**Report of the Working Group on**
**Ecosystem Monitoring and Management**
(Concarneau, France, 24 June to 5 July 2019)

## Contents

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## Introduction

### Opening of the meeting

1.1 The 2019 meeting of WG-EMM was held at the Concarneau Marine Station in Concarneau, Finistère, France, from 24 June to 5 July 2019. The meeting was convened by Dr C. Cárdenas (Chile) who welcomed participants (Appendix A). The meeting was hosted by the Muséum national d'Histoire naturelle (MNHN) and Dr M. Eléaume (Curator of Echinoderms, MNHN and Scientific Committee Representative for France) welcomed all participants to the Marine Station and to Concarneau.

### Adoption of the agenda and appointment of rapporteurs, proposed schedule for the meeting

1.2 Dr Cárdenas outlined the priority work for the Working Group meeting highlighting that the Scientific Committee (SC-CAMLR-XXXVII, paragraphs 13.1 to 13.3) and the Commission (CCAMLR-XXXVII, paragraphs 5.9 and 5.10) had provided very clear guidance in 2018. He emphasised that the Scientific Committee had identified that a priority item of work to be considered by WG-EMM in 2019 would be the development of advice for management of krill resources to advise the review of Conservation Measure (CM) 51-07. Furthermore, the Commission had requested that the Scientific Committee make the development of a preferred option for the management of krill in Area 48 a priority in 2019 and provide clear advice for consideration by CCAMLR-38.

1.3 The Working Group reviewed the provisional agenda (Appendix B) and the documents that had been submitted for consideration to the meeting (Appendix C). In order to streamline the work of the meeting, the agenda item(s) under which some papers were to be considered were revised, and the agenda was adopted.

1.4 In this report, paragraphs that provide advice to the Scientific Committee and its other working groups have been indicated in grey. A summary of these paragraphs is provided in Item 10.

1.5 The report was prepared by M. Belchier (UK), O.A. Bergstad (Norway), T. Brey (Germany), M. Eléaume (France), S. Fielding (UK), E. Grilly (Secretariat), S. Grant and S. Hill (UK), J. Hinke (USA), S. Kawaguchi (Australia), D. Krause (USA), A. Lowther and G. Macaulay (Norway), K. Reid (Secretariat), G. Robson (UK), M. Santos (Argentina), E. Seyboth (Brazil), D. Welsford (Australia) and X. Zhao (China).

## Focus topic on krill fishery management

2.1 The Working Group welcomed the preliminary report of the Workshop on Krill-fishery Management for Subareas 48.1 and 48.2 (WG-EMM-2019/25 Rev. 1). The aim of the

Workshop was to discuss harmonising management strategies (e.g. risk assessment, feedback management (FBM), marine protected areas (MPAs)) for the krill fishery. Multiple Members, industry and non-governmental organisation (NGO) representatives participated. The primary output from the Workshop was a collective vision statement for the future of the krill fishery, which was developed from vision statements for four constituent parts (the marine ecosystem, krill harvesting, scientific knowledge and human interactions). The Workshop further identified several ‘big changes’ and ‘actions’ that would be necessary to achieve the overall vision and constituent vision elements. A full report from the Workshop will be provided to the Scientific Committee this year.

2.2 The Working Group endorsed the vision statements in the Workshop report. The Working Group further recommended that the Scientific Committee consider three of the main recommendations from the Workshop, including:

(i) the development of a krill stock assessment was an urgent priority to achieve the objective of the Convention

(ii) the development of the proposed Domain 1 MPA (D1MPA) and FBM strategies for the krill fishery could be progressed independently

(iii) the need to support and improve working collaborations among Members.

In particular, the Working Group noted the discussions of the Workshop on the need to develop a strategy to better fund and share the burden for research needed to manage the krill fishery.

2.3 The Working Group noted WG-EMM-2019/11, an updated analysis first presented in WG-EMM-16/45. The paper demonstrated that appropriate matching of spatio–temporal scales over which forage species, their predators and fisheries interact, can aid the assessment of fishery impacts on dependent predators. Results indicated that local harvest rates $\geq 0.1$ and future climate warming led to a 0.77 probability of future penguin performance being below its long-term average. The paper concluded that catch limits that are considered precautionary for forage species such as krill, mainly because the limits are small proportions of the species’ standing biomass, may not be precautionary for their predators, and that krill fishery impacts on penguin performance are evident.

2.4 The Working Group agreed that further monitoring would help to reduce uncertainties highlighted in the analysis presented in WG-EMM-2019/11. In particular, the Working Group noted that high local harvest rates during the winter season were associated with decreased penguin performance, but the relationship between krill biomass and penguin performance was less clear. Continued collection of data on local krill biomass, particularly during winter, and foraging distributions of underrepresented demographic groups (e.g. juvenile and fledgling penguins), would be useful to extend our understanding of fishing impacts on predators.

2.5 The Working Group discussed how research on the characteristics of swarms that are targeted by foraging predators and on how fishing activity affects krill swarm structure or distribution could provide a useful means to further understand how fishing impacts dependent predators. The co-existence of several krill-dependent predator species, for example, implies niche partitioning that might be related to krill swarm structure and distributions. It was noted that the natural spatial and temporal variability in the distribution of krill swarms on multiple scales would need to be considered to understand how fishing effects on krill swarm structure would affect predators.

2.6 The Working Group recalled the recent trend for increasing krill catch levels in some fishing hotspots. The Working Group noted that the increasing concentration of catch in space and time, particularly when it leads to high local harvest rates, is likely to erode the level of precaution intended by CM 51-07. The Working Group noted that possible impacts of this trend should be evaluated and recommended that Members study the mechanisms that may cause fishing fleet concentration in some fishing hotspots.

2.7 The Working Group recalled the analyses of krill abundance indices in the main fishing hotspot in the Bransfield Strait (WG-EMM-17/40, 17/41, 18/41), which indicated that both krill acoustic density and catch-per-unit-effort (CPUE) either remain stable through the fishing season in some years or increased towards the closure of the krill fishery in other years. It encouraged further analyses of this type to be considered as the krill fishery management strategy is refined.

2.8 The Working Group noted WG-EMM-2019/28 and 2019/29. Taken together, the papers urge the development of a krill stock assessment because fishing patterns, krill numerical density, demographic structure, distribution and availability to predators, and climate variables differ from when current fisheries management was implemented. The papers expressed that the need for precaution is likely to be greater now than when the trigger level was established and suggested that the Working Group should progress stock assessment methods to provide the advice requested in the terms of reference of the Working Group. They emphasised that considerable uncertainty will be associated with any assessment of the status of the krill stock, and therefore that there is a need for continued precaution. The papers argued that CM 51-07 should be retained while such methods are developed.

2.9 The Working Group noted that the scale and frequency of risk assessment and stock assessment are key considerations in advancing a management strategy for the krill fishery. The Working Group agreed that multi-scale approaches that range from large-scale synoptic surveys of Area 48 (Subareas 48.1 to 48.4) to sub-subarea were likely to yield information necessary to advance a management strategy.

2.10 The Working Group cautioned that while real-time measurement of krill biomass might be an ideal solution to help manage the fishery to avoid unanticipated increases in local harvest rates, precautionary approaches that consider historical envelopes of variability of krill biomass may be more readily achieved. Such precautionary approaches may lend enhanced protection to predators and add stability to a management strategy for the krill fishery by reducing the frequency of adjustments to catch allocations. The Working Group noted that historical and ongoing time series of krill biomass, available within most subareas, can provide such estimates to help maintain the desired level of precaution.

