Report of the
Scientific Committee

Bled, Slovenia, 7-19 June 2016

Annex L: Report of the Working Group on Ecosystem Modelling

**This report is presented as it was at SC/66b.
There may be further editorial changes (e.g. updated references, tables, figures) made before publication.**

International Whaling Commission
Bled, Slovenia, 2016

Annex L

Report of the Working Group on Ecosystem Modelling

Members: Kitakado (Convenor), Baba, Bell, Burkhardt, Butterworth, Charrassin, Cooke, Cosentino, Currey, De la Mare, De Moor, Diallo, Donovan, Double, Elvarsson, Findlay, Torres-Florez, Fortuna, Frey, Galletti Vernazzani, Gerber, Goodman, Gunnlaugsson, Haug, Herr, Hirayama, Iñíguez, Jimenez, Johnson, Kelkar, Leaper, Lee, Lundquist, Mallette, Matsuoka, McKinlay, Mogoe, Morita, Moronuki, Murase, Natoli, New, Øien, Okazoe, Park, Palka, Pastene, Punt, Reeves, Ridoux, Scordino, Skaug, Slooten, Solvang, Stachowitsch, Suydam, Tamura, Tsuji, Vikingsson, Wade, Walløe, Williams, Yasokawa, Yasunaga, Zerbini

1. INTRODUCTORY ITEMS

1.1 Opening remarks

Kitakado welcomed the members of the Ecosystem Modelling Working Group (hereafter Working Group).

1.2 Election of Chair

Kitakado was elected Chair.

1.3 Appointment of rapporteurs

Butterworth, Currey, Elvarsson, Friedlaender and Skaug were appointed as rapporteurs with assistance of the Chair.

1.4 Adoption of Agenda

The adopted Agenda is included as Appendix 1.

1.5 Documents available

The documents available to the Working Group were identified as SC/66b/EM01-EM05, Herr *et al.* (2016, SC/66b/FI10) and IWC/66/04(2016)rev1, Appendix F.

2. REVIEW ISSUES RELEVANT TO ECOSYSTEM MODELLING WITHIN THE COMMITTEE

2.1 Individual-based energetic models

De la Mare presented SC/66b/EM01 which describes a model that uses energetics data in combination with information on feeding behaviour derived from high resolution tags that record individual whale dives and feeding lunges. The aim of the model is to use detailed data on feeding behaviour to develop a function describing the relationship between prey density and the amount of food ingested (the functional response, which is a fundamental component of ecosystem models). In the model, there are two types of feeding dives. First exploratory dives are undertaken at regular intervals to determine the depth of the highest krill density. The animal dives to its maximum depth, making a feeding lunge whenever the local krill density exceeds the threshold. In immediate dives, the animal returns to the depth of highest krill density to feed. Feeding lunges occur during a dive until a maximum number of lunges per dive is reached or until the maximum dive time is reached. Feeding pauses whenever an animal is replete, whereat it rests until some of the food is digested. Feeding lunges occur only where the local density of krill is above a threshold that allows the energy expended in the lunge to be recovered from the prey ingested. An example is given using parameters applicable to Antarctic minke whales, which shows a functional response of approximately the type II form (Holling, 1965). The model is designed to be incorporated into the individual-based energetics model (IBEM: de la Mare, 2014) which then allows for the inclusion of spatial foraging behaviour of animals moving between food patches after they are depleted by the feeding activities of whales. This IBEM can be used with multiple species to explore competition between them in when feeding on various forms of krill spatial and depth distributions and densities

In discussion de la Mare emphasised that the results presented were intended to be illustrative only, so that specific values reported should not be over-interpreted. In due course greater flexibility could be incorporated into the model to encompass a wider range of whale behaviours. Although the emergent functional response appears to be of a Holling Type II nature, in reality it has a Holling Type III form, but is highly asymmetric with the point of inflection at a rather low level of prey density. Advantages and limitations of the data used to inform the model were discussed briefly, and the meeting was pleased to note De la Mare's advice that he intended to apply the approach to humpback and to blue whales as well. The working group thanked the authors and looks forward to receiving any update on this work.

2.2 Competition among baleen whales: how can we measure and model it?

A central focus of the Working Group agenda at SC65b was to discuss methods to model the potential for competition and competitive interactions between baleen whales. For models to be accurate detailed knowledge about the foraging behaviour of individuals within a species is paramount. SC/66b/EM05 reports the use of state-space animal movement models to determine the foraging effort and locations of Antarctic minke whales and humpback whales in the nearshore waters of the western Antarctic Peninsula. This information will help to determine the amount of sympatry in the foraging locations of these two species and the relationship to environmental co-variates (e.g. sea ice).

The authors found differences in the timing, duration, and location of area-restricted search (ARS) for each species and the relationship with physical environmental features such as the marginal ice edge and shore. In terms of space use, they found that humpback whales foraged broadly across a large extent of the continental shelf area of the Western Antarctic Peninsula. In contrast, minke whale foraging locations were generally located inshore or where sea ice persisted, however these areas spanned a greater spatial extent than for humpback whales. Whereas humpback whales foraged across a broad area in summer and then focus their foraging to smaller areas closer to shore in fall, minke whales appeared to increase their movements in nearly all directions from summer to fall and winter. The result of this was that minke whales had a home range (at the 90% isopleth) for ARS that was 13% larger than that of humpback whales. Compared to humpback whales, minke whales foraged significantly closer to shore and the marginal ice edge. Humpback whales did not show any change in the probability of foraging with increasing distance from the ice edge while minke whale foraging was significantly more probable close to the ice edge, diminishing with increasing distance. As both species decrease their foraging probability with increased distance to shore the conclusion can be drawn that humpback whales are not affected by proximity to ice, but rather distance to shore whereas minke whales forage in proximity to sea ice when it is available and when it is not, they are more likely to remain inshore. The results indicate that in areas where little sea ice exists, minke whales remained close to shore in ARS, whereas humpback whales distributed themselves more broadly in open water. When sea ice was available, minke whales ARS was in close proximity to it while there was no observed change in humpback whale ARS based on proximity to this feature. In the coming year the authors will finalise this analysis for publication and move to incorporating dive data into the continued work to better understand the potential for competition between baleen whales in the waters around the Antarctic Peninsula.

