Annex H

Report of the Working Group on Ecosystem Modelling (EM)

Members: Kitakado and Ferguson (Convenors). Aguilar, Arakaki, Baba, Barreto, Bell, C., Bell, E., Biuw, Bouzouma, Brownell, Buss, Campbell, Cassani, Chauca Huánuco, Cholewiak, Dalla Rosa, de Moor, Diallo, Domit, Donovan, Double, Ferreira, Fiogbe, Fyfe, Galletti, Givens, Goetz, Herr, Hielscher, Hodgins, Houtman, Iida, Jaramillo Legorreta, Johnson, Katara, Katsumata, Kelly, Lang, Leal, Lee, M.K., Lent, Lundquist, Mallette, Matsuoka, Moosa, Nelson, New, Noren, O'Loughlin, Øien, Palka, Pastene, Porter, Punt, Reeves, S., Ridoux, Salvador, Schubert, Seakamela, Secchi, Siciliano, Solvang, Stack, Staniland, Tamura, Tulloch, Walløe, Weinrich, Weller, Witting, Yasokawa, Yoo and Zerbini.

1. INTRODUCTORY ITEMS

1.1 Opening remarks
Kitakado welcomed the members of the Standing Working Group on Ecosystem Modelling (hereafter Working Group). He reminded Working Group members that EM was established in 2007 to discuss ecosystem modelling. To date, EM has advanced investigations into key inputs and methodologies for ecosystem modelling, *inter alia*, prey-predator relationships, habitat use and spatial-temporal distribution. Additionally, EM has progressed work on individual-based energetic models to understand the functional responses between large baleen whales and prey species. In addition, EM is responsible for advancing work on Commission resolutions 2016-03 and 2018-02 on the roles of cetaceans and their contributions to ecosystem functioning.

1.2 Election of the Chair
Kitakado was elected Chair. Kelly was elected Co-Chair.

1.3 Appointment of Rapporteurs
Ferguson (participating remotely), Kelly, and Schubert were appointed rapporteurs.

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/69A/EM/01-05, Cunen *et al*. (2020; 2021) and Solvang *et al*. (2022).

2. PREPARATION OF WORKSHOP ON THE ROLE OF CETACEANS IN ECOSYSTEM FUNCTIONING: GAP ANALYSIS

2.1 Review previous Committee discussions on contribution of whales to ecosystem functioning
Whales play a broad range of roles in an ecosystem, including through nutrient transport and cycling (vertically and horizontally), carbon sequestration, and as predators. In response to the Commission's adoption of Resolutions 2016-03 on the role of cetaceans in ecosystem functioning, the Committee was asked to conduct a gap analysis on the subject by examining the existing literature to identify knowledge gaps, and to develop a plan to fill those gaps through research. Resolution 2018-02 encouraged the Committee to collaborate with the Convention on Migratory Species (CMS) and other international organisations in this work.

The Working Group has been tasked with engaging in this work for the Committee. The original plan was to conduct an in-person workshop; however, due to the pandemic, a three-day virtual joint workshop with CMS on a gap analysis was held in 2021. The Terms of Reference for the workshop included: review of existing scientific literature to identify ecosystem functions provided by whales; determination of functions that could be quantified reliably; identification of potential species/taxa and geographical areas on which to focus; identification of knowledge gaps; and development of a prioritised list of recommendations for scientific research to fill those gaps. The workshop included two keynote reviews of cetaceans and ecosystem functioning prepared by Drs. Roman and Wassmann, and additional presentations on specific functions (e.g., whale falls, whale pump, whale conveyor belt, role as predators) provided by other experts. The results of the workshop included the following list of questions, hypotheses, and tasks to be considered at a second workshop on the subject, scheduled for November 2023.

(1) Development or modification of existing ecosystem models for the basis of subsequent items.

(2) Inputs needed for a robust assessment of the contribution of cetaceans in 'ocean fertilization', 'carbon cycle and sequestration', 'delivery of nutrient and energy', and 'habitat provision' (i.e., contribution relative to species other than cetaceans, with respect to consumption, metabolism, biodiversity, and habitat, including deep sea floor).

(3) Quantification of spatial difference in ecosystem functioning of cetaceans, focusing on links with environments and regional ecosystem characteristics (i.e., historical trends in different places).

(4) Quantification of temporal changes in ecosystem functioning of cetaceans, with focus on the difference between pre-whaling and current populations, and identification of information and knowledge.

(5) Qualitative assessment of the future roles and ecosystem functioning of cetaceans, with a focus on implications of global changes.

(6) Different contributions to ecosystem functioning over different cetacean species/functional groups (i.e. small versus large, mysticetes versus odontocetes, etc.).

In 2021, the SC agreed to focus on items 3 and 4 at the second workshop which, as an in-person event, will be better suited to engage in discussions regarding the detailed quantitative analysis of ecosystem functioning and issues related to ecosystem modelling.

2.2 Review progress on estimating pre-exploitation and current abundance of large whale populations

To proceed with the analyses of the ecosystem functioning of cetaceans, pre-exploitation and current abundance estimates of large whale populations are needed as these play a fundamental role in understanding ecosystem functioning. At SC68D, the Committee began identifying existing information and potential resources for those estimates in the North Atlantic Ocean and Southern Ocean, the main areas of interest to the Committee for investigating ecosystem functioning of cetaceans. The Committee recognised that abundance estimates for several North Atlantic stocks have already been approved by the Committee and used for IST, AWMP or RMP. Both NAMMCO and the IWC have developed tables of accepted abundance estimates. Therefore, identifying the best abundance estimate for each stock will be a relatively straightforward undertaking for the North Atlantic. In contrast, the Committee has not recently conducted reviews or In-depth assessments for Southern Ocean whale populations. Reviewing existing and identifying the best abundance estimates for the Southern Ocean will be a larger task; notwithstanding that, this region is of primary importance to the Committee's investigations into the ecosystem functioning of cetaceans. The fact that the Secretariat maintains a database of recent abundance estimates for Southern Ocean stocks, including those listed in the IWC Table of Accepted Abundance Estimates, may assist in this regard.

Last year, the Committee tasked the Southern Ocean and North Atlantic groups to provide plausible sets of pre-exploitation and current abundance estimates of populations of relevant large whale species in their respective regions from the literature, and to conduct additional analyses if needed.

Appendix 2 provides tables containing modelling data estimating pre- and post- commercial whaling abundances in units of number of whales and biomass for Southern Ocean species (blue, fin, humpback, and minke whales). Of particular interest is the relatively robust agreement in the two multi-species models considered as regards the current abundance, ratio of current and historical abundance, and biomass (current and historical) for blue, fin, and humpback whales. Notably, both models estimate that the current biomass of the Southern Ocean whale species today is approximately 20 percent of the historical level. It was noted that the models assume an invariant or constant carrying capacity which, given the impacts of climate change on krill, should be re-examined.

The Working Group thanked the authors for the reports, particularly the additional effort made to estimate whale biomass in the Southern Ocean. It noted the similarity in biomass, abundance, and the ratio between current and historical abundance estimates for the two models for blue, fin, minke and humpback whales and the importance of this information for modelling the role of cetaceans in ecosystem functioning. It was noted that while these abundance estimates may be broadly similar to what is published on the IWC website, they have not been specifically reviewed by ASG or ASI and, therefore, they have yet to be approved by the IWC.

Appendix 3 provides best estimates of pre-exploitation and current biomass of whales in the Northeast Atlantic. The biomass estimates (see Table 1 in Appendix 3) were calculated using current abundance estimates and methods from Skern-Mauritzen *et al*. 2022 (see Appendix 4) while pre-exploitation abundance estimates were taken from the single species model by Christensen (2006) (see Table 2 in Appendix 3). It was produced given the desire to evaluate two regions with contrasting ecosystem and oceanographic structures when assessing the role of cetaceans in ecosystem functioning. Given these differences, the roles of whales in the Southern Ocean and Northeast Atlantic are expected to be different. The ratio between current and pre-exploitation biomass estimates for all cetaceans in the region was 0.312. It was noted that while the Northeast Atlantic is an ideal region to include when evaluating cetaceans and ecosystem function due to the large amount of data on ecosystem structures, some of the abundance estimates would need to be re-examined to ensure that they reflect abundance in the Northeast Atlantic only.

