Annex K1

Report of the Working Group on Ecosystem Modelling

Members: Ferguson (Convenor), Acquarone, Aydin, Brandão, Bravington, Butterworth, Cooke, de la Mare, Elvarsson, Fulton, Funahashi, Gales, Gunnlaugsson, Hakamada, Hatanaka, Haug, Kock, Lockyer, Lusseau, Murase, Okamura, Pastene, Víkingsson, Wade, Walløe, Yamakage, Yasokawa.

1. CONVENOR'S OPENING REMARKS

Ferguson welcomed the members of the Ecosystem Modelling Working Group (hereafter, Working Group) and noted that in addition to the two primary papers submitted to the group, the Committee would be receiving presentations of five papers that had already been published or posted elsewhere. One 'O' and one 'RMP' paper also related to the work of the group and would be presented. The Convenor explained that the group would be hearing presentations about a number of potentially relevant modelling approaches being applied around the world, and emphasised that an important task of the group was to determine how some or all of these could be applied or adapted to provide input into various aspects of the Committee's work.

2. ELECTION OF CHAIR

Ferguson was elected Chair.

3. ADOPTION OF AGENDA

The agenda is given as Appendix 1.

4. APPOINTMENT OF RAPPORTEURS

Cooke acted as rapporteur.

5. REVIEW OF AVAILABLE DOCUMENTS

Documents considered for discussion were SC/63/EM1-2, SC/63/O16, SC/63/RMP25; Fulton *et al.* (2011), Nicol *et al.* (2010), and three Workshop reports: NEMoW - Townsend *et al.* (2008), NEMoWII - Link *et al.* (2010), and the CAMEO Workshop on End-to-End Modelling of Marine Ecosystems (Steele *et al.*, 2010).

6. REVIEW OF RECENT WORK IN ECOSYSTEM MODELLING

6.1 Ecosystem modelling in the North Pacific

6.1.1 Research ongoing within NOAA/NMFS

Aydin presented a summary of ecosystem modelling research ongoing within NOAA/NMFS, explicitly in reference to: (a) advances in statistical fitting procedures using Ecosim models; and (b) recent developments in end-to-end ecosystem models, focusing on biological models built with the Regional Oceanographic Model (ROMS) framework.

On Ecosim modelling, he described a set of model results for the Bering Sea and the Gulf of Alaska, which were produced using Ecosim algorithms implemented independently from the software package Ecopath with Ecosim (EwE), and described in SC/63/EM1. In particular, he highlighted the tradeoffs among parameters for consumption and mortality of predator/prey pairs. The EwE software package, and most previously-published results that use EwE, have focused on fitting Ecosim models to data by fitting 'vulnerability' parameters that govern the amount of predator density-dependence in feeding functional responses. However, the results presented demonstrated the sensitivities of the models, particularly for whales, to the formulation of the terms governing 'other' mortality (M_0) and growth efficiency (GE). He recommended that, in evaluating the results and predictions of Ecosim models, the sensitivity of the models to the full range of parameters should be considered, although this is a data-intensive exercise.

On end-to-end models, he described the Forage/Euphausiid Abundance in Space and Time (FEAST) model currently under development as a biological extension to the ROMS as part of the North Pacific Research Board's Bering Sea Integrated Research Program (BSIERP). This is one of multiple worldwide efforts to investigate biology using ROMS; some other efforts within NOAA/NMFS and elsewhere are summarised in Steele *et al.* (2010). The FEAST model is a 10km horizontal-resolution process model of the Bering Sea and Aleutian Islands, which hindcasts and predicts primary and secondary production, and resulting forage fish growth and distribution, across the grid using a bioenergetics model with sized-based predation functions. While marine mammals are not an explicitly-modelled part of FEAST, the model can be used to predict forage concentrations in areas critical to these species, and marine mammals can be built into the model at a future time using either field-based or agent-based modelling techniques. The primary current challenge of FEAST is its runtime; it takes 20-30 real-time days on a moderate computing cluster (~200 processing cores) to produce a single 50-year simulation; this runtime currently precludes iterative running or fitting procedures. Its primary use in a management setting is anticipated to be as an operating (baseline truth) model for management strategy evaluations (MSEs); an ongoing part of this project is to develop an MSE to test single-species, multi-species minimum-realistic, and Ecosim-style models for use in management scenarios

In discussion, it was noted that the models still had trouble explaining the observed history of populations in the Bering Sea and Gulf of Alaska. It was questioned whether the models adequately took account of prey switching by predators in response to regime shifts. However, Aydin clarified that the modelling exercises are currently 'work in progress' and further progress in these aspects is anticipated.