2.11 The Working Group considered WG-EMM-2019/18 submitted by Norwegian, Chinese and Chilean colleagues who presented it as a response to the Scientific Committee's encouragement to achieve coordination among the various approaches towards developing a practical FBM approach (SC-CAMLR-XXXVI, paragraph 3.23). Following on from the FBM approach that was presented by Norway, Chile and China to the Scientific Committee in 2017 (SC-CAMLR-XXXVI/BG/20), the paper provided a framework and way forward for incorporating aspects of each currently tabled approach, including risk assessments, experimental fishing, decision rule approaches and the FBM approach proposed in 2017. The aim set out in WG-EMM-2019/18 was a comprehensive solution that could be operationalised within reasonable time in relation to the expectations under CM 51-07.

2.12 The Working Group welcomed the efforts to bring together previously considered elements of krill fishery management approaches (WG-EMM-15/10, 16/45 to 16/48 and 16/69). The Working Group noted that a simple approach to a future krill fisheries management strategy would facilitate near-term implementation. The proposed strategy has essential requirements, among others, for a krill stock assessment, predator data to inform a risk assessment, and information on fishery dynamics. Six action points were identified from this strategy that were required to be addressed in order to provide advice to the Scientific Committee in line with the expectations of CM 51-07 (Table 1). The Working Group agreed that sufficient data from these components are available to make progress on addressing them in the near term.

2.13 The Working Group noted that the development of the management strategy is an ongoing process and that some datasets remain desirable targets for future work. The Working Group highlighted that datasets for the risk assessment could include consideration of movement of krill as well as predators that are not represented in the current CCAMLR Ecosystem Monitoring Program (CEMP), particularly krill-dependent cetaceans, pack-ice seals and demographic groups other than adult penguins.

2.14 The Working Group recalled that CM 51-07, paragraph 4, stated that the conservation measure will expire at the end of the 2020/21 fishing season if agreement has not been reached on an update or replacement to the conservation measure.

2.15 The Working Group discussed the possibility that the preferred management strategy for the krill fishery might be delayed beyond 2021 and identified a need for a default krill fishery management position, defined as one that is no less precautionary than the current combination of CMs 51-01 and 51-07. The Working Group agreed that the observed spatial concentration of the fishery and the absence of the spatial allocation provisions of CM 51-07 would be likely to lead to an undesirable distribution of fishing effort and there was general support for such a default management approach. It was suggested that the current provisions of CM 51-07 should provide a default management strategy until the preferred management strategy (paragraphs 2.60 to 2.64), based on focused effort, is agreed and implemented. The Working Group stressed that, while maintaining the option of such a default management approach is desirable, the commitment to progressing a preferred management strategy remained the priority objective.

2.16 The Working Group also noted that several factors external to CCAMLR have contributed to the spatial distribution of fishing effort. Such factors include environmental (e.g. changing sea-ice conditions, weather conditions), economic (e.g. subsidies, vessel operation costs, licensing fees, processing capacity, cost of searching for suitable fishing grounds) and fleet dynamics (e.g. voluntary coastal closures, vessel cooperation, the experience of the skipper). Combined with such factors, the Working Group noted that CM 51-07, which allocates the trigger level among subareas, may inadvertently promote the concentration of fishing effort, especially in the context of Olympic fishing. Such factors may influence future fishery activity and the Working Group agreed that this lends urgency to the work to develop a management strategy for the krill fishery.

2.17 Aware that timelines are helpful to motivate progress on the development of a management strategy for the krill fishery, and noting that CM 51-07 expires after the 2020/21 fishing season, the Working Group agreed a prioritisation of several tasks to advance a management strategy for the krill fishery (Table 1). This prioritisation fully intends to develop the scientific basis for a revision to CM 51-07 while progressing a harvest strategy for krill fishing, including catch limits and their spatial distribution by 2021 (Figure 1).

2.18 The Working Group agreed a prioritised, three-part approach to advance a preferred strategy to manage the krill fishery by:

(i) developing a stock assessment to estimate precautionary harvest rates (Tables 2 and 3)

(ii) developing updated biomass estimates, initially at the subarea scale, but potentially at multiple scales (Tables 4 to 6)

(iii) advancing the risk assessment framework to inform the spatial allocation of catch (Tables 7 and 8).

2.19 The Working Group discussed several aspects of this work plan, noting requests from the Scientific Committee to develop a risk assessment for spatial allocation of the catch, the expiration of CM 51-07 in 2021 and the limited time available for progress, and the extent to which other CCAMLR working groups and subgroups would need to engage with WG-EMM to fulfil the specified commitments.

2.20 Given CCAMLR's prioritisation of the development of a management strategy for the krill fishery, the Working Group agreed that developing the preferred strategy outlined in Tables 1 to 8 and Figure 1 was a matter of urgency. The Working Group recommended that the Scientific Committee prioritise and endorse this work, noting that it may have implications for other working group timetables.

2.21 To progress the work plan, the Working Group requested that the Scientific Committee task the Subgroup on Acoustic Survey and Analysis Methods (SG-ASAM) to develop integrated methods for estimating krill biomass and associated confidence intervals on the subarea scale from available survey data in line with the proposed work plan.

2.22 The first step towards the goal specified in paragraph 2.21 is compiling all available regional biomass estimates. The Working Group requested Members to submit these estimates with associated metadata (Table 6) to the SG-ASAM-2019 meeting. A list of contacts who will coordinate the effort for each subarea is provided in Table 5.

2.23 The Working Group agreed that, in parallel with the work to estimate krill biomass on a subarea scale, a risk assessment should be progressed with an emphasis on finalising data layers on the distribution of krill consumption by critical life-history stages of penguins, Antarctic fur seals (*Arctocephalus gazella*), cetaceans and pack-ice seals. Additionally, consideration should be given to flying seabirds and other cetacean and pinniped species as data become available and time permits. The Working Group further agreed that an analogous data layer for the fishery be developed from C1 catch and vessel monitoring system (VMS) data.

2.24 The Working Group noted that there was a need to review and agree standard methods for the development of layers for the risk assessment. Such standard methods would improve incorporation of new data and allow efficient updating to future risk assessments.

2.25 The Working Group recommended that the Scientific Committee coordinate a focus topic for WG-EMM-2020 to address the development of data standards and quality control if data are to be used to develop risk assessment layers, recognising that such methods may need review by the Working Group on Statistics, Assessments and Modelling (WG-SAM) (paragraphs 9.1 to 9.5).

2.26 The Working Group agreed that, in order to merge the risk assessment and the updated krill biomass estimates, the generalised yield model (GYM) should be further developed to update precautionary catch limits. The Working Group agreed that this development required, inter alia, a re-parametrisation of growth, recruitment and natural mortality, and agreed on an intersessional work plan (Tables 2 and 3).

2.27 The Working Group discussed several aspects of the work plan to develop the GYM and noted extensive simulation studies that have recently been undertaken to explore the values and modelling choice for recruitment and natural mortality (e.g. Kinzey et al., 2013, 2015, 2019; Thanassekos et al., 2014; Murphy and Reid, 2001).