The Working Group thanked the author for the report and noted the difference in ecosystem complexity between the Southern Ocean and Northeast Atlantic, which makes modelling the Northeast Atlantic more difficult. The Working Group inquired about adding biomass data to the tables and was told that the modelling to estimate biomass has already taken place and has been used for estimating both whale consumption and nutrient recycling rates.

In discussion, the Working Group expressed its gratitude for the information in Appendix 3. It noted the similarities between the biomass estimates for the pre and post commercial whaling periods (about 20 and 35 percent, respectively) for the various models used in the Southern Oceans and Northeast Atlantic, which is important for the evaluation of the role of cetaceans in ecosystem functioning.

Appendix 4 summarizes the methodology used to prepare the Wassmann *et al.* (2021) keynote paper presented at the IWC-CMS cetacean and ecosystem functioning workshop in 2021. It describes the approach taken when estimating the role of whales in the carbon cycle of the Barents Sea marine ecosystem. The methodology closely follows that of Smith *et al*. (2015) and Skern-Mauritzen *et al*. (2022) for estimating marine mammal biomass and prey consumption based on the most recent estimates of abundance, residence time and body mass for the species in question. It also describes the methodology used to estimate carbon content in total prey consumption and in whale faeces, and the carbon contribution of whale falls based on both historical and current global whale abundance estimates.

The Working Group thanked the author of Appendix 4, which can provide key ideas to identify ecosystem functioning processes and associated metrics. It also noted that the series of tables provided had been useful to identify data and analytical methods needed to estimate critical parameters.

2.3 Updates from the Conservation Committee WG

Last year, the Working Group received the report of the Conservation Committee's Workshop on Socio-Economic Values of the Contribution of Cetaceans to Ecosystem Functioning, held in April 2022 (CC/68/REP/SEVCEF/01). The Workshop reviewed analytical valuation methods and assessed their possible application under a cetaceans and ecosystem functioning framework. There were extensive discussions regarding the linkage between cetacean traits identified by the IWC-CMS workshop (2021) to an ecosystem service that could be assessed from a socio-economic perspective.

SC/69A/EM/01/Rev1 describes the work done by the Conservation Committee's Working Group after the workshop results were presented at SC68D in 2022. The proposal to advance the pilot project included two stages: initial steps to further refine the proposal including the development of Terms of Reference for the pilot project consultancy and a tender for the proposed consultancy to conduct the pilot project to be undertaken by an advisory group, and then contracting a consultant to conduct the analysis. The IWC agreed to this workplan. It recommended that this proposal be brought to the next SC meeting for input and endorsement and discussed further at the Conservation Committee's Working Group meeting intersessionally. An Advisory Group, including but not limited to experts in the ecological, biological and economic sciences, was formed in 2022 and has, to date, met virtually three times. It is currently working on the selection of the species/population to be assessed, the draft Terms of Reference and the tender for a consultancy. To facilitate the pilot project, the Secretariat has compiled a list of the abundance estimates available for several species. The Advisory Group welcomes input from the SC on the selection of species or species assemblages for the consultancy.

SC/69A/EM/02/Rev2 summarises the ongoing work of the Advisory Group since January 2023. To date, it has focused on the selection of species for assessment in a socio-economic analysis to be undertaken as a pilot project and on the development of Terms of Reference for the consultancy. To facilitate the species selection process for the pilot project, a decision matrix was developed to select the species or population(s) with suitable information that could be the target(s) for analysis. This matrix was shared with participants in the first IWC-CMS workshop on cetaceans and ecosystem functioning to solicit their suggestions for species and/or species assemblages to be potentially considered in the pilot project. The possible candidates offer a wide range of different cases for comparisons, ranging from large whales at breeding or feeding grounds in different ocean basins, as well as small cetaceans. For some of these candidates, there is not sufficient information or agreed abundance estimates to include them in the pilot project. Due to the importance of reliable abundance estimates, emphasis should be placed on those species/species assemblages for which such estimates are available. Of all the proposed candidates, only five populations have abundance estimates previously reviewed by the IWC. Those candidates include: the North Pacific humpback whale, where there is considerable information on ecosystem functioning; the Southern Ocean whale species assemblage (humpback, blue, fin and minke whales); and the Southwest Atlantic southern right whales, for which considerable information is available from their breeding grounds. No species from the North Atlantic were proposed but can still be considered for inclusion if nominated.

In discussion, the Working Group clarified the intent of the two activities: the Scientific Committee's focus is to evaluate 'ecosystem functioning', while the Conservation Committee's focus is on the socio-economics of 'ecosystem services.'

Appendix 5 provides clarification and additional information as to the purpose of the pilot project to examine the socio-economic value of the ecosystem services provided by whales. Not all ecosystem functions are associated with ecosystem services that can be valued as providing a benefit to humans.

The Conservation Committee's Advisory Group seeks the advice of EM on the selection of candidate species/populations for explicit inclusion in the Terms of Reference and the tender for consultancy. Instead of providing endorsement of the species/populations to be assessed in the pilot project, the Working Group noted that there may be outcomes from the second IWC-CMS workshop on cetaceans and ecosystem functioning that will be helpful to the Conservation Committee and its socio-economic Advisory Group and may inform its selection of a candidate species/population.

SC/69A/EM/05 reported progress outside of the Committee after the IWC-CMS workshop in 2021. Whale and Dolphin Conservation (WDC) has established a new core workstream with initial priority for addressing the most pressing research gaps identified at the workshop. Between October 2021 and January 2023, five scientific symposia were convened with a range of experts and researchers working on ecosystem functioning. At the 34th European Cetacean Society meeting, the WDC hosted a workshop to assimilate and discuss the latest research on the contribution of small cetaceans to ecosystem functioning, and identify research gaps, suitable species and/or populations and the different habitats and ecosystems that small cetaceans inhabit. Given the new evidence documenting the important different roles of small cetaceans in nutrient cycling, the ecosystem functioning benefits of coastal cetacean carcasses and the impact of climate change on ecosystem function provision, it would be useful if small cetaceans could be included in IWC work on ecosystem functioning.

The Working Group thanked the authors for their efforts to address some of the research gaps identified at the first IWC-CMS workshop. It noted that the role of small cetaceans in ecosystem functioning was discussed at the first IWC-CMS workshop. If additional information on small cetaceans is generated from the second workshop, this will be summarised and included in the workshop report. The Working Group would welcome additional information on this subject to be presented in the future.

Further discussion on preparation of the 2nd workshop under the Scientific Committee with the CMS is reported under Item 2.5.

2.4 Review Terms of Reference
The Working Group reviewed the Terms of Reference for the IWC-CMS workshop on cetaceans and ecosystem functioning approved by the Commission at IWC66 and determined that no amendments are necessary.

2.5 Discuss plans for upcoming workshop scheduled for November 2023
The Working Group discussed and approved a draft agenda for 2nd IWC-CMS workshop on cetaceans and ecosystem functioning (see Appendix 6). The agenda includes specific research questions and hypotheses to be addressed at the workshop. The results of the workshop will be communicated to SC69B.