6.2. *Atlantis* and *In Vitro* modelling frameworks

Fulton presented the *Atlantis* and *In Vitro* modelling frameworks as examples of a growing list of end-to-end models that include ecological, biogeochemical, climatic and socioeconomic processes, and that are aimed at informing strategic management decisions.

The fields covered by *Atlantis* and *In Vitro* span processes from biogeochemistry and water column transports through food webs and into the dynamics of human industries such as fisheries, tourism and oil and gas. Both model frameworks are intended for use in management strategy evaluation studies of marine and coastal resource use and associated industries. *Atlantis* is primarily based on differential equations, while *In Vitro* uses an agent-based approach (e.g. including decision rules by individual animals or human operators). These modelling frameworks have no set form *per se* as each includes many alternative model formulations for each major process and model component included. In each implementation the user sets the complexity to the level desired given the question and information in hand. This complexity can range from a small number of groups with simple trophic interactions and a Baranov-like catch equation to highly complex models with sophisticated stock structure, multiple fleets, detailed social and economic effort drivers and multiple management options.

The major uses of the models to date have been to: integrate a wide range of system information; gain understanding of marine ecosystem dynamics (including identifying major processes, drivers and responses); highlight major gaps in data and empirical knowledge; and provide a mechanism to 'road test' management strategies before implementing them in reality. With more than a decade of use of these approaches it is now possible to draw together some common lessons learned from their implementation. In particular, the use of the models has highlighted:

(1) multiple factors (system components) should be considered (e.g. human decision processes) if unintended consequences are to be avoided;
(2) no single management lever can successfully address the many trade-offs associated with ecosystem-based management; instead, the mix of measures needed will differ between systems and will change through time;
(3) all management decisions have costs that will be differentially-expressed industry components (e.g. different fleets within a fishery) and objectives (e.g. economic *vs* conservation); this can lead to a strong tension between conservation and economic objectives;
(4) system-specific dynamics and responses mean that reference points and even reference directions for indicators used in monitoring may not be usefully universally employed; while a suite of widely useful indicators exists, their reference points will need to be conditioned on system-specific information and knowledge; and
(5) in a number of cases, full enforcement of existing management rules would go a long way to meeting sustainable management objectives without the requirement to introduce any new management rules.

Experience with the models has also identified weaknesses and points of caution that must always be kept in mind when applying these approaches. Most importantly:

(1) fast growth species such as squid and shrimp are very difficult to model, as are top predators, which have very sophisticated behaviour (e.g. use of forage grounds by birds coming from nesting grounds); agent-based models show promise (especially for central-place foragers and species with small population sizes); and
(2) model complexity and uncertainty must be carefully handled, which means the models should ONLY be used for strategic management questions.

The modelling frameworks, and specific implementations of them, are described in a number of publications (e.g. Fulton *et al.*, 2011) and there is a dedicated web site (*http://atlantis.cmar.csiro.au/*).

The Working Group was impressed by the comprehensive coverage of *Altantis*, which can incorporate many more types of processes than most ecosystem models normally handle. In discussion it was emphasised that *Atlantis* is a modelling framework rather than a specific model. It consists of a number of building blocks and a structure to tie them together. The development of a specific implementation can involve several months of work, depending to what extent the processes to be modelled are covered by existing building blocks.

