Annex K1

Report of the Working Group on Ecosystem Modelling

Members: Ferguson (Convenor), Acquarone, Aruna, Baba, Bejder, Bjørge, Bravington, Butterworth, Campbell, Cañadas, Carvalho, Castellote, Charrassin, De Moor, De Stephanis, Edwards, Elvarsson, Ensor, Funahashi, Gales, Gallego, Goodman, Hammond, Jaramillo-Legorreta, Jérémie, Kasuya, Kitakado, Kelly, Kock, Leaper, Lehodey, Liebschner, Lovell, Luna, Lusseau, Lyrholm, Moore, Murase, Nelson, Øien, Okada, Okamura, Palka, Panigada, Podestá, Punt, Ridoux, Roel, Rojas-Bracho, Rowles, Stachowitsch, Uoya, Uozumi, Urbán, Víkingsson, Wade, Walløe, Weinrich, Werner, Williams, Yamakage, Yasokawa, Young, Zerbini.

1. CONVENOR'S OPENING REMARKS

Ferguson welcomed the members of the Ecosystem Modelling Working Group (hereafter, Working Group) and noted that the Committee had not received any primary ecosystem modelling papers this year. Therefore, the convenor, in collaboration with Gales, had taken this as an opportunity to propose a review of some ecosystem modelling approaches outside of the IWC. To motivate discussion the convenor invited Patrick Lehodey to present his ecosystem modelling research relating to tuna population dynamics and climate change, and also to provide an overview of the Climate Impacts on Oceanic Top Predators (CLIOTOP) project. Additionally, the convenor selected recently published papers on various aspects of marine ecosystem modelling to review and discuss. Item 13.2 from the Draft Scientific Committee Agenda ('Review issues related to functional responses') was not on the revised Working Group Agenda because the Committee had not received any relevant papers on the subject; nevertheless, this topic is still considered important for future discussions in this Working Group.

2. ELECTION OF CHAIR

Ferguson was elected Chair.

3. ADOPTION OF AGENDA

The Agenda is given as Appendix 1.

4. APPOINTMENT OF RAPPORTEURS

Leaper agreed to act as rapporteur.

5. REVIEW OF AVAILABLE DOCUMENTS

Documents considered for discussion were SC/62/EM1, Lehodey *et al.* (2008); Lehodey and Senina (2009); Allen and Fulton (2010); Buckley and Buckley (2010); Lehodey *et al.*(2010a; 2010b) and A'Mar *et al.* (2009).

6. REVIEW ECOSYSTEM MODELS RELEVANT TO THE COMMITTEE'S WORK

6.1 Ecosystem modelling of top marine predators

A general presentation of recent developments and applications of the SEAPODYM model was provided by Lehodey. SEAPODYM was developed for prediction and analysis of spatio-temporal dynamics of tuna populations under the influence of environment and fishing pressure (Lehodey *et al.*, 2008). It has been applied to skipjack, bigeye, yellowfin and albacore in the Pacific Ocean (Lehodey and Senina, 2009).

The first model component, the Mid-Trophic Level (MTL) model (Lehodey *et al.*, 2010a) provides key variables to investigate and model the feeding and spawning habitat of large oceanic species, tuna in particular. These habitats are defined in SEAPODYM and used with the temperature and oceanic currents to control population dynamical processes (both spatial and temporal) such as movement to the feeding or spawning grounds, natural mortality and predation. There is ongoing work to develop acoustic data in the MTL model and thus to optimise the parameterisation of energy transfer coefficients between primary production and the functional groups.

The feeding habitat index is computed based on the accessibility of species (by life stage) to the different functional groups of forage, and the physical conditions (temperature and oxygen) of the vertical layers inhabited by these groups during day and night. The habitat is used to constrain the movement of animals with a system of diffusion-advection equations simulating random and directed movements. A simplified version (i.e. for a single cohort) of the habitat and movement sub-models has been developed using likelihood approaches to obtain the best estimates of feeding habitat and movement parameters based on electronic tagging data in the model. A first application has been successfully conducted with bluefin tuna in the North Atlantic. A further development will be to combine this likelihood component to those associated to catch and length frequency data that are already used to achieve optimal parameter estimates in applications to the whole population dynamics and fisheries (Senina *et al.*, 2008). The current parameter estimation approach consists of minimising a cost function (i.e. a negative log-likelihood) that includes both predicted and observed catch on the original resolution (usually 1x1 degrees for pole-and-line and purse-seine fisheries and 5x5 degrees for long liners), as well as sampled *versus* computed relative length frequencies available at a more coarse resolution (5x5 degrees up to 10x20 degrees).