3. REVIEW ISSUES RELEVANT TO ECOSYSTEM MODELLING WITHIN THE COMMITTEE

3.1 Modelling of competition among whales and relationships between whales and prey
Walløe introduced Cunen *et al*. (2021) which examines changes in the body condition of Antarctic minke whales sampled during the Japanese whaling research programme in the Antarctic (JARPA I from 1987/88 to 2004/05). By way of background, these data were first analysed by stepwise linear regression and presented to the SC in 2007 (Konishi *et al*., 2008). That analysis showed a decline in condition related to fat weight, blubber thickness below dorsal fin and girth at umbilicus. In 2011 in a paper to the SC, de la Mare justifiably criticised the linear regression model for not allowing for interactions or heterogeneity. In subsequent years both groups published results obtained by different linear mixed effects models, using AIC or BIC as their model selection criterion. Konishi *et al.* continued to find a clear decrease in body condition, while de la Mare *et al*. (2017) found no evidence of a decline. To advance this situation, Cunen *et al.* (2021) applied the focused information criterion approach (FIC). In the early 2000's, Claeskens and Hjort had developed this selection method for complex models, which had first been applied for Cox survival models. Model selection procedures based on FIC aim to give the most precise estimate of the key 'focus' parameter. The FIC approach for mixed effects models was developed by Cunen *et al.* (2020) and had been applied to two new minke whale body condition variables in addition to the original three (Cunen *et al.,* 2021). The first step in this FIC analysis had been to specify a 'wide model' (called M0) containing all perceived possible variables and interactions. The model uses year both as a fixed-effect covariate with a quadratic shape, and as a group indicator for the random effect. The wide model has 40 fixed-effects parameters and a number of random effect components, giving a total of 47 parameters. In this model, the authors also tried to include variables which had been suggested by de la Mare *et al.* (2017) in their work. A number of simpler models have also been investigated as part of the FIC analysis, one of them being a model (M1) without fixed year terms. Use of the FIC model led to the result that there had been a substantial decline in body condition over the study period: 10% for fat weight, 7% for blubber thickness and 3% for girth.

Cunen *et al.* (2020) provides a more detailed assessment of the FIC methodology that underlies the analysis and results contained in Cunen *et al.* (2021).

In discussion, the Working Group expressed appreciation for the presentation of both papers. The EM Working Group noted that this matter had been the subject of lengthy discussion during SC67B in 2018. On that occasion, the Committee reported that:

The Committee has been discussing whether there has been a statistically significant (5% level) decline in the blubber thickness and fat weight of Antarctic minke whales over the course of the JARPA I surveys for several years. In conclusion, the Committee agrees:

(1) that, for the data set considered as a whole, all approaches result in point estimates reflecting a decline when fit to a linear trend in time;

(2) however, the extent of the decline estimated differs amongst the methods, and is not statistically significant at the 5% level for all approaches;

(3) for some approaches, when the data are disaggregated by gender and/or area, some point estimates of trend are not negative; and

(4) there are some indications of temporal variation that is more complex than linear.

In addition, the Committee:

(1) encourages the authors to publish the results of their study in peer-reviewed journals; and

(2) agrees that this matter will not be considered during the forthcoming biennium.

A more complete history of this debate is contained in item 2.1.2 in Annex L of the 2018 Scientific Committee report.

The Working Group acknowledged that the authors of Cunen *et al*. (2021) had, as requested, published their results and methodologies in the scientific literature. It was noted that there may be an opportunity to revisit the implications of this finding during future discussion on ecosystem functioning, density dependent effects and climate change.

It was also noted that other papers on body condition of whales, including Vermeulen *et al*. (2023) that used photogrammetry to examine the condition of right whales over the same time period, would be presented in future sessions. However, reservations were expressed about linking these papers with those focused on Antarctica, given latitudinal and regional differences.

The recent trend in temporal and geographical variation in blubber thickness of common minke whales in the northeast Atlantic was presented in Solvang *et al*. (2022). The paper showed a significant negative trend over the entire period with low values in 2011-13. To investigate temporal/geographical associations, three statistical approaches were applied: three simple regression models, one canonical correlation procedure, and an additive model with spatial effects. The data that were analysed were collected from 13,937 individuals during the commercial catch operations on feeding grounds during the period 1993-2020. The analyses using three approaches revealed a significant negative trend in blubber thickness from 1993 until 2015 and increasing thereafter. The geographical effect clearly indicated a gradient with higher blubber thickness in the north and west than farther to the south. The positive effect was also observed for all whales in the Norwegian Sea around 65 degrees north and in the Jan Mayen area. For the northern areas, while no spatial variation in the body condition of males was found, there was a somewhat clear spatial pattern for females with an increased trend from the south via coastal areas of mid-Norway, to the northern areas Bear Island and Svalbard. These areas are known as important feeding grounds where the common minke whales are nourished and deposit fat reserves not only in the blubber but also in muscle and visceral fat during summer, supported by former studies. Recruitment to the cod stock in more recent years has been continuously decreasing after 2013 to the current low level. The analyses indicated significant negative relationship, which may support a connection between cod abundance and common minke whale body condition.

In discussion it was noted that similar results were found with harp seals in the Northeast Atlantic regarding their response to changes in the cod stock, suggesting that capelin may be the common resource for which minke whales and harp seals are competing. A statistical question was raised about whether the models consider interactions between space and time. In response, the author explained that an interaction between space and season was taken into account, while inter-annual changes of spatial effects were not considered in the models. The author noted that new data obtained in 2023 will be subject to the same analysis and that a new model based on a non-parametric approach will be applied to the same dataset. The Working Group expressed its thanks for this important work, which provides a better understanding of the ecosystem, especially the link with the prey species. The Working Group welcomes future work on this subject to stimulate further discussions.

3.2 Krill distribution and abundance

SC/69A/EM/03 summarizes the history of the development of CCAMLR's management of the Antarctic krill fishery, including recent developments towards a revised management approach. The revised krill management approach combines three components: periodic krill biomass estimates, estimation of precautionary harvest rates, and a 'spatial overlap analysis', which incorporates the estimated spatial distribution of prey requirements of krill predators. The role of baleen whale science in the revised krill fishery management approach highlights the need for information on whale abundance estimates, spatial distribution by season, krill consumption rates, residency times on the Antarctic feeding grounds, and a deeper understanding of krill swarm preferences.

In discussion, the Working Group considered the importance of obtaining reliable biomass estimates for krill in absolute terms, which would be helpful in modelling trophic interactions and ecosystem function. The Working Group also recognised the potential implications of climate change on krill populations in the Southern Ocean, which could influence food availability for baleen whales, and the urgency of understanding the impacts of climate change on primary production. It was noted that, acoustically-derived krill biomass estimates from recent decades are likely to be an underestimate compared to total krill biomass in the ecosystem. Additionally, historically, whales and other predators were probably consuming far more krill biomass than current krill production estimates. Given the current distribution of the krill fishery, the Working Group noted that the Antarctic Peninsula and the Scotia Arc were priority areas for whale abundance and consumption estimates for use in CCAMLR's revised krill management approach. Furthermore, it was suggested that this issue provides an important opportunity for CCAMLR and IWC to collaborate to incorporate whale distribution, abundance, and krill consumption rates to inform CCAMLR's spatial overlap analysis.

SC/69A/EM/04/Rev1 provided a high-level summary of a new Australian Antarctic Science project titled 'Managing Antarctic Krill and Conserving the Krill-based Ecosystems (KaKE)'. This 10-year project has two main goals: 1) to inform the sustainable and ecosystem-based management of a krill fishery operating in East Antarctica (30°E-150°E); and 2) to quantify the current and projected impacts of climate change on East Antarctica's krill-based ecosystem. A large body of cetacean-focused research has been proposed under this project which aims to assess the spatial and temporal distribution and variability of krill consumption by whales in areas likely to be targeted by an East Antarctic krill fishery. The current project team seeks to develop collaborations with other nations and scientists that conduct research into the Southern Ocean's krill and krill-based ecosystem.

The relationship between krill biomass estimates from surveys in the Southern Ocean and consumption rates of baleen whales are of great interest. Krill biomass, distribution and aggregation (swarm) characteristics are important variables informing ecosystem models. Although no krill biomass studies were presented at SC69A, the Working Group looks forward to receiving the data related to these krill surveys in the near future.