The set of available building blocks is continually being extended, but already covers most of the processes of interest to fisheries biologists, including, for example, 26 different ways to handle recruitment that can include explicit environmental drivers or simply random fluctuations, and explicit modelling of the processes operating at different stages of recruitment, both pre- and post-settlement. Examples of applications involving marine mammals include the modelling the recovery of mammal populations in Australian and US waters.

Fulton emphasised that *Atlantis* is appropriate for strategic modelling: that is, constructing ecological scenarios (including socio-economic components where appropriate) and examining the broad properties of the system in question, including the possible regime changes that can occur in the system in response to different types of perturbations. She emphasised that it is not the tool of choice for detailed tactical decisions, for example determining specific catch limits for specific stocks. The strategic modelling framework does not replace the tactical models of more limited scope that are in common use, but is an additional layer for the analysis of systems and processes. Strategic frameworks such as *Atlantis* can be a useful tool for exploring what aspects of a system need to be included in the tactical models used for specific management purposes.

She also emphasised that when an implementation of *Atlantis* fits the available data well, that does not mean that all predictions of the model are correct, but merely that it is one option for how the system might behave. Further work may identify alternative models within the framework that also fit the available information for the system in question but that have different properties. However, she noted that experience using different modelling approaches for the same system has tended to lead to convergence in results when the same processes are included in different models.

Models developed within the *Atlantis* framework try not to specify the main properties in advance, such as whether the system is top-down or bottom-up driven, but allow these properties to emerge from the modelling of finer scale processes. The minimal realistic approach is often used, but at the level of individual processes, not for the system as a whole.

6.3 US National Ecosystem Modelling Workshops

The National Marine Fisheries Service (NMFS) has held two National Ecosystem Modelling Workshops. The first workshop (Townsend *et al.*, 2008) called for more emphasis on ecosystem modelling within NMFS and recommended that standards and guidelines for ecosystem modelling should be established. The workshop did not consider that a common modelling framework should be adopted at this stage; rather, the workshop stated that it was important not to stifle innovation and to allow for adaptation to meet local requirements. Best practices in ecosystem modelling should be identified without becoming too prescriptive. Most of the workshop's recommendations related to the development of NMFSs capacity in the field of ecosystem modelling.

The second workshop (Link *et al.*, 2010) had the theme 'Bridging the Credibility Gap - Dealing with Uncertainty in Ecosystem Models'. There was particular focus on the appropriate incorporation of uncertainty into ecosystem models for the provision of living marine resource management advice. The most important information gaps were identified as: (i) lack of trophic ecology data; (ii) lack of spatially explicit data; (iii) lack of data for non-target species; and (iv) lack of socioeconomic data. The workshop identified some common types of modelling uncertainty and some common approaches to address that uncertainty. The main types of uncertainty were noted as: (i) estimation; (ii) model; (iii) implementation; and (iv) communication uncertainty. Establishing and refining a list of best practices to address ecosystem model uncertainty should be continually reevaluated. The workshop emphasised the importance of better engaging stakeholders in terms of communicating, interacting and discussing ecosystem model rationales, uses, applications, and benefits.

6.4 Comparative Analysis of Marine Ecosystem Organization (CAMEO) Workshop on end-to-end modelling of marine ecosystems

The objectives of this Workshop (Steele *et al.*, 2010) were to:

(1) review extant end-to-end models and their underlying rationales;
(2) consider application to management and decision making; and
(3) develop recommendations for skill assessment of end-to-end models.

The Workshop reviewed the strengths and weaknesses of extant modelling frameworks. For example, in the Ecopath with Ecosim (EwE) framework a current weakness, on which further work is encouraged, is the lack of structure for the microbial food web and of physical forcing of the ecosystem.

The Workshop conclusions include the following.

(1) There is a wide range of models that can fit under the end-to-end rubric. Many 'international' proponents were not represented. Nor were the more conceptual approaches to food web theory.
(2) The diversity is valuable and should be encouraged. There was consensus that no single package of models is preferable.
(3) The diversity arises from the variety of possible applications or uses. Simple categories such as 'tactical' and 'strategic' seemed inadequate.
(4) The applications can require long-term interaction with stakeholders. These processes merit more study across research and user communities. It should not be assumed that the interactions will happen automatically after the modeling science is done.
(5) In particular, specialist help or instruction may be necessary. This is not cheap but is not usually budgeted.
(6) Test of the models is a complex process and differs for different models.
(7) There needs to be more work on skill assessment and, particularly, on risk analysis.