The type of results produced with applications for the entire spatial population dynamics of a given species were described using the cases of Pacific skipjack and bigeye tuna. To evaluate the capacity of the model to capture the essential features of the dynamics of the tuna species, hindcast simulations back to the early 1960s were carried out with the fixed 'best-parameterisation' achieved from optimisation experiments in a different time period. Predicted catches based on observed fishing effort were compared to observed catches. Predicted biomass trends were also compared to the estimates from the stock assessment model (MULTIFAN-CL) used for tuna stock assessment studies by the WCPFC. Finally, projections based on future oceanic conditions can be simulated once the optimal parameterisation has been achieved and evaluated.

The discussion focused on the general issues of model fits and validation. Some members noted that previous attempts to link environmental variability to recruitment had generally been unsuccessful. Where short-term relationships between environment and recruitment had been found, these had not persisted through longer time series. They suggested a need for a statistical evaluation of recruitment deviations and cross-validation for the type of modelling approach described. In response, Lehodey noted that optimisation was an issue but that the approach had produced parameter estimates for a number of species that were plausible. The relatively simple mechanisms within the model had allowed sensitivity tests to initial parameterisation through small perturbations of the initial inputs. A number of features were noted that might make the trophic level approach that was applied to tuna more difficult to apply to whales. The movement models rely on a response to parameter gradients. The wider envelope of whales' tolerance to physical factors and their ability to store large amounts of energy in blubber likely make whales less responsive to such gradients. In addition, movement data for whales are still difficult to obtain despite advances in telemetry in recent years.

The group also considered Buckley and Buckley (2010) which contrasted phenomenological and mechanistic ecosystem models. The authors asserted that 'the success of phenomenological models relies on constancy in the processes that produce the described pattern,' and that 'environmental change is likely to drive deviations from this assumption, lending imperatives to developing more mechanistic approaches.' Furthermore, the authors highlighted the importance of individual species' ability to adapt and to find 'loopholes' to 'get around the rules' of biology, and they questioned whether scaling laws or allometric relationships can adequately describe the dynamics of a species or community. They concluded by saying that understanding the critical processes and mechanisms underlying the dynamics of marine populations is necessary in order to advance the rate of progress in modelling those dynamics.

One member believed that current understanding was insufficient for mechanistic models to have a high chance of success and that empirical methods are more likely to yield results of relevance to management. He also suggested that fitting models to data was preferable to the approach of attempting to quantify uncertainty by selecting parameters from distributions.

Selecting an appropriate level of complexity has been a fundamental issue for a number of modelling approaches considered by the Committee in previous years. Two papers examining the trade-offs related to different levels of complexity were considered by the group.

Hannah *et al*. (2010) advocated the use of marine ecosystem models of intermediate complexity. Drawing from the field of complexity theory, the authors asserted that one promising approach to marine ecosystem modelling is founded on the philosophy of 'a willingness to sacrifice process detail in order to increase the number of interacting components.' The authors added that ecosystem models should be judged not only by the accuracy of their predictions but also by their ability to provide ecological insight. Finally, the authors suggested that validation of complex models, such as marine ecosystem models, should shift away from a comparison of point data and move towards determining whether the models capture the main features and statistics of the ecosystem structure.

Allen and Fulton (2010) provided a critique of the intermediate model approach described by Hannah *et al*. (2010) to model marine ecosystems. Specifically, Allen and Fulton (2010) stated that the 'fundamental weakness of the intermediate model approach is that it may end up producing models that are over general and therefore not useful.' They recommended following the middle-out (or rhomboid) approach, in which the greatest resolution (spatial, temporal, ecological) is allocated to the trophic resolution of interest, and the rest of the ecosystem is modelled with less resolution via a hierarchical approach. In short, the authors stated that 'the crux of the issue is that models should be constructed at an appropriate level of complexity to address the hypothesis being tested and the data available to support it.'