3.3 Multi-species distribution models (MSDMs)

The diversity and complexity of analytical methods used for single species distribution models (SDMs) and multispecies distribution models (MSDMs) continue to increase. To ensure that the Committee can evaluate these types of models to determine whether the model results can be used to provide the Commission with management advice, an Intersessional Correspondence Group was established at SC68C to advance the Committee's work on developing guidelines and possible simulation platforms for SDMs and MSDMs. Due to competing priorities during the intersessional period, limited progress was made towards accomplishing the tasks set forth in the ICG's terms of reference. This work will be continued by an ICG during the upcoming intersessional period.

The Committee **agreed** to continue work under an Intersessional Correspondence Group, with membership of Ferguson (convenor), Kitakado (co-convenor), Palacios (co-convenor), Biuw, Genov, Kelly, Herr, New, Palka, and Solvang. The ICG will proceed with the development of guidelines for analyses, with Terms of Reference as follows:

(1) to finalise the guidelines for single species distribution models (SDMs);

(2) to develop guidelines for multi-species distribution models (MSDMs);

(3) to continue to conduct a literature review of SDMs and MSDMs; and

(4) to develop possible simulation platforms to evaluate SDMs and MSDMs.

3.4 Development of individual-based energetic models (IBEMs)

The Working Group received a report on updates made to individual-based energetic models, including a new mechanism to make the computations easier and more rapid, and the capacity to use the model for different species and populations with different foraging ecology in terms of prey distribution and sea-ice extent. The Committee expressed appreciation for these developments. The Working Group received no papers on this subject for SC69A. However, because IBEMs are of interest to EM and IST, this agenda item will remain open for this year and the Working Group welcomes any papers related to this topic that may become available in the future.

3.5 Effects of long-term environmental variability on whale populations
The issue of variability in baleen whale demographics was last examined at a workshop held in 2010 (IWC, 2011). The question posed was whether MSYR is affected by environmental variability. An Intersessional Working Group was established but no materials have been submitted for review.

The Working Group reiterates the importance of understanding the relationships between MSYR and long-term environmental variability and noted the example of the impact of climate change on krill biomass in the Antarctic (see Atkinson *et al.* 2019). The Working Group acknowledged interest in this subject within the Committee, EM, and other Committee entities. Consequently, the Working Group **agreed** to keep the agenda item open for the next year and seeks, as a high priority, the submission of new papers on this topic for consideration at SC69B.

3.6 Other
The Working Group did not raise any other matters regarding ecosystem modelling for discussion.

4. OTHER MATTERS

The Working Group did not raise and other matters for discussion.

5. PROGRESS ON PREVIOUS RECOMMENDATIONS

See Table 1 (on next page).

6. WORKPLAN

See Table 2 for the workplan and Annex V for the intersessional correspondence groups.

Table 2
Summary of the biennial workplan for the Ecosystem Modelling Working Group.

Item	Intersessional 2022/23	2023 Annual Meeting (SC/69A)	Intersessional 2023/24	2024 Annual Meeting (SC/69B)
Update of any exercises on krill distribution and abundance	Conduct any data analysis	Review results of analyses	Collate and review	Review results of further analyses
Ecosystem modelling in the Southern Ocean and northeast Atlantic Ocean	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses
Cetacean and ecosystem functioning: a gap analysis workshop	Continue analyses and hold 2nd workshop	Review result of analyses and outcomes of workshop	Continue further analyses/discussion	Prepare for a report to the Commission in 2024
Species distribution models (SDMs) and multi-species distribution models (MSDM)	Intersessional Correspondence Group activity	Review progress of Working Group	Intersessional Correspondence Group activity	Review progress of Working Group
Effect of long-term environmental variability on whale populations	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses
Further development of individual-based energetic models (IBEMs)	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses
Modelling of competition among whales and relationship between whales and prey	Continue further analyses	Review results of further analyses	Continue further analyses	Review results of further analyses

7. ADOPTION OF REPORT

The report was adopted on 01 May 2023 at 17:37. The Chairs expressed their sincere appreciation to the rapporteurs, Schubert, Kelly and Ferguson, for their excellent and hard work and thanked the participants for their valuable contributions. The participants thanked the Chairs for their able running of the meetings.

Table 1

Progress on Recommendations.

Number	Text	Type	Year	Species	To be Actioned By	Progress	Last Reviewed	Outcome	Further Action
SC19122	The Committee reaffirms the importance of species distribution models (SDMs) to its work and agrees to re-establish the intersessional correspondence group (Annex T) that is working to develop guidelines for best practices for the application of Species Distribution Models (SDMs).	Workplan action	2019		Working Group on Ecosystem Modelling	Complete	12/02/21	Superseded SC20140, SC21128, SC2269	
SC19123	The Committee reiterates (IWC, 2019a, p.46) the need to hold a Workshop to begin the process of responding the Commission' s Resolution asking for advice on the role of cetaceans in ecosystem functioning. Considerable progress has been made and the workshop will be held in the intersessional period and the report will be submitted to the 2020 meeting of the Committee. The Committee: (1) agrees to the revised Terms of Reference and draft agenda for the workshop provided in Annex L, appendix 2 and the guidance provided in Annex L, appendix 3 including the need to explore conducting analyses for regions outside the Southern Ocean to compare ecosystem function of cetaceans amongst different ecosystems; (2) welcomes the advances made with respect to funding and other logistics; and (3) reinstates the workshop Steering Group under Ritter (Annex T).	Workplan action	2019		Working Group on Ecosystem Modelling	Complete	12/02/21	Superseded SC20139	
SC20139	The Committee reiterates (IWC, 2019b, p.46) the need to hold a Workshop to assist in responding to the Commission Resolution 2016-3 asking for advice on the role of cetaceans in ecosystem functioning. Considerable progress was made towards organising the Workshop, but it had to be postponed due to COVID-19. The Committee recommends that the workshop be held during the next intersessional period and the report submitted to the 2021 meeting of the Committee (SC68C). The Committee re-establishes the Workshop Steering Group under Ritter.	Recommend-ation	2020	Small Ceta-ceans	Scientific Committee	Complete	12/03/21	IWC-CMS workshop held April 19-21 2021. SC/68C/ REP/03	Further workshop planned for Nov. 2023
SC20140	The Committee recognises the importance of multi-species distribution models (MSDMs) to its work on ecosystem modelling and agrees to establish an intersessional corres-pondence group to work towards the future development of guidelines for such models.	Workplan action	2020		Scientific Committee	Complete	12/02/21	Superseded SC21128, SC2269	
SC20142	The Committee reiterates the importance of understanding baleen whale demographics and long-term environmental variability and re-establishes an intersessional corresponding group.	Workplan action	2020	Baleen Whales	Scientific Committee	Complete	12/02/21	Superseded SC211332. ICG established	
SC20141	The Committee recognises the importance of further development of IBEMs to account for competitions among whales and agrees to establish an intersessional correspondence group to facilitate work on modelling competition among whales.	Workplan action	2020		Scientific Committee, Working Group on EM	Complete. The group met virtually Feb 16 2021 prior to SC68C	12/02/21	Superseded SC21131. ICG re-established	
SC21128	The Committee agrees to continue SDM-related work under a new Intersessional Correspondence Group, with the following members: Kitakado (Convenor), Ferguson (co-convenor), Palacios (co-convenor), Biuw, Burkhardt, Friedlaender, Genov, Herr, McKinlay, Miller, Kelly, New and Palka. This group will develop guidelines for analyses, with Terms of Reference as follows: (1) to finalise the guidelines for single species distribution models (SDMs); (2) to conduct a literature review of multi-species distribution models (MSDMs); and (3) to develop possible simulation platforms to evaluate these models.	Workplan action	2021		Working Group on Ecosystem Modelling	Complete	29/07/21	Superseded SC2269. ICG continued	
SC21129	The Committee recognises the importance of multi-species distribution models (MSDMs) to its work on ecosystem modelling and agrees to establish an Intersessional Correspondence Group to work towards the future development of guidelines for such models.	Workplan action	2021		Working Group on Ecosystem Modelling	Complete	29/07/21	Superseded SC2269. ICG continued	