The workshop noted two broad categories of models: 'construction kits' and 'virtual worlds', the former being more suitable for tactical purposes and the latter for strategic modelling.

6.5 Update on NAMMCO ecosystem modelling efforts

Aquarone provided an update on modelling efforts planned by the NAMMCO Scientific Committee. At its 17th meeting, in 2008, the NAMMCO Council requested the NAMMCO Scientific Committee (SC) to extend its modelling of marine mammals and fisheries interactions to include all areas of interest to NAMMCO. In light of the distributional shifts (of species) seen under T-NASS 2007, the NAMMCO SC should investigate dynamic changes in spatial distribution due to ecosystem changes and functional responses. The NAMMCO SC considered that developments in modelling and other progress that had occurred in Norway, Canada and Japan warranted a review of the state of the art in this field and forwarded this task to the Working Group (WG) on Marine Mammal-Fisheries Interactions (MMFI).

Multi-species modelling was considered appropriate for a general understanding of the ecological relations between species, but its present development does not allow for providing quantitative management advice, which is presently given by single-species management. Additional research is required in order to develop ecosystem models to a point where it may become possible to use them to provide quantitative management advice.

Acknowledging the suggestions made by the WG on MMFI, the NAMMCO SC recommended, as the best way forward, to carry out a modelling exercise for comparing the results of different models on the same ecosystem(s) using a common dataset. Four modelling approaches were identified.

(1) Minimal realistic model implemented using GADGET: this approach will be headed by Gunnar Stefansson of the University of Iceland.
(2) Ecopath with Ecosim: this approach will be headed by Lyne Morissette of the University of Rimouski (Canada).
(3) Time series regression: this approach will be headed by Dag Hjermann of the University of Oslo (Norway).
(4) Bioenergetic-allometric Modelling of the Barents and Icelandic Sea Ecosystems: This approach will be headed by Garry Stenson and Mariano Koen-Alonso of the Department of Fisheries and Oceans (Canada) and Ulf Lindstrøm of the Norwegian Institute of Marine Research, Tromsø (Norway). This approach is also of the 'minimal realistic' type; however, the essence of the difference from the one implemented using GADGET is that the former considers only the biomass and does not include age structure. The exercise is planned to be carried out for two areas: the Barents Sea and the region around Iceland.

The primary objective of this exercise is to investigate if a variety of models presents robust predictions regarding the direction of the impact on major commercial fish species of reducing marine mammal numbers**.** Walløe and Butterworth will be the overall coordinators of this modelling exercise.

The Working Group welcomed these plans and looks forward to receiving updates on progress.

7. DISCUSSION OF HOW ECOSYSTEM MODELS CAN BE USED IN THE WORK OF THE SCIENTIFIC COMMITTEE

The Working Group stressed the importance of ecosystem modelling, which can serve several functions relevant to the assessment and management of cetaceans, including helping to explain trends that cannot be explained by single-species models, and revealing a range of possible alternative scenarios that would not be predicted by single-species models.

The Working Group emphasised that the utility of the modelling efforts to date lies primarily in their strategic value. They can help to reveal the range of possible scenarios for the dynamics of cetaceans and their ecosystems, relative to which the management of cetacean populations should be robust. The models are not yet able to make specific predictions of effects that could be relied on sufficiently to form the direct basis for management measures.

The Group emphasised the importance of understanding what was driving the behaviour of specific models. When a particular behaviour is observed, it is important to identify which inputs or assumptions are required to generate the behaviour. This can be a challenge with the larger and more complex models.

The Group agreed that it would not be appropriate at this time for the Scientific Committee to develop its own modelling approaches in addition to those being developed elsewhere. Rather, the focus should be on developing ways for the Committee to make use of the results of the modelling work being conducted around the world.