6.2 Review status of papers from the joint CCAMLR-IWC Workshop

The IWC and CCAMLR held a joint Workshop to review input data for Antarctic marine ecosystem models at the CCAMLR headquarters in Hobart, Australia in August 2008 (IWC and CCAMLR, 2010). 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 the IWC. 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. It had been decided not to produce a book of the proceedings but that they should be published in the appropriate journals of CCAMLR and IWC. There were two papers on whales, a review of baleen whales and a review of odontocetes. Both were submitted to the IWC journal and one is in press.

7. CLIOTOP (CLIMATE IMPACTS ON OCEANIC TOP PREDATORS)

7.1 Introduction to CLIOTOP

CLIOTOP is a global project that functions on a regional scale, and is implemented under the IGBP international research programmes GLOBEC (*http://www.globec.org*) and IMBER (*http://www.imber.info/regional_activities.html*). It is a unique initiative to facilitate international research between academic institutions and fishing regional management authorities in the framework of well-known international organisations (GLOBEC, IMBER, IGBP, SCOR, IOC) to enhance the understanding of oceanic top predators in their ecosystems in the context of both climate change and fishing, and to develop new tools leading to the evaluation of management strategies. The programme is piloted by a Steering Committee that meets annually.

The project was organised initially around five working groups focused on key processes and scales to be studied:

(1) top predators' early life history;
(2) physiology, behaviour and distribution of top predators;
(3) trophic pathways in open ocean pelagic ecosystems;
(4) synthesis and modelling, prediction of ecosystem states and management indicators; and
(5) socio-economic aspects and management strategies.

A new technical working group has been established to promote the development of Mid-Trophic Automatic Acoustic Sampling (MAAS) to obtain critical missing information on the forage organisms of oceanic top predators.

A preliminary simulation of the impact of climate change based on the IPCC A2 scenario for Pacific skipjack and bigeye tuna had been tested using the modelling approach described by Lehodey in section 6.1 (Lehodey *et al.*, 2010b).

CLIOTOP held its mid-term workshop in Paris, in February 2010, to review the functioning and the achievements of the programme during its first five-year phase (2004-09) and to define the implementation strategy for its second phase (2010-14) under the IMBER programme. This second phase will put more emphasis on developing scenarios of the evolution of oceanic ecosystems under anthropogenic and natural forces in the 21st century in support of international governance. This will necessitate bridging the gaps between climate, ocean physics, biogeochemistry, ecosystems, predators, fisheries, markets and governance. Based on these efforts, quantitative indicators that characterise ecosystem status and the ongoing performance of fishery management systems are required. Only a large international collaborative effort can help in achieving such an ambitious plan. CLIOTOP will thus search to establish links with other related programmes (including other IMBER programmes) and the RFMOs, including the IWC and CCAMLR.

Lehodey suggested that CLIOTOP and IWC share many common interests and both would benefit in the development of collaborations either through formal links between CLIOTOP and a group of RFMOs representatives, or by individual participation of members of the Committee in CLIOTOP activities. Common scientific interests include: study of behaviour of large predators, movements and definition of their feeding habitat, new technological developments in electronic devices for animal tracking, food consumption rates, predation and competition by/between large predators, acoustic monitoring and modelling of prey fields, standardisations of methods and development of easily accessible global databases, various modelling approaches from individual-based models, environmentally explicit stock assessment models, spatially explicit but trophically aggregated models coupled with Ocean-General-Circulation-Models (OGCMs) and Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) type models. Management issues such as bycatch are also a common interest with IWC.

The Committee welcomed the presentation on CLIOTOP and stressed the importance of the development of collaborative links between multidisciplinary organisations of this type and the IWC Scientific Committee. In particular, the Committee noted the important context that an improved understanding of the effects of changing climate to the higher predators brings to the IWC. The Committee **encouraged** the establishment of collaborations between the IWC and CLIOTOP.