2.28 The results of the series of studies suggested that:

(i) the level of natural mortality used in the GYM of 0.8 to estimate the catch limit based on the CCAMLR 2000 Krill Synoptic Survey of Area 48 (CCAMLR-2000 Survey) is likely to be the lower end of the plausible range of natural mortality. Based on analyses such as those shown in Kinzey et al., 2013 an estimate of M in the range of 0.8–2.0 should be evaluated for use in future assessments. The Working Group noted that the value of natural mortality at the subarea scale and smaller scales would be confounded with the movement of krill

(ii) the current level of recruitment variability reflected by the effective coefficients of variation (CVs) from the base-case Beta model in Kinzey et al., 2013 is lower than the observed effective CVs from field studies. The Working Group agreed that the use of recruitment variability based on empirical data be developed to allow the serially auto-correlated nature of recruitment variability to be included in the assessment process

(iii) growth models used to re-parameterise the growth rate used in the GYM should include both the growth rate and the seasonality of growth, taking account of the time interval used in the risk assessment (i.e. winter and summer).

2.29 The Working Group noted the extensive amount of length-frequency time series existing from different sources (nets, fisheries, predator diets) in Subareas 48.1, 48.2 and 48.3, in which the relative proportion of krill for example less than 40 mm, considered as new recruits, could be used to derive a recruitment index. Size selectivity may be different between these sources but if the selectivity is consistent within the sources, then recruitment indices from these sources can be used for deriving recruitment variability.

2.30 The Working Group also noted that the GYM should be run using different options for recruitment distribution models (proportional or lognormal distribution) or recruitment vectors, and average these outputs by weighting according to available information.

2.31 The Working Group highlighted the nature of the intersessional work which will involve extensive data sharing with various external groups and requested the Secretariat to assist Members with coordinating collation of key datasets. Noting the timeline for the work plan, relatively strict deadlines for data submission need to be set, on the understanding that any data that were not submitted by the deadline could not be used for the intersessional work undertaken up to the 2021 revision of CM 51-07. It also stressed the importance of clarifying the format of datasets to be submitted so that the data processing can be undertaken as efficiently as possible.

2.32 The Working Group agreed that alternative implementation of current decision rules should be considered in the updated GYM simulations. For example, the stock assessments for CCAMLR icefish fisheries, which use short-term (e.g. <5 years) model projections and regular biomass updates may provide a useful framework for the preferred krill fishery management strategy.

2.33 For all three components of this preferred strategy, Members to coordinate progress have been identified. The Working Group encouraged wider collaboration and participation of all interested Members to improve the development of the preferred strategy.

2.34 The Working Group noted the ambitious nature of this work plan. Uncertainties about the appropriate scaling of biomass estimates from disparate survey areas and methods, and the pathologies in the GYM related to the parameterisation of recruitment variability (Kinzey et al., 2013) represent important hurdles to be overcome if this preferred strategy for the management of the krill fishery is to be implemented in a timely fashion.

2.35 The Working Group also noted that subdivision of the catch into smaller spatial scales may have impacts on catch reporting requirements for the krill fishery. The Working Group recalled the practice for forecasting closure of the toothfish fishery in Area 88, where the capacity of the fishing fleet can result in catches achieving catch limits in very short periods of time. Currently, catch reporting for the krill fishery is required in a staged approach, transitioning from monthly reporting to five-day reporting according to the requirements of CM 23-06.

2.36 The Working Group agreed that the practical implementation of a subdivision of the krill catch into smaller spatial scales required further consideration of catch reporting requirements. The Working Group therefore requested that the Secretariat generate risk profiles of overrunning catch allocations across a range of vessel capacity (or catch) and fleet sizes, as it has done for the toothfish fishery in Area 88. Such risk profiles would help understand whether reporting requirements for the krill fishery require revision in the future. To circumvent potential overruns, the Working Group recommended that the Scientific Committee take pre-emptive action to increase the frequency of catch reporting above that specified in CM 23-06.

2.37 Recognising that in the past WG-EMM was not able to deliver advice on a preferred management strategy in agreed timelines, the Working Group noted several factors that may improve its ability to deliver a krill management strategy. Firstly, agreement on a work plan to develop the management strategy is now apparent within the Working Group. Secondly, the preferred strategy is largely empirically based and many aspects of the approach are well parameterised by historical and ongoing data collection efforts at multiple scales. Thirdly, an inclusive approach to foster collaboration and share the burden has been clearly articulated (Tables 1 to 8).

2.38 The Working Group recommended that the Scientific Committee coordinate and agree a work plan for the working groups over the next two years to facilitate the work required to progress the preferred management strategy outlined in Tables 1 to 8.

### Data layers for risk assessment of spatial and temporal distribution

2.39 WG-EMM-2019/23 provided data layers for use in a risk assessment framework for krill fisheries management in Area 48.1, i.e. data layers describing the distribution and krill consumption by krill-dependent predators. The paper described the analysis of at-sea cetacean observations from two surveys undertaken by the PROANTAR (Brazilian Antarctic Program) carried out from the Polar vessel *Almirante Maximiano*, in order to estimate the abundance, distribution and consumption of krill by humpback whales (*Megaptera novaeangliae*). Model outputs presented suggest that humpback whales consume relatively large amounts of krill along the coastline of the Western Antarctic Peninsula (WAP) and the South Shetland Islands. WG-EMM-2019/24 described the use of tracking data to provide corresponding data layers for penguin species in Subarea 48.1 and described progress-to-date in developing relevant data layers to input into the risk assessment framework.

2.40 The Working Group noted WG-EMM-2019/26 which was a description of the Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD). The database underlying MAPPPD includes all publicly available (published and unpublished) count data on emperor (*Aptenodytes forsteri*), gentoo (*Pygoscelis papua*), Adélie (*P. adeliae*) and chinstrap (*P. antarcticus*) penguins in Antarctica.

2.41 The Working Group noted WG-EMM-2019/30 which provided a progress report and presented preliminary results for marine Important Bird and Biodiversity Areas (mIBAs) for penguins within CCAMLR MPA planning domains. A total of 64 definitive sites were identified as mIBAs. The Working Group noted that further results would be presented in forthcoming papers to CCAMLR.

2.42 The Working Group noted WG-EMM-2019/23, 2019/24, 2019/26 and 2019/30 which significantly enhanced the available data layers required for future risk assessments. Especially welcome was the new information on baleen whales; in this respect, some participants informed the Working Group that further information would be forthcoming. Further communication with the experts from the International Whaling Commission Scientific Committee (IWC-SC) and from national programs was encouraged. The authors noted advice to develop standardised methods, but also highlighted that all available data sources should be explored and used in order to consider recovering populations of cetaceans, given their importance as consumers of krill, not only in Subarea 48.1, but also at the Antarctic scale. The Working Group also noted that several taxa of krill consumers were still under consideration for inclusion in the risk assessment, including, for example, pack-ice seals, fur seals and flying seabirds.

2.43 The Working Group noted WG-EMM-2019/42 which was a thorough report from a 53-day multidisciplinary ecosystem survey in the eastern Indian Ocean sector of the Antarctic (Division 58.4.1) with a focus on Antarctic krill (*Euphausia superba*) carried out by the vessel *Kaiyo-maru* during 2018/19. A number of analyses using the data and samples obtained are in preparation and the results will be presented to the expert groups of the Scientific Committee. Narrowband echosounder (38, 70, 120 and 200 kHz) data to estimate biomass of Antarctic krill were recorded along predetermined track lines for 2 519 n miles. Broadband echosounder data were recorded at 24 targeted research midwater trawl (RMT) stations to estimate length distribution and swimming angles of Antarctic krill acoustically. The Working Group noted that SG-ASAM would discuss the acoustic krill survey and the broadband methodology adopted. Australia informed the Working Group on plans for a survey in the same area, and the intention was also to have that considered by SG-ASAM.

