships. It was emphasized that incorporating key components such as these in the manuscript itself or as supplementary online material facilitates model interpretation and evaluation. The authors agreed and said that they would make attempts to add this information to SC/61/FI28 and SC/61/FI39 prior to publication. Murase drew attention to a recommendation from last year's discussion that the model be tested in cases where real data exists such as the Northeast Atlantic and Northwest Pacific. In response, Morissette and Kaschner reiterated that although the parameterization of cetacean groups were affected by large uncertainties, data quality for all other trophic components of the ecosystems modelled was actually above average.

Clapham drew attention to several published papers showing that humpback whales do not feed while they are on the breeding grounds in the Caribbean and thus questioned the value of including humpback whales in the model. Morissette responded that the assumptions of humpback feeding were included so that the model could examine the effects of consumption by humpback whales if this does occur.

There was some discussion about the ground truthing of the models in the absence of reliable estimates of whale abundance for the areas of interest. The authors acknowledged the lack of cetacean abundance data but noted that predicted densities from the global model compared well with survey estimates in other areas with similar habitat types to the areas of interest. The cetacean data are nevertheless one of the weaker aspects of the model compared to other components of the ecosystem.

The sub-committee noted that the papers presented represented a substantial body of work and looked forward to further developments in this area. Such discussions make an important contribution to ecological modelling work involving cetaceans.

Corkeron (2009; SC/61/FI7) compared two sets of modelling approaches. One set modelled interactions between cod, *Gadus morhua*, herring, *Clupea harengus*, capelin, *Mallotus villosus* and common minke whales (Schweder *et al*. 1998, 2000; Schweder 2006). Adding harp seals *Phoca groenlandica* into this top-down modelling approach resulted in unrealistic model outputs (Aldrin and Schweder, 2005). Another set of models of the Barents Sea fish–fisheries system focused on interactions within and between the three fish populations, fisheries and climate. These studies modelled key processes of the system successfully (Hjermann *et al*. 2004a,b,c, 2007; Cury *et al*. 2008). A recent development of the fish-fisheries-climate models has been a paper that concludes with a general, but explicit, suggestion as to how this work can be used to inform ecosystem-based fishery management (Durant *et al*. 2008). Corkeron believed that given the interest in the Committee in using models to inform ecosystem-based fishery management; the current problems with models with a cetacean-focused top-down approach; and the slow development of models derived from lethal sampling programs, this new approach deserves much more consideration.

Víkingsson reported on recent discussions of the NAMMCO Scientific Committee in April 2009 which had proposed that results from four different modelling approaches in the Northeast Atlantic (either for the area around Iceland or the Barents Sea), should be compared. The different approaches to be considered included the work by Hjermann and by Morissette.

Corkeron (2009; SC/61/FI8), included a review of the one paper published on results of the ecosystem survey part of the JARPN II feasibility study (Murase *et al*. 2007). The contention of Corkeron (2009) was that the basic design of the JARPN II feasibility study (fore-stomach sampling coupled with acoustic and trawl surveys for prey) is an unsophisticated approach to investigating the foraging ecology of *Balaenoptera* spp. Published results of the JARPN II feasibility study demonstrate problems with the execution of field work, including relatively few samples being usable for prey selection analysis; sex biases; and sampling whales off-transect. Data analyses presented in Murase *et al*. (2007) were simplistic. In recent years, nonlethal studies into the foraging ecology of *Balaenoptera* spp., using far fewer resources, and producing more definitive information on the ecosystem role of baleen whales, were briefly reviewed in the paper.

Murase responded that several international scientific bodies such as IWC (IWC, 2004) and NAMMCO (NAMMCO, 2004) recognize that diet information obtained from stomach contents is one of the important parameters for ecosystem models. The importance of diet data from stomach contents as a parameter in ecosystem model was also recognized in the CCAMLR-IWC joint workshop (SC/61/Rep2). However, Corkeron (2009) misappropriates the scientific aspects of feeding ecology studies to normative issues by saying “stomach sampling is no longer in common use internationally”. One of the most important parameters in ecosystem models is the shape of functional response. To estimate shape of functional response, stomach contents data play an important role (e.g. Smout and Lindstrøm, 2007). Functional response forms required by ecosystem model for fisheries model at meso and macro scales require long term collection of prey preference data. This point was also realized by the expert panel of the JARPN II expert workshop (SC/61/Rep1). In addition, prey species identification using stomach contents is critically important to estimate prey preference when two or more species which potentially feed on same preys co-exist in the same area (e.g. Murase *et al.*, 2009). Several baleen whale-prey relationship studies based on non-lethal methods were reported (e.g. Friedlaender *et al.,* 2006). However, these studies could not identify species actually consumed by whales. To study and quantify the prey preference of baleen whales, prey species identification using stomach contests is required. Most of the non-lethal methods require stomach contents data as a ground truth. He further believed that the special permit surveys are the only platform in the world to compare the results between lethal and non-lethal methods (SC/61/Rep1) and that data from the special permit surveys will advance the field of feeding ecology study in a scientific manner.