The working group discussed the proximity of minke whales to sea ice and noted the difficulty in obtaining reliable location data in ice. Data from dive linked Limpet tags deployed on minke whales in the Ross Sea and Antarctic Peninsula may help address this and refine definitions of ARS. The working group discussed the potential use of bathymetric data as an alternative factor in the analysis and noted that while this had been considered in previous analysis, it was highly correlated with distance from shore, and limited data were available in some areas.

The working group also discussed what could be inferred from the study about the relative foraging efficiency of humpback and minke whales. It noted that there was relatively limited habitat for minke whales and that this could further reduce under climate change. However it also noted there appeared to be different krill density thresholds for both species based on body size; with minke whales able to survive in areas of lower density. The potential for killer whale predation pressure to influence minke whale habitat was also noted.

The working group noted that the modelling approach in SC/66b/EM01, and the data presented in SC/66b/EM05, could enable an extension of the modelling work to humpback whales or other baleen whales in the near future. The working group thanked the authors of the paper and looks forward to receiving the next update on the work

2.3 Update on body condition analyses for the Antarctic minke whales

McKinlay presented SC/66b/EM02 which provided arguments for considering a wider suite of analysis methods than have currently been employed for considering trends in minke body condition from JARPA/JARPAII data. A simulation experiment contrasted the behaviour of Akaike's Information Criterion (AIC) and the Bayesian Information Criterion (BIC) for model selection in the presence of mild to moderate interactions. Results showed that while AIC reliably recovered simulated trends, BIC can, in some circumstances, oversimplify a model to such an extent that it misrepresents a majority of the data on which the model is based. A plan of work for future analyses was presented that detailed how resampling methods could be used to assess the stability of selected models, the importance of individual variables, and for robust statistical inference about parameters of interest.

At the 2015 meeting, the Committee encouraged scientists from Australia, Japan and Norway to collaborate to develop a set of models that best capture the Committee’s previous recommendations regarding body condition of Antarctic minke whales. To facilitate this, the Committee suggested that interested scientists submit a request for data through Procedure B of the Data Availability Agreement. It encouraged the data holders to respond to requests favorably. Intersessionally, there was a data request and considerable further communication amongst the requesters, the data holders and the DAG. Unfortunately, by the time of SC66b, an agreement had not been reached despite a small group meeting of representatives of all parties in February 2016. The parties have continued to work towards an agreement, which is outlined below. The EM working group supports and **recommended** this two-step process for building a collaboration among selected Australian, Japanese and Norwegian scientists regarding body condition data from Antarctic minke whales. These proposed steps are:

(1) Japan provides de la Mare and his collaborators with data associated with body condition of minke whales and other pertinent data from JARPA (see Table 1).

  (a) Between now and the 2017 Scientific Committee meeting, there will be strong collaboration and communication among the groups of scientists.

(b) Australian, Japanese, and Norwegian scientists will collaboratively prepare a document, if possible, concerning this issue for the 2017 Scientific Committee meeting.

(c) If that collaborative document cannot be agreed, Australian scientists may independently submit a document two months before the 2017 SC meeting for review and possible response by Japanese and Norwegian scientists.

(d) During the 2017 SC meeting, the EM working group will review any papers that are submitted concerning the reanalysis of minke whale body condition data collected during JARPA.

(2) Before and during the 2017 Scientific Committee meeting, the DAG will work with the three sets of scientists to facilitate possible next steps for collaboration including the possible sharing of data on minke whale body condition collected during JARPA II.

These discussions will *inter alia* consider the results of the re-analysis of JARPA data, possible new approaches for re-analysis, and comments from EM. If good collaboration and communication has occurred during the first step and the results from re-analysis of the body condition data and the review of results by EM Working Group encourage additional work, the Scientific Committee will recommend the provision of the relevant JARPA II data to the various scientists and ask the data holders to consider such a request favourably.

The working group thanked the Australian, Japanese, and Norwegian scientists for coming to this agreement, and the DAG Chair, Suydam, for leading the small group's discussions to a successful conclusion.

The working group discussed the potential value of considering other datasets such as buoyancy information from tagged whales as well as remote sensed information, and suggested that the scientists collaborating in the analysis consider such data, where appropriate.

Table 1

List of data set used in a collaborative work on body condition analysis

Item	Note
Date of capture	Year, month, day and local time
Position of capture	Latitude and longitude
Sex indicator	
Body length	
Body weight	
Age	
Diatom adhesion level	
Reader ID for diatom adhesion determination	If possible
Blubber thicknesses	Two sites corresponding to BT11 and BT7
Blubber weight	
Half girth	Two sites of axilla and umbilicus
Weight of forestomach contents excluding liquid	If possible
Foetus length	
Sexual maturity indicator	Only mature males and pregnant females are used for analysis
Pregnant indicator	
Track-line ID	Provided by Australian scientists
Ice-edge indicator	Provided by Australian scientists

3. CO-OPERATION ON ECOSYSTEM MODEL DEVELOPMENT AND MATTERS OF COMMON INTEREST TO IWC AND CCAMLR

3.1 Update from CCAMLR's ecosystem monitoring and management programme (WG-EMM) on krill and its dependent predators

Currey presented the SC-CAMLR Observer report IWC/66/04-2016-Rev1, Appendix F, and in particular the components relevant to the work of the SC-CAMLR WG-EMM. With regards to the current state of the krill-based ecosystem and the krill fishery, SC-CAMLR endorsed the advice of WG-EMM that krill fishing in areas distant from land may not affect land-based predators but could affect pelagic predators such as whales, pack-ice seals, fish and other predators foraging in those areas. Full implementation of krill feedback management requires that CCAMLR is able to estimate the ecosystem effects of fishing. The CCAMLR Ecosystem Monitoring Program currently only includes land-based predators. Detecting ecosystem effects in pelagic areas may require monitoring of krill predators utilising those areas, such as cetaceans, ice seals and fish.