2.44 The study reported in WG-EMM-2019/20 had as a first goal to produce quantitative distribution maps of all six ontogenetic life stages of krill (eggs, nauplii plus metanauplii, calyptopes, furcilia, juveniles and adults) within Area 48, based on a compilation of all available post-1970s data. Input data spanning 41 years (1976–2016) from the existing KRILLBASE-abundance and KRILLBASE-length-frequency databases were analysed. Although adult males and females of spawning age were widely distributed, the distribution of eggs, nauplii and metanauplii indicated that spawning is most intense over the shelf and shelf slope. This contrasts with the distributions of calyptope and furcilia larvae, which were concentrated further offshore, mainly in the southern Scotia Sea. Juveniles, however, were strongly concentrated over shelves along the Scotia Arc. From the early to late part of the austral season, juvenile distribution moves from ocean to shelf, opposite in direction to that for adults. Such habitat partitioning may reduce intraspecific competition for food, which has been suggested to occur when densities are exceptionally high during years of strong recruitment. It also prevents any potential cannibalism by adults on younger stages. The Working Group appreciated the broad-scale approach of this study. This study would enhance understanding of recruitment patterns and processes which is presently a major gap. Temporal variation studies are in progress. It was noted that there is still limited understanding of what happens in oceanic waters.

### 2019 multinational synoptic large-scale krill survey

2.45 WG-EMM-2019/07, 2019/43, 2019/46, 2019/47, 2019/61, 2019/69 and 2019/78 summarised the multi-Member contributions towards the International Synoptic Krill Survey in Area 48, 2019 (hereafter the 2019 Area 48 Survey), as earlier outlined by Norway (SC-CAMLR-XXXVII/12).

2.46 The Working Group highlighted the successful completion of the field work for the 2019 Area 48 Survey, noting that it was a major undertaking amongst multiple Members (Table 9; Figure 2) and was brought to fruition within a fairly short time frame of planning. The Working Group noted the coordination efforts by Norway and the significant contribution by the Association of Responsible Krill harvesting companies (ARK).

2.47 The Working Group noted that there was extensive involvement from fishing vessels, that all vessels had calibrated their echosounders using the standard sphere technique, and that all the vessels collected data at multiple frequencies. This represents a marked increase in the capacity to collect krill stock assessment information and demonstrated a beneficial level of engagement by the krill fishing industry. The Working Group recalled that efforts by the krill fishing industry to implement standardised acoustic methods were relatively recent (since WG-EMM-2011) but had developed very rapidly.

2.48 WG-EMM-2019/55 highlighted four methodological differences between the CCAMLR-2000 Survey and the 2019 Area 48 Survey: (i) the method used to identify krill targets in the acoustic data, (ii) the different trawls used on the various vessels, (iii) conducting acoustic transects during the night, and (iv) the synopticity and direction of the survey. Dr S. Kasatkina (Russia) expressed that it is necessary to develop appropriate methods for the survey analysis and to provide biomass estimates and associated uncertainties arising from the points given above.

2.49 The Working Group considered these and other areas of methodological differences between the 2000 and 2019 surveys and, while recalling that the 2019 Area 48 Survey had been conducted to address the priority science objectives agreed by the Scientific Committee (SC-CAMLR-XXXVII, paragraph 2.13), it noted that some assessment and quantification of these differences could be undertaken by SG-ASAM, including by reviewing the items listed in Table 10. The Working Group encouraged participation in the SG-ASAM-2019 meeting, particularly by those with outstanding concerns.

2.50 The Working Group recalled that the 2019 Area 48 Survey proposal specified the use of swarms-based identification techniques for extracting krill acoustic backscatter from survey data (e.g. SG-ASAM-2018 report, paragraphs 3.4 to 3.8). However, it noted that, where acoustic data were collected at the three frequencies necessary to apply the CCAMLR dB-difference method (as was used for the CCAMLR-2000 Survey analysis), this would enable a comparison of the different identification methodologies at different spatial and temporal scales.

2.51 The Working Group noted that use of a similar krill length clustering method to the CCAMLR-2000 Survey (WG-EMM-2019/47) had identified three clusters of krill length-frequency distribution, with one cluster containing data from only two trawls. The Working Group identified that appropriate techniques to cluster data and use it in the acoustic analyses would benefit from advice by WG-SAM. The Working Group noted that such considerations should include the influence of gear selectivity on measured krill length distributions amongst the 2019 vessels, and between the 2019 and 2000 surveys.

2.52 The Working Group noted that krill length information for the 2018/19 season was available from a variety of additional sources, such as from CEMP predator monitoring and from national scientific surveys (e.g. a 2019 Peruvian survey), in addition to the large-scale survey. It noted that such data could be used to augment and inform on the selectivity of the net surveys and provide information on the wider krill population length-frequency distribution. The Secretariat offered to coordinate the observer and CEMP data for this, for input to SG-ASAM-2019.

2.53 The 2019 Area 48 Survey occupied transects that were undertaken both during day and night, in contrast to daylight only during the CCAMLR-2000 Survey. WG-EMM identified that differences in acoustic estimates of krill density between day and night could arise through both changes in krill tilt angle, as well as krill migrating above the hull-mounted transducer depth and 20 m blind zone. Members were encouraged to make observations of krill orientation and use upward-looking echosounder moorings and other platforms to examine these effects to further understand the impact of this on the swarms-based identification technique and general behaviour.

2.54 The Working Group noted that the 2019 Area 48 Survey was undertaken over a period of three months, compared with one month in 2000. It therefore discussed how krill flux and oceanographic flow could influence whether the survey was truly synoptic. It noted in addition that successive survey transects consistently progressed from east to west in 2000 (perpendicular to the prevailing current), whilst transects during 2019 progressed from west to east. The Working Group identified that oceanographic flow and particle tracking models (e.g. WG-EMM-2019/21) could be used to understand some of the effect of this issue.

### Risk-assessment for the krill fishery

2.55 WG-EMM-2019/22 highlighted issues to be considered if CCAMLR is to progress krill management to smaller spatial and temporal scales than its current procedure. It highlighted that the oceanography of the region encompassed by the Bransfield Strait, South Shetland Islands and the tip of the Antarctic was dominated by three major inflows – the relatively cold Weddell Sea outflow around the tip of the Peninsula, and warmer inflows from the Gerlache and Boyd Straits. Oceanographic models indicate that the relative influence of these features supports hypotheses as to why large aggregations of krill occur in the region, the species-specific distribution of penguin colonies, and how the fishery has been able to consistently reach the Subarea 48.1 trigger limit in recent years despite fishing in a relatively small area.

2.56 The Working Group encouraged ongoing development and analysis using oceanographic models of the Bransfield Strait region, as this was likely to continue to provide important insights into physical drivers of the distribution of krill, krill predators and the krill fishery. It further noted that the contribution of the three main inflows into Bransfield Strait was likely to vary under climate change and El Niño Southern Oscillation (ENSO) fluctuations and encouraged development of model scenarios that included these phenomena. It further noted that tides, eddies and embayments were likely to contribute to the accumulation of krill in this region. It noted that as the fishery and predators target krill aggregations within 30 km of the coastline, extending acoustic transects and glider or sail buoy missions inshore would therefore be important to understand this portion of the krill stock.