In another study (A'Mar *et al.*, 2009), management strategy evaluation was used to examine the impact of regime shifts in average recruitment on the performance of management strategies for the fishery for walleye pollock (*Theragra chalcogramma*), in the Gulf of Alaska. The current and four alternative management strategies were evaluated. The alternatives included management strategies with different definitions of the average recruitment used when calculating management reference points. The current management strategy, which ignores the possibility of future regime shifts, kept the spawning biomass higher relative to the target level than the other management strategies and had the lowest risk of fishing mortality exceeding the overfishing limit. The sliding-window management strategy achieved the highest catches and the lowest inter-annual variation in catch, although at the cost of a higher risk of the fishing mortality exceeding the overfishing limit.

This study suggested that management strategies relying on empirical data through fisheries statistics appeared to offer better performance than ones that tried to incorporate ecological information. There was some discussion about whether detecting regime shifts might be more useful for species with other life histories, such as whales. Regime shifts may affect recruitment or survival. For whale populations with long time series of data, it has proven possible to detect variations in recruitment, but measuring survival is very difficult. In the context of the RMP, the *CLA* appears to respond adequately to regime shifts. Compared to some fisheries data, the *CLA* has the advantage of a time series of absolute abundance of the exploited population rather than having to make inferences about total numbers from other data. It was suggested that ecological data were of value in constructing and constraining the range of ecosystem models and that such models could be used to inform the operating models used in management strategy evaluations.

It was noted that many of the global climate change models do not produce reliable predictions at the finer spatial scales of fisheries models. Within the CLIOTOP project, there are efforts to develop climate models at finer spatial scales and to connect climate models to biological models. A distinction was made between the general use of such models to understand the overall likely impacts of climate change and models used to provide fisheries management advice. CLIOTOP had attempted to encourage a range of different approaches to ecosystem modelling. The next stage is to define boundaries of realistic modelling predictions across a number of scenarios in order to examine the plausibility of the different approaches.

Linking projects with large data networks in a standardised form, for example telemetry projects for a range of pelagic predators across ocean basins, is critical for this type of modelling work. There are fewer data on movements of individual whales compared to other top predators because of the difficulties of tag attachment. Furthermore, for many whale populations, the location of breeding grounds is still unknown. Whale distribution patterns may also be inferred from passive acoustic monitoring showing the presence of calling animals. Acoustic networks of monitoring devices are being developed within CLIOTOP and also through whale focused programmes such as the Southern Ocean Research Partnerships (SORP).

8. RECOMMENDATIONS ON THE ROLE OF THIS WORKING GROUP WITHIN THE SCIENTIFIC COMMITTEE

The Chair summarised SC/62/EM1, which was intended to start discussion on the role of the Ecosystem Modelling Working Group within the Scientific Committee. She reiterated the distinction between 'tactical' models (e.g. used to set catch limits or make other management advice) and 'strategic' models (e.g. used to simulate an environment in which to test simpler models), pointed to some of the ecological and analytical issues that have been recurrent in Committee discussions to date, and, most importantly, listed several recommendations towards enabling the Committee to evaluate ecosystem models, given the numerous uncertainties inherent in the modelling process. The recommendations are as follows.

(1) Standardised templates should be developed for documenting metadata and analytical techniques.
(2) Performance criteria should be established, including testing model fit to historic or present data and assessing its ability to generate ecologically reasonable predictions into the future.
(3) Sensitivity analyses should be conducted to quantify and perhaps better understand the importance of model inputs (which can guide data collection priorities) and assumptions on model outputs.
(4) The IWC should allow all Scientific Committee members access to the code and relevant background information of ecosystem models considered in informing management decisions. This access would be achieved via the Secretariat.
(5) Ecosystems are complex and dynamic; therefore, the Scientific Committee should explore different ecosystem modelling approaches for a system in order to compare performance across models.
(6) Intersessional meetings should be used, when necessary, to allow in-depth examination of competing models.
(7) Finally, the Working Group should continue to convene every year, or as needed, at the Annual Scientific Committee Meetings to address issues relevant to the Scientific Committee.