Corkeron suggested that the perception of misappropriation to ‘normative issue’ arose from differing perspectives of the current state of this area of science. Murase's focus was on discussions at international bodies such as the IWC and NAMMCO; while Corkeron was referring to recent papers published in refereed scientific journals.

NAMMCO has also recommended studies to compare non-lethal chemical methods for examining diet with stomach contents data. Víkingsson noted that comparisons of lethal and non-lethal methods for assessing diet had been included in the Icelandic research programme, but although he believed non-lethal methods were promising, they were unlikely to fully replace stomach contents analysis for data such as age composition of the prey.

5.3 Review of data relevant to parameter estimation and ecological interactions

Tamura presented SC/61/JR2 including revision of some of the calculations. The uncertainties of some parameters and consumption estimates by different models were examined, and suggestions for future collection of data and works were made. The differences in consumption rates estimated from different models increased with body mass. At this stage it is not possible to disregard the difference of energy contents among the prey. Daily prey consumption was estimated using two different models (Equation 6 providing the smallest estimates and Equation 7 providing the largest estimate). The range of daily consumption estimates of mature female common minke, sei and Bryde’s whales were 45-148kg, 102-491 and 132-577 kg, respectively. A comparison of these estimates by the two models with actual stomach content weight suggested that consumption by Equation 6) appears to be underestimated because consumption estimates by this equation is equal to just a single intake. The range of total prey consumption in the JARPN II research area for common minke whales during March and October was 128 thousands tons (95%CI: 83-199 thousands tones) by Equation 6 and 425 thousands tones (95%CI: 270-674 thousands tones) by Equation 7, respectively. The value of Equation 7 was 3.3 times larger than the value of Equation 6. The validity of different models for estimating the total consumption can be investigated with additional data collected by JARPN II. In this way it might be possible in the near future to provide estimates with narrow range.

A number of computational and methodological concerns were raised with these estimates. Computational issues included some unrealistically high estimates of average daily consumption and combinations of parameter values which did not appear consistent with available data on the ability of minke whales to store energy during the high feeding season. In addition, computational errors were indicated because the estimated variances of the consumption estimates were considerably lower than the variances of the abundance estimates. Methodological concerns related to seasonal extrapolation and the treatment of uncertainty. The estimates in JR2 relied on seasonal extrapolation of data from surveys in May to March and April and the estimates from these two months alone accounted for nearly 50% of the total consumption estimates in SC/61/JR2.

Tamura noted that he had had limited time to undertake these calculations following the JARPNII review and that he would like to investigate the discrepancies further and present revised estimates at next years meeting. Víkingsson noted the wide range of estimates of daily consumption produced by the different allometric equations given in SC/61/JR2. Verification of these equations has proven difficult due to lack of data on large cetaceans, but available data on stomach content and energy deposition appear to be inconsistent with the low estimates for large whales produced by Equation 6. Data collected by JARPNII could be useful in narrowing this wide range of estimates of consumption rates.

The sub-committee **agreed** that until the computational issues were resolved it was not in a position to consider the estimates presented in SC/61/JR2 or evaluate whether the work would adequately address the issues raised by the JARPNII review panel. The sub-committee looked forward to revised analyses at next year’s meeting and encouraged the authors to present the sensitivity of the results to the full range of sources of uncertainty. For example, uncertainty in the length of the feeding season should be fully taken into account.

Examination of the sensitivity of estimates of consumption to uncertainty would enable research to be prioritised towards better estimation of the parameters that had most influence on the results. For example, the estimated variance of a consumption estimate cannot be less than the estimated variance of the associated abundance estimate. The CVs for abundance estimates presented in JR2 are large (0.33 to 1.59), indicating the importance of more sightings survey data. Tamura confirmed that there were plans for further sightings surveys in order to improve the CVs of the abundance estimates.