2.57 WG-EMM-2019/58 summarised results from three experiments conducted to estimate rates of flux of acoustic krill targets with respect to geostrophic circulation at different scales in Subarea 48.3 in 1990, in Subarea 48.2 near Coronation Island in 1992 and again in Subarea 48.2 in 1996. Dr Kasatkina noted that the results of these field experiments across time showed that movement of krill biomass was complex and variable on study areas and demonstrated the effect of krill flux on fishing performance in areas of fleet operations. She also noted that in the past, vessels fishing in Area 48 had drifted with patches of krill for large distances. Summarising data from field experiments and estimating krill flux from the Russian large-scale surveys and CCAMLR-2000 Survey it was noted that krill flux intensity and structure are characterised by different spatial and temporal variability across Area 48. Dr Kasatkina emphasised that an understanding of the influence of krill flux at a range of temporal and spatial scales was important to consider in developing biomass estimates for stock assessment and data layers for risk assessment.

2.58 The Working Group agreed that krill flux was an important source of uncertainty in modelling krill biomass and distribution, and noted that the results in WG-EMM-2019/58 indicated the relative impact of flux increases in importance at smaller scales, particularly at the 10s of km scale. It noted that improved estimates of flux would be likely to substantially improve understanding of the impact of the fishery at the scale of fishing grounds. It noted that disregarding flux at these scales is likely to result in underestimates of biomass. However, it noted that, as methods for assessing stock dynamics at the scale of fishing grounds are still at an early stage of development, using conservative estimates of biomass is consistent with CCAMLR's precautionary approach. It also noted that in synoptic surveys at the subarea and area scales, it was reasonable to assume that the impact of krill flux was relatively small compared to other sources of uncertainty inherent in acoustic biomass estimates (WG-EMM-2019/22). It agreed that new technologies such as moorings, gliders and sail buoys are likely to hold significant promise for understanding krill flux and swarm behaviours. It also noted that oceanographic models indicate that krill transport and retention is likely to be influenced by a combination of mechanisms, including tides, eddies, inshore bathymetry, geostrophic flow and krill behaviours such as diel vertical migration.

2.59 The Working Group recognised that enhanced management of the krill fishery, moving from the current situation to a more dynamic, science-based management procedure including stock assessments and risk assessments, would improve understanding across a range of spatial and temporal scales.

## Advice to the Scientific Committee on the development of a preferred option for the management of the krill fishery in Area 48

2.60 The Working Group recalled the task it was given by the Scientific Committee and the Commission to make the development of a preferred option for the management of krill in Area 48 a priority in 2019 and to advise the review of CM 51-07. The Working Group recalled that on 30 November 2021, CM 51-07 will expire, if agreement has not been reached on an update or replacement of the conservation measure.

2.61 The Working Group defined a preferred option for management of the krill fishery in Area 48 based on data which are currently available or will become available before 2021 (Tables 1 to 6). This preferred option would take a subarea-based approach, nested within an overall large-scale approach, for Subareas 48.1 to 48.4 based on subarea-scale stock assessment models and biomass estimates from regular surveys within subareas, to determine precautionary catch limits. The spatial distribution and scaling of the catch limits would then be based on the risk assessment framework. This will require the development of:

(i) an implementation of the GYM and the krill decision rules that is appropriate for estimating area and subarea catch limits

(ii) methods to estimate area and subarea biomass or density based on available surveys

(iii) data layers and implementation of the risk assessment framework to evaluate catch distribution options at the area, subarea and fishing ground scales

(iv) a management strategy evaluation (Table 1).

2.62 The Working Group agreed on a work plan toward a preferred management strategy for the krill fishery by 2021 (Figure 1 and paragraphs 2.20 and 2.38). This strategy consists of three components:

(i) a stock assessment to estimate precautionary harvest rates (Table 2)

(ii) updated biomass estimates, initially at the subarea scale, but potentially at multiple scales (Tables 4 to 6)

(iii) a risk assessment to inform the spatial allocation of catch (Tables 7 and 8).

2.63 The Working Group requested that the Scientific Committee evaluate and endorse the preferred strategy and the work plan.

2.64 The Working Group highlighted the potential need to extend the provisions of CM 51-07 beyond its current expiry date as a default management position for the krill fishery if there is no agreement on the development and implementation of the preferred management strategy for the krill fishery (paragraphs 2.14 to 2.20).

## Krill fishery

Fishing activities (updates and data)

3.1 The Working Group welcomed the update on krill fishing activities for the 2017/18 season (1 December 2017 to 30 November 2018) and for the 2018/19 season up to 25 June 2019 provided by the Secretariat and noted that:

(i) the total catch of krill reported in catch and effort reports was 312 743 tonnes, the highest catch since the early 1990s and that fishing had taken place in Subarea 48.2 in the period from July to October for the first time

(ii) so far in 2018/19, catches are higher than up to the same time last year and, in particular, there has been an increase in the level of catch in Subarea 48.2 in the period December to March, with 160 532 tonnes taken in 2018/19 compared to 96 110 tonnes in the same period in 2017/18

(iii) at the time of the Working Group meeting, the Secretariat closure forecast indicated that the fishery in Subarea 48.1 would close on 15 July 2019 when the catch limit of 155 000 tonnes is reached

(iv) as in the two previous years, there had been small catches (12 tonnes) of krill in Division 58.4.2 in 2018/19.

3.2 The Working Group noted that five Members had notified their intention to fish for krill in 2019/20 and that the 14 vessels notified included two new, purpose-built, krill fishing vessels. The increase in the number of vessels represents an increase in processing capacity from 4 620 to 5 750 tonnes per day compared to 2018/19.

3.3 The Working Group recalled that the Scientific Committee had noted that this increase in catches and the changes in the seasonal distribution of the fishery underlined the timeliness of progressing the development of the management scenarios for the krill fishery (SC-CAMLR-XXXVII, paragraph 3.2).

3.4 The Working Group welcomed the updated information in the Krill Fishery Report 2018 (www.ccamlr.org/node/103782).

3.5 The Working Group noted that, although current data reporting requirements are for monthly catch and effort reporting for Subarea 48.2 until catch once reaches 80% of its trigger limit, operators are already voluntarily reporting at five-day intervals. The Working Group suggested, for the consistency with current operation and operational simplicity, this could be reflected in CM 23-06 (see also paragraph 2.36).

Krill fishery data

3.6 The Science Manager briefly described the ongoing work in the Secretariat on improving the quality, documentation and availability of data related to the krill fishery. The work so far this year had focussed on documenting the changes over time in the catch reporting requirements, and hence the availability of individual haul-by-haul data as well as catch data aggregated by 10-day or monthly time periods.

3.7 The Working Group recognised that this work was of importance as the C1 data include a mixture of time and space scales of catch reporting that are important when used in historical analysis. For example, most of the catch data from the late 1980s is from 1° longitude by 0.5° latitude cells aggregated by monthly and/or 10-day time periods, whereas catch data since the early 2000s has been reported at a haul-by-haul level.

3.8 The Working Group noted that the comparison of the catch data from the krill fishery gridded at 1° longitude by 0.5° latitude scale from 1988–1991 and 2015–2018 (Figure 3) that included the aggregated and the haul-by-haul data, clearly showed the spatial concentration of the fishery in the more recent years.