The RMP sub-committee has been developing increasingly sophisticated operating models for whale populations, some of which include external influences such as multi-species effects and environmental drivers, but to date these influences have either been assumed to be purely random, or they have been modelled through arbitrary changes in, for example, carrying capacity. Ecosystem and multi-species models have the potential for generating more explicit and realistic scenarios for each case.

The Group agreed that the approach followed in the development of the RMP to date, of going for robustness across a broad range of scenarios, rather than placing too much faith in any single scenario, should be continued, but with the choice of scenarios guided by the results of multi-species and ecosystem models.

Ideally, ecosystem models or components of them could be directly linked into management simulations, so that whale management can be simulated under a given ecosystem model. However, the Group recognised that this still poses substantial technical challenges. For example, for use in RMP implementations, it is necessary to run multiple replicates of different scenarios reasonably quickly, so that probability distributions of the consequences of alternate management policies under a range of scenarios and assumptions can be generated. The computational intensity of current versions of many ecosystem models precludes this functionality, and it is unlikely to be realised in the near future. The group therefore recommended that the ecosystem modelling frameworks be used to develop a range of alternative scenarios for the dynamics of whale populations of interest, and that the key features of the behaviour of these scenarios be extracted and encapsulated in simpler, self-contained models. The latter can be designed more along the lines of the tactical, minimal realistic models (MRMs). These could then be linked into management simulations. The Group agreed to place this subject as the first item on its work plan for next year.

8. REVIEW OF ISSUES RELATING TO ECOSYSTEM MODELLING

8.1 Role of baleen whales in iron fertilisation of the Southern Ocean

The Working Group discussed a recent study (Nicol *et al.*, 2010) that examined a hypothesis proposed by Victor Smetacek concerning the recycling of iron in surface waters of the Southern Ocean through whale faeces. The study estimated iron content of the faeces of four baleen whale species and the tissues of seven krill species. It was estimated that krill contain approx. 24% of the total iron present in Antarctic surface waters. The study concluded that pre-exploitation levels of baleen whale populations would have resulted in more iron present in surface waters, which may have elevated productivity. Therefore, the depletion and recovery of baleen whales may involve positive feedbacks, in contrast to the usual assumptions of negative feedbacks driving whale and krill dynamics.

In discussion, Murase pointed out the difficulties of identifying prey species in faecal samples in the water column, because species present in the water will be sampled in addition to those in the faeces. He recommended direct sampling of faeces from the colon rather than in the water. He also noted the importance of taking into account the sex and maturity status of the whales, because concentrations of hepatic iron of Antarctic minke whales have been found to vary with sex and age (Yasunaga *et al.*, 2006). Sampling locations and timing of faeces were not specified in Nicol *et al.* (2010). In addition, prey species compositions in the faecal samples were not described. The unclear origin of the faecal samples made it difficult to assess whether the results of the analysis could be applicable to the Southern Ocean. It was clarified in discussion that the faecal samples analysed were from the Southern Ocean. Murase further noted that, while it is generally recognised that iron is one limiting factor of primary production, the results of *in situ* iron enrichment experiments did not always exhibit the predicted increase in primary production (e.g. Street and Paytan, 2005).

The Working Group considered that processes of the kind examined by Nicol *et al.* (2010) were potentially of great importance for ecosystem modelling because they can generate dynamics that are qualitatively different from those assumed in conventional whale population models. The Group encourages experimental studies to assess whether the proposed mechanism is actually a significant driving factor.

8.2 Analysis of trends in blubber thickness of Antarctic minke whales

Both the JARPA Review Workshop in 2006 and, subsequently, the Ecosystem Modelling Working Group have previously considered analyses of trends in blubber thickness from JARPA measurements that appeared to show a significant decline of about 0.2mm per year over the 18-year JARPA period in mean blubber thickness of minke whales in Antarctic areas IV and V (Konishi *et al.*, 2008).