The question was asked if another ice seal survey was under consideration. The response was that there is a growing recognition that the CEMP data set is not complete and active discussion how to implement feedback management, specifically in Area 48. There is a recognition of this, but how to deal with that is another question.

3.2 New information on relationships between whales and krill

Herr *et al.* (2016, SC/66b/FI10) was presented, a recent paper published in Polar Biology on a helicopter survey for whales conducted concurrently to a krill survey around the western side of the Antarctic Peninsula. The authors analysed the distribution of humpback and fin whales against a suite of environmental variables. Both models performed well and densities of whales were predicted in two areas; the Drake Passage and Bransfield Strait areas. Species specific distribution patterns of humpback and fin whales suggest horizontal niche separation, with fin whales largely using the Drake Passage and humpback whales the Bransfield Strait. Krill data were available from net sampling stations and distributions of *Euphausia superba*, *E. crystallorophias* and *Thysanoessa macrura* were modelled to obtain density surfaces. Comparisons with whale distribution patterns showed specific relationships. The authors suggest fin whales were largely feeding on *Thysanoessa macrura* during the time of the survey while humpback whales occurred in areas where *Euphausia superba* dominated. Further investigation of this relationship was suggested for future studies. It was noted that this manuscript was largely the result of a joint effort from different projects on the same expedition and should be lauded.

In discussion, several questions were raised relating to the distribution of both krill and whales from the research. It was thought that *E. superba* was distributed broadly in the region, but not shown in this study and *T. macrura* seems to be more distributed in the Drake Passage in the study area. A question was also raised if estimates of abundance from this area could be used in a larger assessment from more dedicated survey cruises. The information on fin whales could be valuable and there must be other papers in CCAMLR that report population estimates in them and what is the likelihood of this being assembled together. It was noted that authors had produced estimates for catch per unit efforts for fin whales and could bring them next year and they could be used to compare with modern distributions presented in this paper. It was then noted that the cetacean and krill data were analysed separately, but a hierarchical model including them both with krill as a predictor of whales would be interesting and if there are plans to do this in the future.

The Working Group thanked the authors and looks forward to receiving further updates.

3.3 Update on planning for joint IWC-CCAMLR workshop

In 2008, IWC and CCAMLR held a joint workshop where data holders on krill predators and oceanography came together. Due to a lack of formal channels for communications, objectives, and time lines, collaboration was limited. Now this group is seeking formal channels for cooperation. Last year, an idea of a joint workshop in 2016 was raised, but scheduling conflicts precluded this and it was postponed. Now a formal proposal is being formed to develop multi-species model. A small group convened by Currey was set up with a membership of Butterworth, Currey, de la Mare, Double, Friedlaender, Kitakado, Murase, New, Palka, and discussed further refinement of the proposal.

The outcome of discussion is shown in Appendix 2. A joint IWC-CCAMLR workshop is planned with 2-step approach: a workshop pre-meeting before IWC in 2017 to review data from 2008 and promote ideas for multi-species models and then how to develop multi-species models. The western Antarctic Peninsula will be a focus area for modelling as it is a high priority area for krill management and there are considerable data available.

The Working Group endorsed this plan and looks forward to hearing its progress.

4. SPECEIS DISTRIBUTION MODEL (SDM)

4.1 Review progress for developing guidelines

An intersessional corresponding group was established in SC65b under the Working Group to develop guidelines and recommendations for best modelling practices of species distribution models (SDMs). SC/66b/EM04 reported progress made by the intersessional corresponding group between SC66a and SC66b. In that period, the group conducted preliminary reviews of machine learning methods which are commonly used as SDMs: maximum entropy model (Maxent), genetic algorithm (GA), support vector machines (SVMs), Bayesian network (BN) and random forest (RF). The results are summarised in Appendix 3. The intersessional group also considered preliminary framework guideline for SDMs applied to cetaceans. The details of reviews were presented as appendices of SC/66b/EM04, and the following are summaries of them.

Maxent is, at its most basic level, a method for making predictions or inferences from incomplete information. Maxent generates presence-only models of species distributions by estimating the probability of distribution relative to maximum entropy (i.e. uniformity). The probability of a species occurrence is constrained as a function of environmental variables included as predictor variables. In order to generate a model of a species' environmental requirements, Maxent uses a set of occurrence localities (presences). The environmental features that can be used in Maxent to predict a species distribution can be derived from both continuous and categorical variables. Maxent employs a number of features to fit a function of the covariates that include linear, product, quadratic, hinge threshold, and categorical. To date, Maxent has been used in a number of cetacean studies.

GA is a stochastic search optimisation technique that iteratively develops a solution using analogues of mechanisms that operate in genetic evolution of natural populations. In the context of SDM, they develop rules for probabilistic classification of species presence across a study domain based on observed species presences, absence data (often inferred) and environmental covariates. GA have been applied widely to the problem of SDM in non-cetacean species, but relatively rarely for cetaceans. The technique appears to have fallen from favour in recent years due to several comparative studies showing r that a popular implementation of GA for SDM predicts poorly compared with other SDM approaches. It is unclear the degree to which this poor performance is a failing of particular software, or genetic algorithms more generally. There are no known advantages to using GA in relation to SDM studies of cetacean species. Many of the issues associated with applying SDM to cetaceans are unlikely to be able to be directly addressed through a GA framework, including issues related to paucity of data, observer biases, and a lack of direct links between sightings and environmental correlates during migratory behaviour. In light of these limitations, including the poor predictive performance of GA shown in several studies, the approach is currently not recommended for developing SDM for cetacean species.