3.9 The Working Group welcomed the update on the data management work being carried out in the Secretariat and looked forward to receiving further updates and data products.

### Net monitoring cable trials

3.10 WG-EMM-2019/16 described the outcomes of trials with a net monitoring cable aimed at developing real-time monitoring of the fishing gear on the *Saga Sea* that were first presented in WG-EMM-16/06. A derogation from the prohibition on the use of net monitoring cables in CM 25-02 was provided for this trial. Because the trials on the *Saga Sea* were unsuccessful with the existing rigging configuration, the vessel has introduced the same trawl rigging as used on the *Antarctic Sea* and has also introduced the same operating approach for the net monitoring cable.

3.11 The Working Group noted that the net monitoring cable was integral to the approach to improving catch data reporting (see paragraphs 3.16 to 3.21) and was positioned close to the trawl warp and may simply appear as a single warp in terms of the risk to seabirds. However, recognising the efforts that had been introduced in CCAMLR to avoid the incidental mortality of seabirds associated with fishing, the use of net monitoring cables in a manner not consistent with previously agreed best practice should not be allowed.

3.12 The Working Group noted that in 2016 a one-year derogation on the prohibition of the use of a net monitoring cable was given on the basis of the trial described in WG-EMM-16/06 (SC-CAMLR-XXXV, paragraphs 4.10 to 4.13; SC-CAMLR-XXXVI, paragraphs 3.10 and 3.11), this was extended in 2017 but was apparently no longer in place when the trial was conducted (SC-CAMLR-XXXVII, paragraphs 3.14 and 3.15). As WG-EMM-2019/16 indicated that the operating approach for the net monitoring cable remained in use, the Working Group requested the advice of the Scientific Committee and the Standing Committee on Implementation and Compliance (SCIC) on the status of the trial. It further requested the authors of the paper to provide the Scientific Committee with a clarification of the sequence of events involved in the trial.

3.13 Dr Bergstad informed the Working Group that communication with the author of WG-EMM-2019/16 and the vessel owner had revealed that the suggestion in the paper that the trials had continued into the 2018/19 season was incorrect. The experiments on the *Saga Sea* were conducted in 2016/17 and 2017/18 as reported in WG-EMM-2019/16. He noted the suggestion to have the Scientific Committee and SCIC evaluate the trials as reported and will provide additional information as required. He also informed the Working Group that:

(i) When the trials were completed in 2017/18, no satisfactory solution had been found. The vessel therefore decided to change the rigging of the vessel prior to the 2018/19 season. The *Saga Sea* now has the same rigging as the *Antarctic Sea* and the *Antarctic Endeavour*.

(ii) The vessels use a cable connection to the net sensors. This cable runs along the single trawl warp and is aligned with that warp. Dr Bergstad recognised the need to describe and illustrate this rigging to the Scientific Committee in order to enhance clarity. It is emphasised that this rigging is very different from that used on classical double-warp trawlers where the cable normally runs freely between the warps as a third cable. He provided a full description of the use of cables in an information document submitted during the Working Group meeting. The intention is to develop this as a working paper to the Scientific Committee.

(iii) The alternative to the current system now harmonised on the three vessels is a cable-free system with battery-powered sensors on the trawl. This would imply having to retrieve the trawl frequently to recharge batteries and is thus considered an inferior solution at this time. A battery-powered solution will not permit implementation of an acoustic catch sensor and the possibility of running long-term monitoring of the trawl for catch efficiency, by-catch and krill behaviour studies.

### Net-mounted acoustic data collection

3.14 WG-EMM-2019/15 described the testing of net-mounted acoustics devices to collect data on the amount of krill entering the net on vessels using the continuous fishing system. The authors indicated that following some difficulties in the development of the system, there was now a plan to trial the system during the Norwegian survey in Subarea 48.2 in 2020 and then on commercial gear later that year.

3.15 The Working Group noted the update on net-mounted acoustics, recognising that the integration of data on acoustics and catch data could provide important information on krill density and swarm structure, as well as improvements in catch reporting, and looked forward to further updates on this project.

### Continuous trawl catch recording

3.16 WG-EMM-2019/06, which was presented in response to SC-CAMLR-XXXVII, paragraphs 3.7 to 3.13 and the WG-EMM-2018 report, paragraphs 2.44 to 2.54, provided an update on the methods described in WG-EMM-18/22 on using the holding tank volume recorded at two-hour intervals to estimate the green weight of krill. WG-EMM-18/22 described experiments where the relationship between tank volume and krill biomass was estimated for individual holding tanks. This allows estimation of catch weight by two-hour intervals based on the monitoring of the change in filling level during fishing.

3.17 WG-EMM-2019/06 described the method for how estimates based on tank filling recordings during two-hour periods were obtained. It confirmed that the same method was now used on all Norwegian krill fishing vessels. Every day, the sum of the two-hour estimates for the previous 24-hour period is compared with the corresponding 24-hour catch recorded by the flow scale, since there may be minor discrepancies between the sum of two-hour catch estimates and the 24-hour flow-scale readout, i.e. the best record of the 24-hour catch. When this occurs, the officer in charge adjusts the two-hour catch records proportionally so that they sum up to the 24-hour catch recorded by the flow scale. The adjusted two-hour catches are thus regarded as the best estimates of two-hour catches and are reported on the C1 forms.

3.18 The Working Group recalled its previous discussion on catch reporting for vessels using the continuous fishing system (WG-EMM-2018 report, paragraphs 2.44 to 2.54). The overall catch data were precise and unbiased at 24-hour time periods. Those previous discussions (in 2018, based on WG-EMM-18/22) concluded that historical catches for two-hour periods were also likely unbiased, but the precision was rather lower than expected. The Working Group recognised that the precision of historical two-hour catches could not be enhanced. The Working Group accordingly reiterated the request made in 2018 to the Secretariat for information to be provided to Members requesting access to C1 data from vessels using the continuous trawling method (WG-EMM-2018 report, paragraph 2.49).

3.19 The descriptions of the current methods for estimating the green weight of krill are specified in CM 21-03, Annex 21-03/B. The method described in WG-EMM-2019/06 is a combination of two methods. The Working Group requested those Members using this method to provide a description of the method that would allow the appropriate changes to CM 21-03, Annex 21-03/B. The Working Group further requested that the Scientific Committee consider this revision to the conservation measure.

3.20 The Working Group recommended that, in the interim of the full documentation and analysis of the method described in WG-EMM-2019/18, Norway should report the two-hour catch estimates derived from monitoring of filling levels in the holding tanks and the 24-hour catches from the flow scale to allow the scale of any correction of the two-hour catch estimates to be evaluated. The Working Group agreed that this would also provide a better understanding of the catch data, including from other vessels that only use the tank volume method.

3.21 The Working Group recalled that the spatial concentration of krill fishing highlights the importance of accurate catch reporting and that the issues associated with catch reporting from the continuous fishing system have a long history (e.g. WG-EMM-2009 report, paragraph 3.43). Some disappointment was expressed that historical catch data from the continuous fishing system cannot be reconstructed and that this is not a satisfactory position as it impedes the ability of CCAMLR to understand the impact of the fishery. It was, however, also noted that the issue was discussed in 2018 (WG-EMM-2018 report, paragraphs 2.46 to 2.48) and the Working Group at that time agreed, with reference to the analyses in WG-EMM-18/22, that historical analyses were possible but that analyses at the finest spatial and temporal scale were likely to be affected by the low precision and lack of consistency in catch reporting methods between vessels using the continuous fishing system in the past.