The Group considered that indices of body condition are potentially of importance to ecosystem modelling, because they can enable detection of changes over a shorter time period than changes in abundance. Studies of body condition in others species such as gray whales have revealed apparent correlations with reproductive rates (Bradford *et al.*, 2008). Particularly in the context of the models of minke whale population dynamics being discussed in the IA sub-committee (see Annex G), blubber thickness is a possible additional source of information that might indicate consistency or otherwise with the population and recruitment changes estimated by these models.

SC/63/O16 reports on simulation studies into issues relating to the estimation of time trends in the body condition of Antarctic minke whales published by Konishi *et al.* (2008). Konishi *et al.* reported analyses of condition indicators including blubber thickness, fat weight and half girth, using a specific form of multiple linear regression model (referred to below as the Konishi model) intended to correct for the effects of heterogeneity in the method of sampling, as well as provide statistical inference. SC/63/O16 argues that certain features of the Konishi model are not biologically plausible. The most important independent variable in the Konishi model is the date of capture, whose linear coefficient (slope) represents an estimate of the daily growth in blubber thickness. The Konishi model estimates this as a single constant coefficient applicable for all months, latitudes, longitudes and years. The other terms of the Konishi model adjust the intercept of the growth line, not its slope. Basic energetic principles predict that animals in poor feeding conditions will have a lower growth rate for blubber thickness than those in good feeding conditions. It would also be expected that feeding conditions, and hence blubber growth rates, will vary both spatially and from year to year; the Konishi model precludes these possibilities. The critical question is whether the Konishi model is reliable in correcting for sampling heterogeneity when the assumption fails that blubber growth rate is the same everywhere and in every year. SC/63/O16 explores whether other types of linear model that allow for variation in blubber growth rates both inter-annually and spatially might be more appropriate. The simulations generate data with no underlying linear year trend in blubber thickness. Fitting the Konishi model with the realised sampling design of JARPA to simulated data show that spatial heterogeneity in blubber growth can lead to a range of estimated year trends in blubber thickness, a high proportion of which are spuriously statistically significant. Another set of trials show that random inter-annual variability in the blubber growth coefficient can also lead to apparently significant trends in year effect. Combined effects of spatial variation and random year effects can also lead to apparently significant year trends. Statistical significance will be overstated because of 'pseudo-replication' if there is inter-annual variability in blubber growth rates. Fitting mixed effects models that allow for spatial variation and random year effects substantially reduce the frequency of apparently spurious significant statistical results. Mixed effects models reduce the frequency of apparently statistically significant year trends to much nearer the nominal probability level.

In response, Walløe considered that many of the potential issues noted in SC/63/O16 did not appear to be of concern in this particular case. He also questioned whether the simulated data generated in SC/63/O16 matched the properties of the actual data set. The fact that trends were broadly similar across a range of subsets of the data tended to support the conclusion of an overall downward trend in blubber thickness. A jackknife approach to variance estimation with year as the sampling unit to subsume the consequences of lack of independence in the data indicated an increased variance for the estimate of trend, but this estimate remained statistically significant.

In a written contribution presented to the Working Group, Konishi also criticised a number of points of detail in SC/63/O16, and considered that the models proposed in SC/63/O16 were too simplistic in light of the observed segregation of minke whales by sex and maturity status.

The Working Group was unable to address all the points raised in SC/63/O16 and the responses to it, but agreed that the main issue of concern was the presence of additional components of variance that had not been included in the Konishi *et al*. analysis. Their omission tends to have the effect of underestimating the variance of apparent trends and overestimating their significance levels. This is an issue that affects many regression analyses and that is often overlooked. Biases would only arise if the data are unbalanced in a particularly disadvantageous way. The Group agreed to conduct regressions involving additional components of variance. The time trend within the season should be allowed to vary among years and longitudinal sectors, using mixed effect models.

Skaug applied a range of mixed effect models to the data (Appendix 2). As predicted, the estimated variance of the estimated trend in blubber thickness was much greater when these additional components of variance were included. However, the estimated trend remained negative in all the models examined, and was significantly different from zero in all but one. For the best-fitting model (based on the AIC criterion) the estimated trend was −0.19 mm/yr (SE 0.07, t-Value=−2.724).