SVMs use a functional relationship known as a kernel to map training data onto a new hyperspace in which complicated patterns between animal distribution and environmental variables can be more simply represented and then used to predict that pattern using data from a test dataset. The response variable has usually been either presence/absence or even just presence, though more complicated categorisations are possible. SVMs have been applied successfully to text categorisation, handwriting recognition, gene-function prediction, and remote sensing classification, demonstrating the utility of the method across disciplines, proving that SVMs produce very competitive results with the best available classification methods. They have infrequently been applied to ecological predications only in the last decade. However, there are no known applications to cetaceans, so far.

Bayesian network (BN) has been used as SDMs since early 2000s. BN is a kind of probabilistic graphical models in which correlative and causal relationship among variables is represented graphically and probabilistically. BN has been applied as SDMs for vertebrates but all of them are inland species. The response variables were not abundance but presence and absence. Because of the limitation that variables should be discretised in some extent, utility of BN for management of cetaceans could be limited as detailed information is lost due the discretisation. However, BN could be useful tool for exploratory research to investigate causal relationship among variables based on expert knowledge which cannot be handled by other SDMs.

RF is a machine learning technique that combines many single decision trees in an embedded way to calculate the importance of each predictor. The technique combines the ideas of bagging and random selection of features. From a bootstrap sample, a large number of regression trees are fitted using randomly chosen covariates on each node. Trees are fully grown (rather than pruned), and the results of all trees are averaged for the final prediction. RF performs well in relation to other classification techniques. Use of RF in SDM has proven robust and stable. The technique is being widely used, both as stand-alone and as part of ensemble distribution forecasting on a variety of plant and animal taxa. Software for RF is well developed in the R statistical language. Although RF has apparently not been used in SDM with cetacean survey data to date, the technique is well suited for this purpose, and existing studies from the seabird literature should serve as excellent background.

In discussion regarding the ‘probability of occurrence’ estimated by Maxent, the Working Group noted that this is not actually a probability, but is a predicted relative density. If the ‘probability of occurrence’ is $f(x)$ at a point x, then the predicted number of animals in a small neighbourhood around the point x is proportional to $f(x)\,dA$, where dA is the area of the small neighbourhood. The Group also noted that methods such as Maxent that use only ‘presence’ data make the implicit assumption that survey effort is uniform in space, or at least uniform relative to the marginal distributions of each covariate. This is not the same as making no assumptions about effort. The Group is aware that there are various views on this point. The uniform effort assumption may be acceptable in some cases, but in general the Working Group **recommended** that effort be taken into account where possible. Effort tends to be better quantified in cetacean datasets than in many other applications, not least because of the focus of the Committee on this aspect over many years.

Some initial thought on framework of guideline for SDMs applied to cetaceans is presented in SC/66b/EM04, Appendix 6. Ten iterative steps in development and evaluation of models proposed by Jakeman et al. (2006) are used as a templated for this purpose. Written statement of these steps will help reviewers. Through this consideration, necessity of development of two kinds of guidelines was recognised. One is general guideline applicable to all statistical models. The other is a specific guideline for a particular statistical model.

The Working Group thanked authors of the report for a comprehensive compilation on the available modelling methods and looks forward to further updates at next year’s Committee meeting. The Working Group **endorsed** further evaluation of the various modelling approaches based on a common dataset.

4.2 Review progress by NMFS

Last year in San Diego, a joint pre-meeting workshop was held between the IWC and the USA National Marine Fisheries (NMFS), titled ‘Towards Ensemble Averaging of Cetacean Distribution Models’. Approaches for model averaging, or ensemble, have been an attractive topic in statistical science and machine learning as a way to address model uncertainty and to achieve robustness in predictions. The discussions and recommendations from the workshop are published in SC/66a/Rep10, including a proposed work plan to be led by a steering group (SG) made up by Becker, DeAngelis, Palacios and Redfern. Although none of the members of the SG could attend SC66b, the Working Group received a progress report.

In the last year the SG recognised that it would be difficult to make intersessional progress on the tasks listed in the work plan due to limitations in funding and personnel time. They determined that a scaled-down approach was more viable, as follows: (a) focus the overarching management question to the risk of ships striking blue whales on west coast of the USA, and (b) limit the models to be used in the ensemble to those covering the entire region and that had a similar output type (i.e., those presented by Becker and by Hazen at the workshop, plus others that have been developed more recently).

Intersessionally, members of the SG together with Forney and Hazen conducted a preliminary ensemble of these models and are currently exploring the results. A number of issues were identified by this exercise, as follows: (a) determining the spatial and temporal resolution of the predictions, (b) determining whether to scale the predictions to a consistent range, (c) identifying external metrics to compare and validate the ensemble, and (d) considering how to assign weights to the different input models. In the next year the SG will continue to address these issues and will reported the results to the EM Working Group at the 2017 Committee meeting.

The Working Group thanked the report by the SG and looks forward to receiving any updates at next year's Committee meeting.

5. REPORT OF KRILL SURVEY IN NEWREP–A

SC/66b/EM03 described the first NEWREP-A's dedicated sighting survey vessel-based krill survey, which was conducted in Antarctic Area IV-E during the 2015/16 austral summer season. The survey was conducted along the tracklines designed for a cetacean sighting survey. Acoustic data were recorded continuously for 31 days using a quantitative echosounder (EK80). EK80 operated with frequencies at 38, 120 and 200kHz. Net samplings using a small ring net (1m in mouth diameter and 3m length) equipped with LED were carried out to identify species and size compositions of echo signs at 29 stations. Oceanographic observation was also conducted at 29 stations using a CTD. Krill and oceanographic data are being currently examined, and the results will be considered for the planning of the second survey in the 2016/17 season. Survey design together with the preliminary krill and oceanographic results obtained in the 2015/16 season will be presented to a CCAMLR specialists' workshop (CCAMLR-SAM). Feedback from the specialists will be reflected in the planning of the 2016/17 survey.