## Scientific observation

### Glider-based estimates of Antarctic krill biomass

3.22 WG-EMM-2019/13 explored the feasibility of using gliders to replace vessel-based biomass surveys of krill at several temporal and spatial scales in the Bransfield Strait and the western shelf of Livingston Island, Antarctica, between mid-December 2018 and mid-March 2019. The authors of the paper concluded that acoustically equipped glider surveys can provide estimates of krill density and distribution, sufficient to inform management, and should allow the continuation of time series monitoring that has historically been conducted by ships.

3.23 The Working Group welcomed the use of this new technology and noted that consideration should be given to the acoustic frequencies and data standardisation for the estimation of krill biomass. The Working Group suggested undertaking comparisons between glider-based biomass estimates and the results from the 2019 Area 48 Survey. The Working Group suggested a need for observing shallower coastal areas that are important predator habitat by using additional gliders (paragraphs 2.27 and 2.28).

3.24 WG-EMM-2019/17 described initial trials with a sail buoy, a wind-propelled vehicle with solar-powered scientific sensors including an echosounder, to map krill distribution. Operational and functional tests were trialled from the end of January to mid-February 2019, demonstrating its capability to run survey transects, observe variability at a location and survey predator prey fields. The presence of an iceberg prevented the sail buoy survey area overlapping with concurrent predator tracking locations, this will be pursued in future surveys. The Working Group welcomed the use of automated surface devices to conduct detailed surveys of areas that are otherwise inaccessible due to logistical reasons and noted that the application of this technology will help improve fishery management as well as to increase the efficiency of searching for fishing grounds.

3.25 The Working Group noted that advances in the use of automated surface and underwater vehicles means that we are in a period of rapid change, and there is a need to promote this work more widely. The Working Group further noted that coordination between Members will enhance and optimise the use of these vehicles and subsequent data analysis.

### Krill length composition

3.26 WG-EMM-2019/56 discussed the importance of reliable estimations of the spatial–temporal distribution of krill length composition in Subarea 48.1 required for integrated stock assessment models, developing management advice, FBM and revision of CM 51-07. The authors noted that krill flux from the Bellingshausen Sea and Weddell Sea across Subarea 48.1 may create spatial and temporal variability of krill length compositions. The authors also noted that gear selectivity and potentially the CCAMLR Scheme of International Scientific Observation (SISO) observer sampling procedure used may affect krill length estimation from commercial catches. The authors indicated that they would analyse the size composition in different temporal scales to improve the sampling procedure used by SISO observers.

3.27 The Working Group highlighted that a review of the sampling regime used to obtain krill biometric data could be conducted in the context of the intended purpose of the data collected as part of SISO. An analysis would then be needed to develop the most appropriate sampling regime, i.e. to estimate the mean length or length-frequency distribution in the catch.

3.28 The Working Group noted that previously conducted analyses have been used for a range of different purposes, and the sampling regime should be reviewed in the context of current research and management priorities. The Working Group also noted that an increase in the number of biometric samples may be beneficial, and particularly when acoustic transects are conducted.

## Scientific observation

### SISO observer manual and sampling requirements

3.29 The Working Group endorsed the updated SISO manuals and logbooks presented in WG-EMM-2019/75 and thanked the Secretariat for providing these in a fishery-specific format.

3.30 The Working Group highlighted the importance of krill length data collected by scientific observers as this is one of the most important data sources for understanding dynamics of krill and pursuing stock assessment to develop management advice for the krill fishery.

3.31 The Working Group recalled that a sampling requirement specified in the observer logbook instructions is to measure 200 krill from one randomly selected haul every three days or five days depending on the period of the season. This requirement for 200 krill per haul is based on the sample size required to allow evaluation of the overall length-frequency distribution rather than the mean length (WG-EMM-2008 report, paragraph 4.48).

3.32 An analysis of the number of krill measured per sample from 2015 to 2019 indicated that the number ranged between 50 and 400, with some vessels regularly measuring 100 krill per haul, while other vessels measured 200 individuals. However, it was noted that since 2018 all vessels were measuring 200 krill per sample.

3.33 During the meeting it was explained that these differences were caused by different interpretations of the SISO instruction.

3.34 The Working Group noted that at the 2017 SISO workshop (SC-CAMLR-XXXVI/08) one of the objectives was the development of a standard set of krill measuring instructions to ensure consistency of measurements between SISO observers. The Workshop had included a review of the sampling instructions and it appears that this was indeed very useful in creating the consistency required.

3.35 The Working Group also agreed that the current instructions may not provide sufficient detail on krill sampling from a trawl to ensure unbiased sampling as there may be a tendency to select larger krill for measurement. Given the importance of sampling across the entire size range, the Working Group suggested that this might be better achieved by requesting observers to collect a subsample and to measure all krill in the subsample. This approach should be designed to provide a sufficient sample size and remove the potential bias in selecting the individuals for measurement.

3.36 The Working Group recommended that in order that the sampling requirements in the SISO manual and instructions be updated from specifying 200 krill per trawl to measuring all of the krill in a random sample of krill from a trawl, those Members deploying observers in the krill fishery were requested to evaluate sampling approaches that would achieve this objective.

3.37 The Working Group agreed that, given the priority of understanding the dynamics of the krill population in the area of the fishery, having sampling frequencies of sampling one trawl every three days throughout the year would simplify the instruction for the observers. The Working Group noted that this may have some implications for other tasks that the observers are required to undertake (e.g. fish by-catch sampling).

3.38 The Working Group acknowledged the progress made towards development of krill fishery management this year, and that recruitment has been identified as a priority parameter for stock assessment. Given that krill observer coverage will reach 100% from the 2020 fishing season, the Working Group stressed the timeliness of holding a focused workshop on the priorities for data collection, information sharing and overall tasking for observers in the krill fishery. The Working Group welcomed the offer from China to host such a workshop in 2020 and asked Dr G. Zhu (China) to develop draft terms of reference and a budget for the workshop to be considered by the Scientific Committee.

3.39 The Working Group noted the importance of providing SISO observers with feedback from the analyses conducted using observer data to provide a wider perspective and understanding of the krill fishery and thanked the SISO observers for their hard work and acknowledged the important resource they provide for research and management of the krill fishery.

### CPUE and spatial dynamics

3.40 WG-EMM-2019/09 provided a description of the operations of the Chilean krill fishing vessel *Antarctic Endeavour* throughout its first year of operation (2017/18) including the fishing locations, CPUE and the length-frequency distributions of krill.

3.41 The Working Group noted the information provided in WG-EMM-2019/09 and that the increases in CPUE over the year and the variability in green weight to meal conversion factors probably reflect the development of the processing capabilities of the vessel during its first season in operation. The Working Group encouraged other Members participating in the krill fishery to provide similar reports as this was helpful in better understanding data from individual vessels.

3.42 The Working Group noted WG-EMM-2019/41 which provided an analysis of the krill fishery in the context of the northwestern Antarctic Peninsula (NWAP) zones of the D1MPA proposal (with the addition of a main fishing hotspot within the current regular fishing zone). A suite of indicators, including total catch and measures of CPUE, were used to characterise how the fishing fleet used the different zones. CPUE was generally stable and showed low interannual and spatial variability in the different D1MPA zones, particularly in the main fishing hotspot, however, a decreasing trend in CPUE was observed in the Gerlache Strait zone in 2017 while it was stable in other years.