Given the potential importance of body condition indices to the Scientific Committee's work, the Working Group agreed that further analysis of the data was warranted to determine:

(1) whether the models fitted so far captured all the main features of the data; and
(2) whether the estimate of trend (whose confidence limits using the best fitting model in Appendix 2 range from near zero to values that could be of appreciable biological significance) could be made more precise.

The Group requested, *inter alia*, results from analysing the two sexes separately and the inclusion of slopes by latitudinal band as a random effect.

The Group recommended that the authors of SC/63/O16 and of Konishi *et al.*, as appropriate, apply for access to the data under Procedure B of the Data Availability Agreement, and requested that the data holders consider these requests favourably, so that further analyses can be reviewed by the Group next year.

8.3 Definition and estimation of MSYR in a multi-species context

SC/63/RMP25 examined some implications of estimating maximum sustainable yield rate (MSYR) from the recovery trajectories of competing populations in a multi-species context. A simulation study illustrated how inter-species competition can affect values of MSY and MSYR, and also the estimation of these values from population trends. Current attempts to estimate MSYR make use of information on the recovery of depleted populations predominantly in the context where potential competitors are also depleted. Possible competition undermines the single-species model assumption that populations are isolated. A model of intra-specific competition based on a two-species version of the Pella-Tomlinson model is used to derive yield curves under various conditions. In this class of model, the yield curves both in terms of MSY and MSYR for either population depend on the abundance of the competing population.

The Group agreed that multi-species effects can be important both for the definition and estimation of MSYR and related parameters, but referred detailed consideration of the issue to the RMP sub-committee (see Annex D).

8.4 Ecosystem modelling under the JARPNII programme

The Working Group was reminded of the ecosystem modelling for the western North Pacific that arose out of the JARPN II programme. The results of three types of ecosystem modelling in the western North Pacific were presented to the expert Workshop to review the ongoing JARPN II programme held in January 2009 (IWC, 2010). Recommendations specific to each model were made by the expert panel. Okamura *et al.* (2009) developed a preliminary population dynamics model to investigate the effects of consumption by minke whales on sandlance in the Sanriku region, using a hierarchical Bayesian approach. It was recommended that if there are other predators making individual contributions to sandlance mortality of similar size to that estimated for minke whales, their explicit inclusions in this model should be considered. Mori *et al*. (2009) presented the results of an initial attempt to evaluate the possible impact of whales migrating to the JARPNII survey area on Japanese fisheries resources, using the EwE software. The panel recommended concentrating first on improving the Ecopath component of this EwE analysis before moving on to the next step of extending the modelling effort from a static to a dynamic model such as Ecosim. Kawahara (2009) reported on the initial work to construct a minimum realistic model for the offshore survey area of JARPNII with difference equations. As this model was the most preliminary among the three models, the panel recommend that further work on MRM approaches be encouraged and focus in particular on fitting such models to time series of data. The panel made a general recommendation that more emphasis needs to be placed on ecosystem modelling if the objective of the programme is to have a chance of being realised in a reasonable time frame. Further work is being undertaken in response to the panel recommendations, as described in Pastene *et al.* (2009). Results will be presented to the next JARPNII review workshop.

9. Work plan

Explore how ecosystem models might contribute to developing scenarios for simulation testing of the RMP, and delineate the steps required to develop a framework for this purpose.

Review other issues relevant to ecosystem modelling within the Committee:
- update on Antarctic minke whale body condition analyses; and
- other, if new information is available.

Review ecosystem modelling efforts undertaken outside the IWC:
- status update on NAMMCO ecosystem modelling; and
- other.

Review any new information on ecosystem model skill assessment.

10. Adoption of Report

The report was adopted at 12:30 on 7 June 2011. The Group thanked Ferguson for her cheerful and competent chairing.