Apostolaki questioned whether further collection of stomach content data is needed. She noted that there are a number of factors that can contribute to the uncertainty in the results from stomach content analysis and which cannot be addressed with further collection of stomach data (e.g. prey availability and competition for food). Therefore she argued that a sensitivity analysis should be undertaken as a priority to assess if further stomach content collection is needed, and identify those parameters to which ecosystem models are more sensitive.

The issues of sample size and uncertainty are common to both lethal and non-lethal techniques and there is a need for all types of methodologies to examine the benefits of increasing sample sizes in terms of reducing the variance of final estimates.

5.4 Review of other papers

SC/61/EM1 references severe declines in megafauna worldwide in relation to the role of top predators in ecosystem structure. In the Antarctic, the 'Krill-Surplus Hypothesis' posits that the killing of more than two million large whales led to competitive release for krill eating species like the Antarctic minke whale, which was not a primary target for commercial whaling. If true, then the Antarctic minke whale population should have experienced an expansion of abundance as an indirect result of whaling during the 20th century. SC/61/EM1 attempts to test this hypothesis by estimating long-term population size of the Antarctic minke whale prior to whaling using DNA sequences from eleven nuclear genetic markers from 52 modern samples purchased in Japanese meat markets. This dataset includes nearly 500,000 base pairs of diploid DNA sequence diversity (comparable to Alter *et al*. 2007), representing an incremental improvement of some previous estimates of genetic diversity in baleen whales. Based upon Bayesian estimates of mutation rate and coalescence times among loci, the long-term population size was estimated to be 670,000 individuals (95% CI: 374,000-1,150,000). As this long-term evolutionary estimate of abundance encompasses the range of most contemporary estimates of Antarctic minke whales, the conclusion is that competitive release, assumed by the krill-surplus hypothesis, is not necessary to explain current abundance. Although the genetic estimate in SC/61/EM1 cannot reject unequivocally some increase over this time frame, it is sufficiently precise to reject as unlikely, the roughly 8-fold increase predicted under the hypothesis of competitive release by Ohsumi (1979) and the predicted pre-exploitation abundance of 319,000 by Mori and Butterworth (2006). These results suggest that the use of stock assessment, modelling, and genetic data could be a powerful way to test alternative hypotheses and improve biological plausibility of model outputs.

Butterworth highlighted that the data upon which the pre-exploitation abundance estimate of Mori and Butterworth (2006) was based, was not corrected for detection probability g(0), and this could explain the apparent inconsistency with the results in SC/61/EM1. He believed that there was scope for integration of genetic studies, population and ecosystem models but that the genetic data alone could not reject the krill surplus hypothesis. In addition, Mori and Butterworth (2006) suggest an increase in minke whale numbers that was only 3-fold and recent catch-at-age analyses tend to support lower increases than suggested by Ohsumi (1979).

Some caution is needed in using genetic methods to make inferences on absolute numbers. The mutation rate is still uncertain and absolute estimates will also be sensitive to the ratio of effective to mature population size. Population structure may also be an issue and sensitivity analyses to the implications of multiple stocks had been conducted in SC/61/EM1 and found to be low. Comparison with survey abundance estimates is also complicated due to whales in unsurveyed areas of sea ice habitat. Studies of krill abundance are also informative in relation to the krill surplus hypothesis.

5.5 Work plan

There was a general discussion of the level of detail to which the sub-committee could discuss individual modelling approaches. Many of these models are highly complex and there is unlikely to be time to examine these in detail. A more detailed discussion of the EM's role in the SC is scheduled for IWC62. The sub-committee does however need to consider models that are relevant to the Committee's evaluation of special permit whaling, as well as other relevant ecosystem models.

Gales suggested that it would be useful for the sub-committee to discuss the issues surrounding functional responses at next year's meeting.

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Appendix 1

AGENDA

1. ECOSYSTEM MODELLING (EM)
   - 1.1 INTRODUCTORY ITEMS
     - 1.1.1 Convenors opening remarks
     - 1.1.2 Election of Chair, appointment of rapporteurs
     - 1.1.3 Adoption of Agenda
     - 1.1.4 Review of documents
   - 1.2 Review report from the Joint CCAMLR-IWC Workshop on modelling Antarctic krill predators
   - 1.3 Review of progress in the development of ecosystem models
     - 1.3.1 Review of models from JARPN II
     - 1.3.2 Review of other papers
   - 1.4 Review of data relevant to parameter estimation and ecological interactions
   - 1.5 Other
   - 1.6 Work Plan