In discussion, clarification was sought regarding technical details of the survey procedure and results. It was noted that the two stratum in the survey, IV-NE and IV-SE, which were surveyed for 15 and 16 days respectively, had covered markedly different distances, or 935.7 and 635.5 n.miles respectively. The reason for this difference was the number of whale sightings in the respective strata was substantially different, allowing the vessel to travel at a greater speed in the IV-NE strata where the number of sightings was low.

Concerns regarding the noise level from the vessel's engines in relation to the type of vessel and age, as engine vibrations could mask important acoustic signals. Japanese scientists informed the Working Group that the vessel had been specially designed for acoustic surveys, notably by insulating the engines.

Additional concerns were raised regarding the sampling gear as it was noted that the gear was not particularly well suited for krill sampling. Japanese scientist indicated that they were aware of this issue and were investigating ways to improve this. They had however managed to obtain more samples than expected in the survey, although they believed the size distribution was not representative as main focus was to obtain species occurrence to compare with the echosounder.

Japanese scientist reported that future survey may include an additional survey vessel, allowing for greater coverage. It was further noted that this survey could provide information on species interactions. The Working Group **encouraged** further work on the survey by consultation of CCAMLR specialists.

6. OTHER MATTERS

The working group noted there were no specific papers tabled on the effects of long-term environmental variability on whale populations at this meeting. However it noted that the individual-based energetics model presented in SC/66b/EM01 was relevant to this issue as was the planning for the joint IWC-CCAMLR workshop. The working group encouraged the intersessional Correspondence Group to continue the discussion and added Friedlaender to the existing group of Cooke (convenor), de la Mare and Palacios.

7. WORK PLAN AND BUDGET REQUESTS

The Working Group **agreed** that its work plan before the 2017 Annual Meeting would be as follows.

(1) Joint SC-CAMLR and IWC SC Workshops

A Steering Group with members from both IWC-SC and SC-CAMLR was formed to plan and oversee the joint Workshops intersessionally (see Tables 2 and 3). Two Joint SC-CAMLR and IWC-SC Workshops are proposed for 2017 and 2018 to foster collaboration between the ecosystem modelling working groups of both Commissions responsible for managing whales and marine living resources in the Southern Ocean (see Table 4).

(2) Applications of species distribution models (SDMs)

An intersessional Correspondence Group (see Tables 2 and 3) will continue the review of applications of species distribution models in the context of requirements within the Committee in order to develop guidelines and recommendations for best modelling practices (see also Appendix 4).

(3) The effects of long-term environmental variability on whale populations

An intersessional Correspondence Group (see Tables 2 and 3) will continue the discussion of the effects of long-term environmental variability on whale populations.

One request for funding was advanced at SC66b. This was a request to fund the attendance of Invited Participants to the two upcoming joint IWC-CCAMLR Workshops. The Working Group endorsed the terms of reference, welcomed the progress to date, **recommended** the workshop preparations continue and noted CCAMLR XXXIV endorsement of this work.

Table 2

Summary of the work plan for EM Working Group.

Item	Intersessional 2016/17	2017 Annual Meeting (SC/67a)
(1) Joint SC-CAMLR - IWC SC Workshops	Prepare a pre-meeting Workshop under a Steering Group (see Table 3)	Hold a pre-meeting Workshop to review the status of multispecies models and available data series (see Appendix 2)
(2) Applications of species distribution models (SDMs)	Intersessional Working Group activity (see Table 3)	Review progress by SDM working group
(3) Effects of long-term environmental variability on whale populations	Intersessional Working Group activity (see Table 3)	Review progress by working group
(4) Further investigation of individual-based energetics models	Continue further analyses	Review results of further analyses
(5) Modelling of competition among whales	Continue further analyses	Review results of further analyses
(6) Update of information on krill distribution and abundance by NEWREP-A	Conduct a survey by consultation of CCAMLR specialists.	Review results of the survey and analysis

Item	Intersessional 2016/17	2017 Annual Meeting (SC/67a)
(1) Joint SC-CAMLR - IWC SC Workshops	Prepare a pre-meeting Workshop under a Steering Group (see Table 3)	Hold a pre-meeting Workshop to review the status of multispecies models and available data series (see Appendix 2)
(2) Applications of species distribution models (SDMs)	Intersessional Working Group activity (see Table 3)	Review progress by SDM working group
(3) Effects of long-term environmental variability on whale populations	Intersessional Working Group activity (see Table 3)	Review progress by working group
(4) Further investigation of individual-based energetics models	Continue further analyses	Review results of further analyses
(5) Modelling of competition among whales	Continue further analyses	Review results of further analyses
(6) Update of information on krill distribution and abundance by NEWREP-A	Conduct a survey by consultation of CCAMLR specialists.	Review results of the survey and analysis

Table 3

E-mail Intersessional Correspondence Groups, Steering Groups, Working Groups and Terms of Reference.

Group	Sub-committee	Terms of Reference	Membership
(1) Joint SC-CAMLR-IWC SC Workshops planning	EM	Commence planning of a joint workshop between IWC-SC EM and SC-CAMLR WG-EMM	Kitakado (co-convenor), Kawaguchi (co-convenor), Butterworth, Currey, de la Mare, Double, Friedlaender, Hill, Ichii, Kovacs, Murase, Palka, Trathan, Watters
(2) Applications of species distribution models (SDMs)	EM	Develop guidelines and recommendations for best practice in species distribution modelling	Murase (convenor), Friedlaender McKinlay, Kelly, Kitakado, Palacios, Palka
(3) Effects of long-term environmental variability on whale populations	EM	Identify long time series (>=20 yr) of cetacean demographic parameters and/or abundance Identify potentially relevant environmental time series	Cooke (convenor), de la Mare, Friedlaender and Palacios

Table 4

Summary of budget requests for the 2017-2018 period. For explanation and details of each project see text.