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Appendix 1

AGENDA

1. Convenor's opening remarks
2. Election of chair
3. Adoption of agenda
4. Appointment of rapporteurs
5. Review of available documents
6. Review of recent work in ecosystem modelling
    6.1 Ecosystem modelling in the North Pacific
        6.1.1 Research ongoing within NOAA/NMFS
    6.2. *Atlantis* and *In Vitro* modelling frameworks
    6.3. US National Ecosystem Modelling Workshops
    6.4. Comparative Analysis of Marine Ecosystem Organization (CAMEO) Workshop on End-to-End Modelling of Marine Ecosystems
    6.5 Update on NAMMCO ecosystem modelling efforts
7. Discussion of how ecosystem models can be used in the work of the Scientific Committee
8. Review of issues relating to ecosystem modelling
    8.1. Role of baleen whales in iron fertilisation of the Southern Ocean
    8.2 Analysis of trends in blubber thickness of Antarctic minke whales
    8.3 Definition and estimation of MSYR in a multi-species context
    8.4 Ecosystem modelling under the JARPNII programme
9. Work plan
10. Review and adoption of report

Appendix 2

RESULTS OF MIXED-EFFECTS REGRESSION ANALSYSES OF BUBBER THICKNESS IN ANTARCTIC MINKE WHALES FROM DATA COLLECTED UNDER JARPA

Hans J. Skaug

SC/63/O16 questioned the conclusion in Konishi *et al.* (2008) about decline in blubber thickness of Antarctic minke whales, and suggested that mixed regression should be fitted to account for various forms of heterogeneity. This Appendix fits a selection of models that arose in the discussion of SC/63/O16.

The models are displayed in standard R notation, where 'DateNum' is date within year, and 'YearNum' is year number. The parameter of interest is the slope associated with 'YearNum'. The following 6 models were fitted:

m1 = lm(BT11 ~ DateNum + Diatom + Sex + LongDegE + YearNum + Latitude + BLm, data=blubber).

Note 1: The original model from Konishi *et al.* (2008).

m2 = lm(BT11 ~ DateNum + Diatom + Sex + LongDegE + LongCat + YearNum + Latitude + BLm, data=blubber).

Note 2: Categorical variable 'LongCat', coding for 6 areas, added.

m3 = lmer(BT11 ~ (DateNum-1|Year) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex data=blubber, REML=reml)

Note 3: The slope associated with 'DateNum' variable between years (treated as random effect). Note that 'Year' is a categorical version of 'YearNum'.

m3b = lmer(BT11 ~ (DateNum-1|Year) + Diatom + LongDegE:LongCat + YearNum + Latitude:LongCat + BLm + Sex, data=blubber,REML=reml).

Note 3b: Same as model 3, but with area specific slopes for 'Longitude' and 'Latitude'.

m4 = lmer(BT11 ~ (DateNum|Year) + (DateNum|LongCat) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex, data=blubber,REML=reml).

Note 4: As model 3, with the addition of (1) a random intercept associated with 'Year', and (2) a random intercept and slope (of 'DateNum') associated with 'LongCat'.

m5 = lmer(BT11 ~ (DateNum|Year:LongCat) + Diatom + LongDegE + YearNum + Latitude + BLm + Sex, data=blubber,REML=reml)

Note 5: As model 4, but with an interaction between the random effects associated with 'Year' and 'LongCat'.

The results are given in Table 1. m4 gives the best fit according to AIC.

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Table 1

Summary of results for «year effect» (YearNum).

	AIC	MLE			REML		
		Estimate	Std. error	t value	Estimate	Std. error	t value
m1	10766.096	-0.0203966	0.0022408	-9.102	-0.0203966	0.0022408	-9.102
m2	10719.26	-0.0232417	0.0023087	-10.067	-0.0232417	0.0023087	-10.067
m3	10629.824	-0.007234	0.005917	-1.223	-0.0072328	0.0059212	-1.222
m3b	10610.875	-0.0167368	0.0067975	-2.462	-0.0167367	0.0068098	-2.458
m4	10574.961	-0.0189226	0.0068127	-2.778	-0.0192157	0.0070532	-2.724
m5	10603.012	-0.0257900	0.0060251	-4.280	-0.025708	0.006279	-4.094