Number	Text	Type	Year	Species	To be Actioned By	Progress	Last Reviewed	Outcome	Further Action
SC21130	The Committee agrees that future efforts should be directed toward making the IBEM easier to use directly, rather than in further refining the emulator. A possible exception is in the conditioning of RMP trials, where the emulator may be useful for the purpose of making operating model parameters more compatible with the current information.	Recommend-ation	2021			Ongoing	29/07/21		
SC21131	The Committee agrees to re-establish the intersessional correspondence group with members Friedlaender (convenor), Biuw, Cooke, de la Mare, Donovan, Kitakado, Palacios and Palka to facilitate this work with new terms of reference: 1) to further develop individual-based energetics models (IBEMs), with emphasis on their application to Southern Hemisphere baleen whale populations and their interaction with krill; 2) find ways to incorporate existing ecological and demographic data; and 3) use the model to infer functional responses for baleen whale feeding on krill.	Workplan action	2021	Baleen Whales	Working Group on Ecosystem Modelling	Ongoing	29/07/21		
SC21132	The Committee reiterates the importance of understanding baleen whale demographics and long-term environmental variability and re-established an intersessional corresponding group led by Cooke (convenor) with membership of Butterworth, Friedlaender, Kitakado, de la Mare, Palacios and Tulloch to conduct a literature review into the effects of climate change and environmental variability on whales and marine ecosystems.	Workplan action	2021	Baleen Whales	Working Group on Ecosystem Modelling	Ongoing	29/07/21		
SC2269	The Committee Recommends continued work under an Intersessional Correspondence Group, with membership of Ferguson (convenor), Kitakado (co-convenor), Palacios (co-convenor), Biuw, Burkhardt, El-Gabbas, Friedlaender, Genov, Herr, McKinlay, Miller, Kelly, New, Palka and Solvang, for future development of guidelines for analyses, with Terms of Reference as follows: (1) to finalise the guidelines for single species distribution models (SDMs); (2) to develop guidelines for multi-species distribution models (MSDMs); (3) to continue to conduct a literature review of SDMs and MSDMs; and (4) to develop possible simulation platforms to evaluate SDMs and MSDMs.	Recommend-ation	2022		Scientific Committee	Ongoing	25/10/22		

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Appendix 1

AGENDA

1. Introductory items
   1.1 Opening remarks
   1.2 Election of the Chair
   1.3 Appointment of rapporteurs
   1.4 Adoption of agenda
   1.5 Documents available
2. Preparation of workshop on the role of cetaceans in ecosystem functioning: gap analysis
   2.1 Review previous Committee discussions on contribution of whales to ecosystem functioning
   2.2 Review progress on estimating pre-exploitation and current abundance of large whale populations
   2.3 Ecosystem modelling in the Antarctic Ocean and northeast Atlantic Ocean
   2.4 Updates from the Conservation Committee WG
   2.5 Review of terms of reference
   2.6 Discuss plans for upcoming workshop scheduled for November 2023
3. Review issues relevant to ecosystem modelling within the Committee
   3.1 Modelling of competition among whales and relationships between whales and prey
   3.2 Krill distribution and abundance
   3.3 Multi-species distribution models (MSDMs)
   3.4 Development of individual-based energetic models (IBEMs)
   3.5 Effects of long-term environmental variability on whale populations
   3.6 Other
4. Other matters
5. Progress on previous recommendations
6. Workplan
7. Adoption of report

Appendix 2

THE EXISTING ESTIMATES OF PRE-EXPLOITATION AND CURRENT ABUNDANCES OF WHALE POPULATIONS IN THE SOUTHERN OCEAN

N. Moosa and D.S. Butterworth

The average of the male and female whale mean mass from Trites and Pauly (1998) are used to determine an average mass (mt) for the large baleen whales considered (Table 1).

Table 1 lists the average body weights for the large baleen whale species considered.

Table 1

Average body weights for large baleen whale species considered.

Whale species	Average body weight (mt)
Antarctic blue (*B. musculus*)	102.74
Fin (*B. physalus*)	55.59
Humpback (*M. novaeangliae*)	30.41
Antarctic minke (*B. acutorostrata*)	6.57

More information regarding these quantities can be found in Moosa (2017) and Moosa and Butterworth (2017).

The whale biomass (B) in metric tonnes is calculated using Equation 1 as follows:

$$B = w \times N_y \tag{1}$$

where

w is the average weight (mt) of the large baleen whale species considered (see Table 1); and

N_y is the abundance in year y of the large baleen whale species considered.

Table 2

Revised table – whale biomass estimates have been included for the large baleen whales considered, where applicable.

Whale species	Historical (1780/81)	Current (2014/15)	Ratio	Historical Biomass (1780/81) $\times 10^6$ (mt)	Current Biomass (2014/15) $\times 10^6$ (mt)
Moosa (2017)					
Antarctic blue (*B. musculus*)	198,805	5,140	0.0259	20.4252	0.5281
Fin (*B. physalus*)	321,032	52,278	0.1628	17.8462	2.9061
Humpback (*M. novaeangliae*)	117,722	98,999	0.8410	3.5799	3.0106
Antarctic minke (*B. acutorostrata*)	368,442	573,252	1.5559	2.4207	3.7763
Total	**1,006,001**	**729,669**	**0.7253**	**44**	**10 (Ratio: 0.2306)**
Whale species	Historical (1890)	Current (2014/15)	Ratio	Historical Biomass (1890) $\times 10^6$ (mt)	Current Biomass (2014/15) $\times 10^6$ (mt)
Tulloch *et al.* (unpub) – incl. climate drivers					
Antarctic blue (*B. musculus*)	236,203	4,940	0.0209	24.2675	0.5075
Fin (*B. physalus*)	464,797	53,973	0.1161	25.8381	3.0004
Humpback (*M. novaeangliae*)	144,920	108,941	0.7517	4.4070	3.3129
Antarctic minke (*B. acutorostrata*)	215,193	601,501	2.7952	1.4138	3.9519
Southern right (*E. australis*)	1,045		10.4967	-	-
Southern right (*E. australis*), pre-1800	143,748	10,969	0.0763	-	-
Total (w/out right whales)	**1,061,113**	**769,335**	**0.7250**	**56**	**11 (Ratio: 0.1926)**
Total (with right whales)	**1,205,906**	**780,324**	**0.6471**	**-**	**-**

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Appendix 3

BIOMASS AND FAECAL CARBON EFFLUX BASED ON ESTIMATED PRE-EXPLOITATION AND CURRENT ABUNDANCE OF KEY WHALE POPULATIONS IN THE NORTHEAST ATLANTIC

Martin Biuw

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This brief document is an addendum to papers discussed during the Ecosystem Modelling sub-committee sessions at the IWC-SC meeting in Bled, April-May 2023. Here we provide a table of estimated pre-exploitation and current biomass of key cetaceans in the Northeast Atlantic, based on abundance estimates and average body masses used by Skern-Mauritzen *et al.* (2022). This table also contain estimated annual carbon content of faeces, estimated using methods initially presented in one of the keynote papers at the 2021 Ecosystem Functioning workshop. The pre-exploitation abundance estimates used here are those of Christensen (2006). These are subject to change as more updated estimates have been included, following recommendations received during the 2023 IWC-SC meeting.

As can be seen in Table 1, estimated pre-exploitation biomasses ranged from 0.18 megatonnes for sei whales to 7.2 megatonnes for bowhead whales, while current biomasses ranged from 0.027 megatonnes for bowhead whales to 2.4 megatonnes for fin whales. These biomasses translates to estimated biomass ratios of 0.0038 for bowhead whales to 1.4 for humpback whales (ratio in total biomass = 0.312).