SC/66b	RP no.	Title	Relevance to which sub-committee(s)?	2017 (£)	2018 (£)
		Joint SC-CAMLR and IWC-SC Workshops 2017-2018	EM	5,520	15,820
Total request				5,520	15,820

8. ADOPTION OF REPORT

The report was adopted on 14 June 2016 at 16:15. The Chair expressed his sincere appreciation to the rapporteurs, Butterworth, Currey, Elvarsson, Friedlaender and Skaug for their excellent work. The Working Group thanked Kitakado for his leadership and gratefully accepted his offer to convene the Group next year.

References

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Appendix 1

AGENDA

1. Introductory items
    - 1.1 Convenor's opening remarks
    - 1.2 Election of Chair
    - 1.3 Appointment of rapporteurs
    - 1.4 Adoption of Agenda
    - 1.5 Documents available
2. Review issues relevant to ecosystem modelling within the Committee
    - 2.1 Individual-based energetic models
    - 2.2 Competition among baleen whales: how can we measure and model it?
    - 2.3 Update on body condition analyses for the Antarctic minke whales
3. Co-operation on ecosystem model development and matters of common interest to IWC and CCAMLR
    - 3.1 Update from CCAMLR's ecosystem monitoring and management programme (WG-EMM) on krill and its dependent predators
    - 3.2 New information on relationships between whales and krill
    - 3.3 Update on planning for joint IWC-CCAMLR workshop
4. Species distribution models (SDM)
    - 4.1 Review progress for developing guidelines
    - 4.2 Review progress by NMFS
5. Report of krill survey in NEWREP–A
6. Other matters
7. Work plan and budget requests
8. Adoption of report

Appendix 2

PLANS FOR THE JOINT SC-CAMLR AND SC-IWC WORKSHOP 2017-2018

A proposal for a Joint SC-CAMLR and IWC-SC two-day Workshop to develop multi-species models of the Antarctic marine ecosystem was discussed at the SC-CCAMLR 2014, and a steering group to progress a Joint IWC–CCAMLR Workshop was formed (SC-CAMLR 2014 Paragraph 10.25). The joint workshop was perceived as an opportunity to increase knowledge on specific species and their interactions in different management areas, possibly initially focussing on the Antarctic Peninsula given it is a high-priority area for both CCAMLR and IWC (IWC SC 2015 Report). The steering group developed a paper identifying draft terms of reference (SC-CAMLR-XXXIV/BG/33). This was tabled to and endorsed by the SC-CAMLR 2015. These ToR are also scheduled to be discussed at the IWC-SC meeting in June 2016 together with the draft agenda proposed in this document.

Terms of Reference (ToR) endorsed by SC-CCAMLR to guide the two CCAMLR-IWC Modelling Workshops in 2017 and 2018.

(1) Foster collaboration between SC-IWC and SC-CAMLR.

(2) Review outcomes from the joint workshop in 2008, assess progress since then including information on species interactions for species of interest to CCAMLR and IWC.

(3) Initial discussion on multispecies models of the Antarctic marine ecosystem and develop work plans toward the second workshop.

(4) Consider multispecies models of the Antarctic marine ecosystem, at a scale that is able to inform strategic management advice, mainly focussing on the Antarctic Peninsula area as a test-case area, and set directions for future collaborative research activities that would be of mutual interest.

The 1st workshop (two days) in 2017 should review outcomes from the joint workshop held in 2008 (assess progress since then and highlight information on species interactions that are of mutual interest to CCAMLR and IWC). It should initiate discussion on the purpose and the types of multispecies models that are needed by both organisations, and develop work plans towards the 2nd workshop in 2018. The ToR for the 2nd workshop will be updated following the 1st workshop. After consideration, the steering group suggests the following draft agenda for the 1st workshop in 2017.

Draft Agenda

1. Introduction
    1.1 Terms of reference
    1.2 Agenda and organisation of the meeting
    1.3 Background
2. Review the status of multispecies models and available data series
    2.1 Outcomes from the 2008 joint WS and progress since then
    2.2 Key questions to be addressed by multispecies ecosystem models
    2.3 Purpose, status of, and suggestions regarding, relevant multispecies models
    2.4 Abundance and trends of species relevant for developing and fitting multispecies models
    2.5 Outstanding questions
3. Workplan for the 2nd WS
    3.1 Review priority questions of mutual interest into the future
    3.2 The scale and the types of model to be developed
    3.3 Geographic areas and ecological issues of mutual interest
    3.4 Tasks and milestones
4. Report adoption
5. Close of the meeting.

Workshop preparation

The steering group will identify a list of potential participants and presenters by January 2017, and prepare a call for papers to be submitted to the workshop, with a deadline at least 2 weeks prior to the workshop. The call for papers will highlight the purpose of the workshop and identify the level of information sought including the purpose of existing models, the data required and data available for such models. The CCAMLR Observer (Currey) is requested to liaise with CCAMLR Secretariat to discuss available from the CCAMLR Ecosystem Monitoring Program (CEMP) and krill fishery data and how that might be prepared and summarised ahead of the workshop.

References

IWC SC Report (2015)

SC-CAMLR-XXVII Annex 12 (2008)

SC-CCAMLR-XXXIII (2014)

SC-CAMLR-XXXIV/BG/33 (2015)

Appendix 3

A SUMMARY OF PRELIMINARY REVIEW OF MACHINE LEARNING METHODS APPLIED AS SPECIES DISTRIBUTION MODELS (SC/66B/EM4). MAXENT: Maximum Entropy Models; GA: Genetic Algorithms; GARP: Genetic Algorithm for Rule set Production; SVM: support vector machines; BN: Bayesian networks; RF: random forests.