The Working Group agreed to these recommendations with the following points of clarification. It was agreed that the full mathematical specification of all models considered in informing management decisions should be made available, but there were some concerns that making code available could impinge upon intellectual property rights. It was noted that the list of recommendations was ambitious and the Working Group should prioritise a subset of items in its work plan. It was suggested that the Working Group should continue to meet annually in order to ensure the Committee remains informed about new developments in the ecosystem modelling field in general and ecosystem models relevant to the management of large whales in particular. It was **emphasised** that the Working Group is an important forum for evaluating ecosystem model inputs, structure, assumptions and predictions related to the work of the Committee. In addition, it is the appropriate body within the Committee for reviewing the ecosystem aspects of ongoing Special Permit whaling programmes.

It was suggested that the activities of the Working Group could be structured around the timetable of upcoming RMP assessments and *Implementations*, such that ecosystem models relevant to a specific stock being assessed will be reviewed prior to the assessment. With this recommendation in mind, the Working Group should consider ecosystem models relevant to North Pacific sei whales, southern hemisphere minke whales and North Pacific minke whales to be of primary importance. The Working Group identified the North Pacific as the region of emphasis for next year's meeting.

It was noted that NAMMCO has initiated a project to compare four different modelling approaches in two areas of the North Atlantic. One of the objectives was to examine the robustness of conclusions across different models. Although still at the planning stage, the Working Group encouraged a paper describing the status of this work to be presented at next year's meeting.

Two additional issues were identified for discussion next year, if primary papers can be prepared in advance: (1) a review of functional responses; and (2) a review of methods for evaluating ecosystem models. The goal for the latter is to develop a document detailing the framework that the Committee will use to guide future ecosystem model evaluations. The aim is to provide model developers with specific details regarding the information required to determine whether the input data and parameters, the model and the resulting predictions should be considered acceptable to inform the work of the Committee.

Several researchers outside the IWC were identified as potential Invited Participants for future meetings based on their expertise in ecosystem modelling. The Working Group agreed to try to engage in informal intersessional discussions with key researchers involved in the ecosystem modelling efforts of the International Council for the Exploration of the Sea (ICES) and the North Atlantic Marine Mammal Commission (NAMMCO), which focus on North Atlantic ecosystems; the Pacific ICES (PICES) and the North Pacific Research Board (North Pacific ecosystems); and CCAMLR (Southern Ocean ecosystems). The goals of these discussions would be to establish a channel for communicating the state of ecosystem modelling science and its feedback into management among these diverse institutions, and to solicit expert feedback from outside the Committee on how ecosystem models could inform management decisions within the IWC.

9. OTHER ECOSYSTEM MODELLING RELATED ISSUES

There were no issues raised under this Agenda Item.

10. WORK PLAN

(1) Review ecosystem models from the North Pacific that may be relevant to assessments and RMP *Implementations*.
(2) Review other issues relevant to ecosystem modelling within the Committee:
    (a) aspects of the report of the 2010 IWC Small Cetaceans and Climate Change Workshop that are relevant to ecosystem modelling;
    (b) status of Southern Ocean ecosystem modelling efforts arising from the 2009 Second Climate Change Workshop; and
    (c) status of Arctic ecosystem modelling efforts arising from the 2009 Second Climate Change Workshop.
(3) Review ecosystem modelling efforts undertaken outside the IWC:
    (a) introduction to NAMMCO ecosystem modelling efforts: description of the ecosystems studied and overview of modelling approaches.

11. REVIEW AND ADOPT REPORT

The report was adopted on 6 June 2010.

REFERENCES

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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 available documents
6. Review ecosystem models relevant to the Committee's work
   - 6.1 Ecosystem modelling of top marine predators
   - 6.2 Review status of papers from the Joint CCAMLR-IWC Workshop
7. CLIOTOP (CLimate Impacts on Oceanic TOp Predators)
   - 7.1 Introduction to CLIOTOP
   - 7.2 Review ecosystem model related to CLIOTOP
   - 7.3 Discuss how the IWC and CLIOTOP might be able to interact in the future
8. Recommendations on the role of this Working Group within the Committee
9. Other ecosystem modelling related issues
10. Work plan
11. Review and adopt report