Table 1

Estimates pre-exploitation and current total biomass and amounts of annual carbon output from faeces.

		Biomass (Megatonnes)			Faecal carbon (tonnes)	
Species	Body mass (tonnes)	Pre-exploitation	Current	Ratio	Pre-exploitation	Current
Blue	100	0.72	0.26	0.36	7,206	2,601
Bowhead	80	7.2	0.027	0.0038	72,287	273
Fin	55	4.1	2.4	0.58	41,391	23,832
Humpback	30	0.48	0.69	1.4	4,846	6,940
Minke	6.6	1.4	0.95	0.68	13,994	9,537
Sei	17	0.18	0.074	0.42	1,774	741
Total		**14.08**	**4.401**	**0.312**	**141,498**	**43,924**

Table 2

Estimates of current and pre-exploitation abundance for key large cetaceans in the Northeast Atlantic north of 60°N. Current estimates are taken from Skern-Mauritzen *et al.* (2022), while pre-exploitation estimates are taken from Christensen (2006) and Smith *et al.* (2019). Sources and references for individual estimates can be found in Supplementary Tables 1-3 for that paper.

			Pre-exploitation				
	Current		Christensen (2006)	Smith *et al.* (2019)		Ratios	
Species	Mean	CV	Mean	95%CI	Mean	Christensen (2006)	Smith *et al.* (2019)
Blue whales	2,650	0.39	7,430	5,920-8,480	7,500	0.357	0.353
Bowhead whales	346	-	89,000	67,000-114,000	80, 000	0.004	0.004
Fin whales	42,950	0.14	72,900	54,900-111,000	73,000	0.589	0.588
Humpback whales	22,894	0.35	16,200	11,300-33,300	112,000	1.413	0.204
Minke whales	144,224	0.15	211,000	159,000-284,000	211,000	0.684	0.684
Sei whales	4,300	-	10,600	7,420-18,800	10,600	0.406	0.406
Sperm whales	7,786	0.35			367,000		0.021

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Appendix 4

A CRITICAL EVALUATION OF WHALES AS ECOSYSTEM ENGINEERS - METHODS DESCRIPTION

Paul Wassmann, Tore Haug and Martin Biuw

This appendix describes the approach taken when estimating the role of whales in the carbon cycle of the Barents Sea marine ecosystem. The approach closely follows that of Smith *et al*. (2015) in terms of estimating marine mammal biomass and prey consumption based on the most recent estimates of abundance, residence time and body mass for the species in question. While Smith *et al*. (2015) focussed on the Northeast US continental shelf, the same approach is used in a comprehensive analysis to estimate prey consumption of marine mammals in the Northeast Atlantic (Skern-Mauritzen *et al*., 2022). We have taken the estimates from (Skern-Mauritzen *et al*., 2022) as input in our analyses.

Marine mammal abundance and estimated prey consumption in the Barents Sea

Skern-Mauritzen *et al*. (2022) consider 21 marine mammal species that inhabit the Northeast Atlantic, of which 18 are known to be present in the Barents sea either seasonally or permanently. Of these, 7 are pinnipeds, while 14 are cetaceans. Here we consider only large whales, including blue, fin, sei, humpback, sperm, minke and bowhead whales.

Due to limited knowledge on consumption rates or energy requirements for many species included in this study, we follow Skern-Mauritzen *et al*. (2022) and base our estimations on the generalized form of the Kleiber equation that scales average daily consumption C to body mass M:

$$C = \alpha M^{\beta}$$

where α and β are species- or taxon-specific parameters (Kleiber 1932, Leaper and Lavigne 2007). Skern-Mauritzen *et al*. (2022) generally use parameters suggested by Smith *et al*. (2015) in their thorough evaluation, but exclude those that resulted in unrealistic estimates of consumption rates. For each taxonomic group (pinnipeds, odontocetes and mysticetes), several different parameterizations were available, and are presented in supplementary Table S2 in Skern-Mauritzen *et al*. (2022). Uncertainty estimates for consumption were obtained by Skern-Mauritzen *et al*. (2022) by running 1,000 Monte Carlo simulations for each species, where a different α/β parameter pair was randomly selected from the available parameter pairs for that taxonomic group.

Table 1

Abundance (mean & CV), average body mass (kg) residence time (days) of large whales in the Barents Sea, and their estimated prey consumption (median and 95% confidence limits).

Species	Abundance	Body mass (kg)	Residence time (d)	Consumption (x 1000 T)
Blue	100 (0.5)	100,000	180	23.9 (8, 50.8)
Fin	4,506 (0.54)	55,500	180	691.9 (217.4, 1,510.1)
Sei	0 (0)	17,000	0	0 (0, 0)
Humpback	8,563 (0.81)	30,400	180	953.3 (223.6, 2,391.8)
Sperm	806 (0.71)	40,000	150	58.4 (10.3, 157.7)
Minke	47,295 (0.3)	6,600	180	1,665.5 (742.4, 3,082.6)
Bowhead	173 (0.49)	80,000	365	63.2 (23.7, 131.5)

Carbon content of total prey consumption and in faeces

To estimate the role of large whales in the Barents Sea carbon cycle based on the estimated prey consumption presented in Table 1, we use estimates from Lavery *et al.* (2014). We assume a dry weight equal to 20% of total consumption, whereof 50% is assumed to represent carbon, i.e. a prey carbon content of 10%. Further, we assume an assimilation rate of 90% of dry weight. This means that 10% of the ingested dry weight will be excreted in the feces, representing 2% of the total biomass consumed. Assuming 50% of this dry weight is carbon leads to fecal carbon content representing 1% of the total ingested prey biomass. Therefore, dividing the prey consumption estimates in Table 1 by 100 gives us an estimate of the amount of carbon released by large whales annually in the Barents Sea (Table 2).

Table 2

Total prey consumption, dietary dry weight, dietary carbon content, fecal dry weight and fecal carbon content. All are expressed in 1,000 tonnes.

Species	Prey consumption	Prey dry weight	Prey carbon	Fecal dry weight	Fecal carbon
Blue	23.9 (8, 50.8)	4.78 (1.6, 10.16)	2.39 (0.8, 5.08)	0.48 (0.16, 1.02)	0.24 (0.08, 0.51)
Fin	691.9 (217.4, 1,510.1)	138.38 (43.48, 302.02)	69.19 (21.74, 151.01)	13.84 (4.35, 30.2)	6.92 (2.17, 15.1)
Sei	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)
Humpback	953.3 (223.6, 2,391.8)	190.66 (44.72, 478.36)	95.33 (22.36, 239.18)	19.07 (4.47, 47.84)	9.53 (2.24, 23.92)
Sperm	58.4 (10.3, 157.7)	11.68 (2.06, 31.54)	5.84 (1.03, 15.77)	1.17 (0.21, 3.15)	0.58 (0.1, 1.58)
Minke	1,665.5 (742.4, 3,082.6)	333.1 (148.48, 616.52)	166.55 (74.24, 308.26)	33.31 (14.85, 61.65)	16.66 (7.42, 30.83)
Bowhead	63.2 (23.7, 131.5)	12.64 (4.74, 26.3)	6.32 (2.37, 13.15)	1.26 (0.47, 2.63)	0.63 (0.24, 1.32)

Global whale biomass and 'whale falls'

To estimate both historical and current carbon contribution of whale falls into the deep ocean, we use abundance estimates from Christensen (2006). To estimate biomass, we simulate 1000 population sizes, based on mean and CVs presented in Table 1. In each of these simulated populations, we randomly assign a body mass for each individual, using body masses in Table 1 and a common CV of 0.2. Note that in terms of body size, we assume all individuals are adults. We then calculate the total biomass for each of the simulated populations. We then estimate the number of whales dying annually, assuming that 20% of the population are calves and that annual mortality rates are 0.1 and 0.03 for calves and adults respectively. Note that, while we assume different mortality rates for calves and adults, we do not model entire population demographics in this simple example. Summary statistics across these simulated populations are presented in Tables 3 (pre-whaling) and 4 (current).