Methods	Maxent	GA (GARP)	SVM	BN	RF
Response variable					
Presence only	X	X	X	-	-
Presence and absence	-	-	X	X	X
Abundance	-	-	-	X	X
Explanatory variable					
Continuous variable	X	X	X	X	X
Discrete variable	X	X	X	X	X
Advantages	• Maxent requires only presence data and environmental information for the study area rather than full/dedicated abundance estimates from surveys. • It can integrate both continuous and categorical environmental variables and incorporate interactions between variables. • Deterministic algorithms have been developed that converge to the optimal (maximum entropy) probability distribution. • The resulting probability distributions have a concise mathematical definition that is amenable to further analysis. • Over-fitting of a species' probability of distribution can be avoided using regularization algorithms. • The resulting probability distributions based on the distribution of occurrence localities are explicit and can allow for more formal examination of sampling bias. • Model outputs are continuous, allowing for fine distinctions to be made the model suitability of different areas. • Maxent can also be applied to presence/absence data by using a conditional model. • Maxent is a generative, rather than discriminative approach, which has advantages when the amount of training data (e.g. smaller data sets) used is limited.	• GA solutions are not reliant on derivative-based optimisation techniques, allowing the method to search highly complex optimization surfaces with multiple local minima. • Methods lend themselves to distributed computing. • Alternate, equally plausible solutions are captured for examination.	• The methods are easy to use. Unlike many other machine learning algorithms, which rely on creativity and extensive tuning of parameters by users, SVMs require a minimum of tuning. SVMs are stable and thus require less model tuning and have fewer parameters then other computational optimization methods. • Because SVSs are theoretically-based models, combining optimization, statistics and functional analysis to achieve maximum separation, they have many appealing characteristics: SVMs are distribution free making no assumption on the underlying probability distribution; they do not require independent input data (and therefore can overcome the autocorrelation problem); are able to represent various data distribution shapes in feature space (e.g., banana shapes, sphere shapes, or even very irregular shapes); results are free from local minima; they are computationally efficient; and they provide outstanding performance in many situations.	• Risk and uncertainty can be estimated more accurately than in models where only values are taken into account because nodes are modelled by means of probability distributions. • The probability of particular hypothesis can be automatically computed because numeric values are attached to the relationship between the variables. • The probability distribution of a node given its parents, and even the other way round, the probability distribution of a parents nodes given its child nodes can also obtained once the model is learned. This allows as to know the effects given the causes and the causes given the effects. They can be used as inferential model given this characteristic. • Expert knowledge can be incorporated in BNs through a participatory modelling procedure because the relations between variables can be visualized easily by the graphical representation of the network and so they can be modified by the experts just by adding or removing variables and links in the graph. • BNs can model complex systems with a large number of variables. • BNs can manage missing values in input data and perform the proper predictions with the model built from them.	• RF is ideal for modelling ordinal and categorical data, including presence-absence. Additionally, it is among the techniques well suited to deal with the zero-inflated, overdispersed data typical of line-transect abundance surveys (together with negative binomial generalized linear modelling and Hurdle modelling). • RF makes few assumptions about the distribution of variables, is robust to over-fitting, and is widely recognized to produce predictions that typically outperform traditional regression-based approaches . • RF predictions can easily be projected into new variable space, making it an appropriate algorithm for projective modelling such as climate change. • In contrast to other dimensionality reduction techniques like those based on projection (e.g. principal component analysis) or compression (e.g. using information theory), RF does not alter the original representation of the variables, but merely selects a subset of them, thus maintaining their interpretability.

Methods	Maxent	GA (GARP)	SVM	BN	RF
Disadvantages	• Maxent is relatively new and not as mature as GLM/GAM so there are fewer guidelines and methods for estimating error. • More work needs to be done to determine the effectiveness of avoiding of over-fitting compared with other variable-selection methods. • Maxent uses an exponential model for probabilities that can give large predicted values for environmental conditions outside the range present in the study area. • As a stand-alone package, Maxent software is required.	• Computationally intensive. • No direct model-based estimates of uncertainty. • Care must be taken to resolve issues of premature convergence (a few comparatively good but non-optimal solutions come to dominate the population) and slow finishing (the population of solutions has largely converged but a global solution remains elusive). • Current implementations of GARP do not easily accommodate categorical variables. • Perhaps most importantly, predictive performance has been shown to be inferior to other available SDM approaches.	·It is computationally complex and slow; difficult to determine optimal parameters when training data is not linearly separable, and difficult to understand the structure of the algorithm. Perhaps it could also be used in describing temporal trends that include inter- and intra-annual variabilities.	• To maintain the accuracy in the estimations and in the network topology, the building process of the network and the parameter estimation requires more data as the number of variables increases. • BNs can manage continuous data and hybrid of continuous and discrete data but the limitations are too restrictive and the most extend solution is discretization of variables. • Expert knowledge with an unknown degree of bias and inaccuracy can be easily incorporated in BNs. • Handling of feedback functions and temporal relationships are not possible. • Though complex systems can be modelled by BNs, this should be sparingly to avoid crating unwieldy model structures.	• When used as a classifier, ancillary data are necessary for training the RF algorithm and validating classes, which can be problematic for small datasets and which also requires time-consuming visual classification. • While providing highly accurate predictions, and despite maintaining the original representation of the covariates, RF models can be difficult to interpret. • RF can be sensitive to the number of covariates and to the number of trees comprising the classifier. Multi-collinearity and imbalance between classes are additional factors that can affect model performance. • The two major limitations of the ROC as an evaluation metric is that it is only suited for discrete data and few strategies exist for validating more than two classes (presence-absence). For multi-class models the Kappa statistic has been criticized because it is not truly chance-constrained, although a weighting function has been implemented to account for near agreement and adjust for expectation in the frequency of observations.
Typical software	Maxent https://www.cs.princeton.edu/~schapire/maxent/	DK-GAR Phttp://www.nhm.ku.edu/desktopgarp OM-GARP http://openmodeller.sourceforge.net/ R package https://cran.r-project.org/web/views/Optimization.html	LIBSVM https://www.csie.ntu.edu.tw/~cjlin/libsvm/	Netica https://www.norsys.com/index.html	R http://cran.r-project.org/web/views/MachineLearning.html
Application to cetaceans	Bombosch et al. (2014), Friedlaender et al. (2011), Smith et al. (2012)	MacLeod et al. (2008), Ready et al. (2010)	NA	NA	NA