Table 3

Estimated pre-whaling total biomass and biomass contained in animals dying during one year, expressed in 1,000 tonnes.
NA = North Atlantic, NP = North Pacific, SH = Southern Hemisphere.

Species	Basin	N	Biomass	N Dead	Dead biomass
Bowhead	Arctic	89,063 (0.13)	7,125 (5,350, 8,900)	3,919 (0.13)	314 (235, 392)
Sperm	Global	957,949 (0.11)	38,318 (29,909, 46,727)	42,150 (0.11)	1,686 (1,316, 2,056)
Sei	NA	10,515 (0.15)	179 (125, 232)	463 (0.15)	8 (6, 10)
Fin	NA	72,591 (0.13)	4,029 (3,020, 5,037)	3,194 (0.13)	177 (133, 222)
Blue	NA	7,409 (0.1)	741 (593, 889)	326 (0.1)	33 (26, 39)
Humpback	NA	16,105 (0.16)	490 (340, 639)	709 (0.16)	22 (15, 28)
Minke	NA	211,032 (0.13)	1,393 (1,037, 1,749)	9,285 (0.13)	61 (46, 77)
Right whale (N Atl.)	NA	14,091 (0.14)	1,198 (862, 1,533)	620 (0.14)	53 (38, 67)
Right whale (N Pac.)	NP	14,248 (0.15)	1,211 (859, 1,563)	627 (0.15)	53 (38, 69)
Sei	NP	68,253 (0.1)	1,160 (931, 1,389)	3,003 (0.1)	51 (41, 61)
Fin	NP	64,624 (0.12)	3,587 (2,741, 4,432)	2,843 (0.12)	158 (121, 195)
Grey	NP	21,220 (0.06)	849 (749, 949)	934 (0.06)	37 (33, 42)
Blue	NP	5,856 (0.11)	586 (457, 714)	258 (0.11)	26 (20, 31)
Bryde's	NP	52,505 (0.1)	2,100 (1,677, 2,523)	2,310 (0.1)	92 (74, 111)
Humpback	NP	16,373 (0.19)	498 (316, 680)	720 (0.19)	22 (14, 30)
Minke	NP	47,112 (0.12)	311 (241, 381)	2,073 (0.12)	14 (11, 17)
Sei	SH	166,911 (0.03)	2,837 (2,667, 3,008)	7,344 (0.03)	125 (117, 132)
Southern right	SH	85,849 (0.07)	7,297 (6,243, 8,352)	3,777 (0.07)	321 (275, 367)
Fin	SH	630,116 (0.13)	34,972 (26,343, 43,601)	27,725 (0.13)	1,539 (1,159, 1,918)
Blue	SH	326,762 (0.05)	32,676 (29,726, 35,626)	14,378 (0.05)	1,438 (1,308, 1,567)
Bryde's	SH	93,148 (0.13)	3,726 (2,775, 4,677)	4,099 (0.13)	164 (122, 206)
Humpback	SH	200,682 (0.15)	6,101 (4,354, 7,847)	8,830 (0.15)	268 (192, 345)
Minke	SH	380,484 (0.11)	2,511 (1,993, 3,030)	16,741 (0.11)	110 (88, 133)

Table 4

Estimated current (2001) total biomass and biomass contained in animals dying during one year, expressed in 1,000 tonnes. NA = North Atlantic, NP = North Pacific, SH = Southern Hemisphere.

Species	Basin	N	Biomass	N Dead	Dead biomass
Bowhead	Arctic	9,450 (0.11)	756 (600, 912)	416 (0.11)	33 (26, 40)
Sperm	Global	375,269 (0.11)	15,011 (11,870, 18,151)	16,512 (0.11)	660 (522, 799)
Sei	NA	6,892 (0.12)	117 (89, 145)	303 (0.12)	5 (4, 6)
Fin	NA	56,112 (0.13)	3,114 (2,344, 3,884)	2,469 (0.13)	137 (103, 171)
Blue	NA	367 (0.15)	37 (26, 47)	16 (0.15)	2 (1, 2)
Humpback	NA	12,367 (0.1)	376 (300, 452)	544 (0.1)	17 (13, 20)
Minke	NA	155,740 (0.13)	1,028 (773, 1,283)	6,853 (0.13)	45 (34, 56)
Right whale (N Atl.)	NA	368 (0.16)	31 (22, 41)	16 (0.16)	1 (1, 2)
Right whale (N Pac.)	NP	369 (0.15)	31 (22, 41)	16 (0.16)	1 (1, 2)
Sei	NP	14,795 (0.23)	252 (137, 366)	651 (0.23)	11 (6, 16)
Fin	NP	30,568 (0.31)	1,696 (650, 2,743)	1,345 (0.31)	75 (29, 121)
Grey	NP	15,800 (0.04)	632 (587, 677)	695 (0.04)	28 (26, 30)
Blue	NP	3,172 (0.16)	317 (220, 414)	140 (0.16)	14 (10, 18)
Bryde's	NP	40,951 (0.13)	1,638 (1,228, 2,048)	1,802 (0.13)	72 (54, 90)
Humpback	NP	7,184 (0.13)	218 (161, 276)	316 (0.13)	10 (7, 12)
Minke	NP	31,946 (0.12)	211 (160, 262)	1,406 (0.12)	9 (7, 12)
Sei	SH	27,406 (0.24)	466 (245, 687)	1,206 (0.24)	20 (11, 30)
Southern right	SH	66,177 (0.47)	5,625 (404, 10,846)	2,912 (0.47)	247 (18, 477)
Fin	SH	23,526 (0.2)	1,306 (800, 1,812)	1,035 (0.2)	57 (35, 80)
Blue	SH	1,185 (0.13)	118 (88, 149)	52 (0.13)	5 (4, 7)
Bryde's	SH	90,861 (0.14)	3,634 (2,618, 4,651)	3,998 (0.14)	160 (115, 205)
Humpback	SH	22,492 (0.14)	684 (499, 869)	990 (0.14)	30 (22, 38)
Minke	SH	318,752 (0.11)	2,104 (1,655, 2,552)	14,025 (0.11)	93 (73, 112)

The estimated total global biomass of great whales prior to industrial whaling is estimated to 153.9 (95% CI: 123.3 - 184.5) million tonnes. The biomass for whales dying annually is estimated to 6.77 (95% CI: 5.43 - 8.12) million tonnes.

The equivalent numbers for estimated 2001 populations are 39.4 (95% CI: 25.5-53.3) million tonnes of live biomass and 1.73 (95% CI: 1.12-2.35) million tonnes of estimated dead biomass.

Assuming the same ratios of wet to dry weight and carbon content of dry matter as above, these estimates translate to 677,121 (95% CI: 542,529-811,713) tonnes of carbon per year contained in dead whales during pre-whaling times, and 173,373 (95% CI: 112,148-234,598) tonnes of carbon per year contained in dead whales using the 2001 estimates from Christensen (2006).

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Appendix 5

CLARIFICATIONS ON PAPER SC/69A/EM/02REV2 REGARDING THE SPECIES CANDIDATES FOR THE PILOT PROJECT TO ASSESS THE SOCIO-ECONOMIC VALUES OF ECOSYSTEM SERVICES OF CETACEANS

Barbara Galletti

From a socio-economic perspective, ecosystem services are different from ecosystem functions. Ecosystem functions (e.g., carbon sequestration, nutrient transport and cycling, role as predator or prey) cannot be valued in an economic sense unless they provide a service to humans. In the case of cetaceans, while there is an intrinsic value in a whale independent of any services the animal may provide to humans, we are focused on the direct, utilitarian, or so-called instrumental value of a cetaceans or group of cetaceans. Based on existing data and knowledge, only a fraction of the ecosystem functions provided by cetaceans (e.g., carbon sequestration) have a utilitarian value to humans that can be assessed using traditional economic tools.