Appendix 4

WORK PLAN OF THE INTERSESSIONAL CORRESPONDING GROUP 'APPLICATIONS OF SPECIES DISTRIBUTION MODELS (SDMS)' BETWEEN 66B AND 67A IWC/SC

Hiroto Murase, Ari Friedlaender, Natalie Kelly, Toshihide Kitakado, John Mckinlay, Daniel M. Palacios, Debra Palka

INTRODUCTION

Species distribution models (SDMs) attract interests from several sub-committees of the IWC/SC to address different questions. Some of examples of the questions are as follows: estimation of abundance in RMP and IA; investigation on reasons of changes in abundance in spatial context in IA; assessment of risk from co-occurrence of whales and human threats (e.g. shipping density or fishing effort) in HIM; investigation on effects of climate change on temporal and spatial distribution of cetaceans in E. It is obvious that reliable modelling outputs are required to address these questions. However, the IWC/SC doesn't have consistent method to evaluate them. An intersessional corresponding group, 'Applications of species distribution models (SDMs)', was established under the Working Group on Ecosystem Modelling (EM) in 65b IWC/SC (IWC, 2015). In the first year (between 65b and 66a IWC/SC), the group conducted a preliminary review of the literature on SDMs applied to baleen whales (Murase *et al.*, 2015). In the second year, (between 66a and 66b), the group conducted preliminary reviews of machine learning methods which are commonly used as SDMs (SC/66b/EM4). The following machine learning methods were reviewed: maximum entropy models (MAXENT), genetic algorithms (GA), support vector machines (SVMs), Bayesian networks (BNs) and random forest (RF). The group also considered a preliminary framework guideline of broad principles for SDMs applied to cetaceans in the second year. The results are presented as paper SC/66b/EM4. Finalisation of these preliminary works will be the main focus of the group in the next year.

Initiatives related to SDMs have also been considered in other intersessional groups established in the IWC/SC. The Sub-Committee on the RMP of the IWC/SC is currently trying to develop a guideline for model-based abundance estimation methods, mainly focusing on generalised additive models (GAMs) (Hedley and Bravington, 2014). It is expected that the review and development of a guideline will be completed by the 2016 annual meeting (IWC, 2016a). Although a workshop for the review and training of this guideline was planned as a pre-meeting to IWC/SC 66a, it was postponed. Separately, the Joint NMFS-IWC Preparatory Workshop 'Towards Ensemble Averaging of Cetacean Distribution Models' was held as a pre-meeting of the IWC/SC 66a (IWC, 2016b). The workshop developed a work plan to construct an ensemble model using the Eastern North Pacific blue whale data sets as a template. Three corresponding groups were established under EM to accomplish the goals set forth by this workshop. Of particular relevance to this intersessional correspondence group, one of those groups will review statistical literature and report on techniques for building ensemble models. The role of our 'Applications of species distribution models (SDMs)' group would be to oversee and coordinate efforts undertaken by existing and future groups that may be established in the IWC/SC. But for the mean time, we propose the following work plan to minimise overlap among the above-mentioned corresponding groups so that the IWC/SC can maximise efficiency on the development of guidelines on SDMs. That said, our group will collate outcomes from each group to make a synthesis of guidelines on SDMs in the future. Furthermore, once the guidelines are developed, our group would be well positioned to lead the testing of the performance of different modelling techniques using common data sets of relevance to the IWC/SC.

NAME OF CORRESPONDENCE GROUP

Applications of species distribution models (SDMs)

TERMS OF REFERENCES

Terms of reference are as follows:

- Finalise review of SDMs applied to baleen whales
- Finalise review of machine learning methods including some guideline
- Initiate planning on a model comparison study using common data sets

DETAILS OF WORK PLAN

Review of SDMs applied to baleen whales

The group will complete a review of the literature on SDMs applied to baleen whales (i.e., an extension of Murase et al., 2015) and submit it to a peer-reviewed journal by 67a IWC/SC. Terminology associated to SDMs will be defined in the paper.

Review of machine learning methods

The group will complete reviews of machine learning methods by 67a IWC/SC. The following points which were not considered explicitly in some of the reviews in SC/66b/EM4 will be considered in the final versions: (1) selection of model features and families, (2) choice of how model structure and parameter values are to be found, (3) choice of estimation performance criteria and technique, (4) identification of model structure and parameters, (5) conditional verification including diagnostic checking, (6) quantification of uncertainty and (7) model evaluation or testing. In addition, a review of boosted regression trees (BRT), which were not presented to this meeting, will also be completed by 67a IWC/SC.

Planning on a model comparison study using common data sets

The group will initiate planning on a model comparison study using common data sets (e.g. POWER data and sample data of DISATNCE software) by 67a IWC/SC. Models for estimation of probability of occurrence and abundance will be considered in such exercises. Because the latter models can be considered as an extension of former models, same data sets can be applied to both model classes. The initial plan will be presented to 67a IWC/SC.

MEMBERSHIP

Hiroto Murase, Ari Friedlaender, Natalie Kelly, Toshihide Kitakado, John Mckinlay, Daniel M. Palacios, Debra Palka

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