Development of Terms of Reference (ToR) and a tender for a pilot project to assess the socio-economic values of a single (or set of) species or populations of cetaceans to humans is in response to direction provided by the Commission at IWC68. The pilot project is not intended to assess the full value of the target species, population, or assemblage of species but, rather, it is intended to merely provide a representation of what services have utilitarian value to humans, how that value is assessed, the extent of that value, how the value can change over time (e.g., as populations increase or decrease), and what data would be needed to fully assess the utilitarian value of other services (e.g., the whale pump and its impact on fish production). As a pilot project, there is a need to limit the number of services to be valued with the intention of using the results as a framework to advance future socio-economic analyses. Consequently, the ToR needs to be simple and focus on one or few species or populations for which relevant data is available to assess their utilitarian value.

Therefore, it is envisaged that the pilot project should at a minimum: (1) focus on developing accurate estimates of the utilitarian value (including a sensitivity analysis) of the services provided by the target species, species assemblage, or population for which data is available; (2) define the methodology or methodologies available to assess such value; and (3) develop a research and modelling framework that will guide future work including to identify and broadly assess the potential utilitarian value of other services that, at present, cannot be explicitly valued due to a lack of data.

The matrix on table 1 in SC/69A/EM/02rev2 is for information only to show all candidate species/populations that were received in response to a survey distributed to the participants in the first Scientific Committee workshop on cetaceans and ecosystem functions. Not all of cetacean species/populations have sufficient information to warrant their selection for assessment in the pilot project. For example, rigorous and agreed abundance estimates are a cornerstone of any socio-economic valuation exercise.

Therefore, a preliminary assessment of these species/populations that could be assessed in the pilot project include:

(1) the North Pacific Humpback whale;
(2) the Southern Ocean species assemblage (blue, fin, humpback and minke whale); and
(3) the Southwest Atlantic Southern right whales.

The Northeast Atlantic species were not proposed in response to the survey but they may also be considered as potential candidates due to the work undertaken by the EM. Small cetaceans were not considered due to lack of data/information available at this time to assess their utilitarian value but may be candidates for future analyses if such data becomes available.

To better understand the possible extent of the pilot project work, the preliminary table below provides an overview of the links between ecosystem services with ecosystem functions and associated whale data. This table is depicting the different topics involved, however the economic models and data used will be ultimately defined by the consultants.

Ecosystem service	Ecosystem function	Potential whale data used*	Socio-economics models
Carbon sequestration and climate regulation	Biomass (body and carcasses)	Body mass, carcass sinking to deep-sea floor, mortality rate, life span, reproduction rate	Direct (for any species)
Carbon sequestration and climate regulation	Whale Pump (increase of carbon sequestration through phytoplankton)	Macronutrients in whale feces, excretion rate, iron content in feces, consumption rate	Indirect (need phytoplankton scenarios)
Nutrient cycling (ocean fertilization)	Whale pump (increase of fisheries through phytoplankton)	Macronutrients in whale feces, excretion rate, iron content in feces, consumption rate	Indirect (need increase of fisheries scenarios)

*All models need population estimates, and to estimate NPV cash flows are needed and therefore data on trend in abundance may be preferred. If there would be required to compare pre-exploitation levels to current estimates, pre-exploitation levels will also be needed.

The IWC Conservation Committee Advisory Group on the Socio-Economic Value of Cetaceans is seeking input from the Scientific Committee on which candidate species/populations are warranted for assessment in the pilot project.

Appendix 6

2ND IWC-CMS WORKSHOP ON CETACEAN ECOSYSTEM FUNCTIONING

DATE AND PLACE
Date: Nov 14-16, 2023

Place: CMS (Bonn, Germany)

TERMS OF REFERENCE (from previous EM reports, when discussing about workshop plan before 2021 workshop)

(1) The workshop will review existing scientific information through:

1a) receive a review relevant scientific studies, on the contribution of cetaceans to ecosystem functioning (will be accomplished in advance of the workshop/meeting through contract, results to be presented at workshop/meeting); and

1b) receive presentations from selected experts on their research into how cetaceans affect ecosystem functions;

(2) An assessment of what can realistically and reliably be quantified currently.

(3) Identification of potential geographical areas and species/taxa on which to focus.

(4) Identify knowledge gaps as well as data gaps in our understanding of cetaceans and their impact and role in ecosystem functioning.

(5) Develop a prioritized list of recommendations for scientific research to fill identified knowledge gaps, including studies on methodological approaches to study how cetaceans affect ecosystem functioning.

FOCUSED TASKS IN THE 2ND WORKSHOP

- Quantification of spatial difference in ecosystem functioning of cetaceans, with focusing on link with environments and regional ecosystem characteristics? (historical trends in different places…)
- Quantification of temporal changes in ecosystem functioning of cetaceans, with focus on difference between pre-whaling and current populations and identification of information and knowledge gaps

STEERING MEMBERS (To be confirmed later)
IWC: Biuw, Butterworth, Donovan, Double, Ferguson, Freitas, Galletti, Kitakado (co-Convenor), Lindstrom, Punt, Ritter, Schubert (organizing Convenor), Stainland, Zerbini, Webster

CMS: Renell (more to come, TBD)

IP: Roman (more to come, TBD)

DRAFT WORKSHOP AGENDA

1. Introductory items
   - 1.1 Welcoming remarks
   - 1.2 Election of Chairs
   - 1.3 Appointment of rapporteurs
   - 1.4 Adoption of Agenda
   - 1.5 Review of documents
2. Review of the terms of reference
3. Background materials
   - 3.1 Summary of Commission Resolutions and discussions (Resolutions 2016-3 and 2018-2)
   - 3.2 Summary of outcomes of 1st IWC-CMS Workshop on cetacean and ecosystem functioning (in April 2021)
   - 3.3 Summary of outcomes of IWC Conservation Committee workshop on socio-economic values of the contribution of cetaceans to the ecosystem functioning (in April 2022)
4. Key steps for quantifying of roles of ecosystem functioning
   - 4.1 Identify ecosystem functioning processes and associated metrics*
   - 4.2 Develop conceptual models, including target species, regions, and critical parameters needed to estimate the ecosystem functioning metrics in the past and during the present time
     - 4.2.1 Proposed regions
       - 4.2.1.1 Southern Ocean
       - 4.2.1.2 North Atlantic Ocean
       - 4.2.1.3 Other regions (TBD, by correspondence)

4.2.2 Review and discuss existing ecosystem models for the proposed regions, including strengths, weaknesses, and next steps

4.3 Identify data and analytical methods needed to estimate critical parameters

4.4 If possible, evaluate likely sensitivity of ecosystem functioning model results to critical parameters

4.5 If possible, evaluate the likelihood of resolving the uncertainty in critical parameters within a reasonable timeframe so that they can be used for this round of modelling

*Annotations: Processes that have been identified as priorities for this round of ecosystem functioning modelling include: nutrient circulation and ocean fertilization; carbon sequestration; and whale falls. The workshop will discuss and further refine this list of focal processes.

5. Other items *

*Annotations: The workshop will be attended by one or more ecological economists, who will provide input throughout the workshop discussions on how the results from the IWC SC ecosystem functioning modeling might be used to further the development of the IWC CC pilot project investigating ecosystem services.

6. Summary and research needs
    6.1 Current conclusions
    6.2 Prioritising research
7. Recommendations to the SC
8. Adoption of reports

Rough timeline till next SC through the Workshop

Task	Responsible party	Deadline
Select Workshop IPs and send invitation	Steering group	By the end of July 2023
Share any documents	IPs and Steering group	By the end of September 2023
Share any presentation files	IPs and Steering group	By the end of October 2023
Hold the 2nd workshop (14-16 Nov 2023)		
Finalise the Workshop report and submit the report to the SC	Workshop participants, then finalised by Steering group	By mid December 2023
Discuss and endorse (?) the report at SC69B	SC	April-May, 2024