3.43 The Working Group noted that this analysis could be useful in the design of reference areas proposed in the D1MPA proposal and should be regularly updated to examine if the trends observed reflect natural variability in the krill population or changes that arise from increased spatial concentration of fishing activity.

3.44 The Working Group agreed that the analysis clearly showed the change in operation of the fishery in Subarea 48.1 and in particular the concentration of the fishery in Bransfield Strait and in the increased level of catch in the Gerlache Strait since 2006. In respect to the increase in catches in the Gerlache Strait, and a decreasing daily CPUE during 2017, the Working Group noted the need for precaution as this is an important area for predators.

3.45 The Working Group noted that the introduction of voluntary buffers in 2019, analysed in WG-EMM-2019/41, has the potential to cause the krill fishery in the area to further concentrate fishing effort in space and time.

3.46 The Working Group noted that there was relatively little variability in many of the indices of CPUE in WG-EMM-2019/41 and considered that spatial concentration of large krill swarms and the fishery in the fishing hotspot could lead to hyper-stability in CPUE.

3.47 The Working Group recalled earlier discussions (WG-EMM-2017 report, paragraphs 3.96 to 3.100) on the potential to use acoustics data from krill fishing vessels along with the CPUE to better understand the relationship between CPUE and krill abundance. Furthermore, increases in swarm density and increasing modal length of krill have been observed over the period March to May in Subarea 48.1 (WG-EMM-2017 report, paragraphs 3.15 and 3.18).

3.48 The Working Group encouraged continued analysis of simultaneous acoustic data and catch data across a range of vessels and gear types to further progress the interpretation of CPUE data.

3.49 Dr Zhu informed the Working Group that observers on a Chinese krill fishing vessel were conducting instantaneous growth rate experiments to examine growth rates during the period of operation of the fishery and that the results from these experiments would help elucidate the causes of changes in modal length observed and provide an additional source of information with which to examine CPUE dynamics.

### Fishing vessel surveys

3.50 WG-EMM-2019/32 provided information on a Norwegian study into the use of stationary echosounders mounted on moorings to assess the effects of krill vertical distribution on vessel-derived survey results. Data obtained from the South Orkney Islands during the 2019 survey using a Nortek broadband echosounder indicated substantial temporal and geographical variation in diel vertical migration (DVM) with 13% of the macro zooplankton backscatter found in a depth shallower than ~20 m during daytime, while 24% was found above ~20 m during the night. The Working Group noted that such upward-looking devices are useful for acoustic sampling in near-surface waters where the use of research and fishing vessel-mounted devices is difficult.

3.51 The Working Group noted the development of studies to assess diurnal movement of krill using stationary echosounders and noted their value in assisting with interpretation of output from vessel-borne surveys. The Working Group recommended that SG-ASAM consider the use and analysis of data derived from stationary moorings to provide information on krill DVM. It noted that similar devices have been deployed in Subarea 48.1, including in the Bransfield Strait. Collection of data from stationary echosounders in areas with high predator densities could provide information on how predator presence influences krill distribution and behaviour.

## Krill-based ecosystem interactions

Krill biology, ecology and population dynamics

4.1 WG-EMM-2019/03 outlined Australia's plan to conduct a krill survey in Division 58.4.2, east of 55°E, from 23 January to 25 March 2021 to estimate biomass of krill. The main objectives of the survey are to update the krill biomass estimate in Division 58.4.2, east of 55°E, and to design a tractable and sustainable long-term monitoring plan and evaluate spatial management of the krill fishery. The project also plans to understand distribution and structure of krill swarms and its relation to predator activities, as well as contribution of deep-sea krill to the overall krill biomass and its dynamics.

4.2 The Working Group welcomed the development of the survey by Australia. It noted the importance of liaising with SG-ASAM, including intersessionally through e-groups, on technical issues to ensure consistency of methods with CCAMLR standard protocols, as well as choice of echosounder frequencies concerning observation of deep-sea krill. It also noted that results and experience from the recent Japanese survey in Division 58.4.1 will provide useful insights for this survey.

4.3 WG-EMM-2019/79 outlined the planned survey by India from December 2019 to February 2020 in the Prydz Bay region. Specific goals of the survey are to understand the distribution and biomass of krill in the western Indian Ocean sector of the Southern Ocean, and to relate larval/adult krill with the prevailing oceanography and the environment to examine the drivers that control the krill ecosystem. The ultimate goal of the survey is to assess impacts of changing climate or long-term variations into the future. The Working Group welcomed this planned survey and looked forward to the report of the voyage in coming years.

4.4 WG-EMM-2019/12 Rev. 1 reported on the second annual meeting of the SCAR Krill Action Group (SKAG) which took place on 15 and 16 June 2019 in Concarneau, France, and was attended by 24 scientists from 10 nations.

4.5 At the meeting the group:

(i) formalised its structure

(ii) identified 'recruitment' and 'krill's plasticity to climate change' as two important knowledge gaps in krill research that provide critical scientific information for krill fishery management

(iii) identified a list of actions that can be taken within the remaining 18 months (until the end of the current SKAG phase)

(iv) ensured and encouraged active participation of young scientists by assigning young scientists roles as well as plans to establish links through existing platforms for early career scientists.

4.6 The Working Group highlighted SKAG's important role as a conduit between CCAMLR and the wider krill research community to assist in providing critical scientific information, such as on recruitment and mortality, in light of the Working Group's plan in progressing improvement of the krill fishery management (paragraphs 2.26 to 2.29).

4.7 Dr T. Ichii (Japan) drew the Working Group’s attention to an important opportunity for SKAG for testing the theory of intraspecific competition for food as the main driver of the krill population dynamics (Ryabov et al., 2017), in which their model suggested that an increase of predators initially drives down and then stabilises the high oscillation of krill biomass within a five- to six-year cycle. He noted that, given the high predator abundance and increasing fishing pressure on krill in the Bransfield Strait, such models should be investigated as a priority. Dr Kawaguchi, as the Vice-Chair of SKAG, clarified that such hypothesis testing using the Ryabov et al. (2017) model is a candidate research priority for SKAG.

4.8 WG-EMM-2019/70 outlined a current project that uses metabolomic and transcriptomic approaches to better understand the mechanisms that govern geographic distributions and metabolic responses generated by an environmental stress (i.e. temperature) in krill species. The information to be generated from this project deepens the understanding of the mechanisms of the adaptation of Euphausiids to cold environments. The ultimate goal of the project is to enable prediction of the responses of organisms that are affected by the impact of global warming and an increasingly intensive fishery, especially for Antarctic krill.

4.9 The Working Group welcomed the presentation of the project noting its importance to evaluating how climate change might change the structure of the Southern Ocean ecosystems and looked forward to future updates on the progress of the project.

4.10 WG-EMM-2019/76 considered krill length data collected through both SISO and CEMP, focusing on length-frequency distributions in the Bransfield Strait and their potential use to support krill fisheries management. Differences in mean lengths and length frequencies were apparent but both data sources appeared to be tracking similar processes. The paper stressed the importance of using long-term data collected by different sources to gain an adequate understanding of trends in krill population structure and dynamics for use in fisheries management.

4.11 The Working Group thanked the Secretariat and underscored the importance of such analyses, especially given the recent suspension of several time series based on predator diets. It suggested publishing all the composite length-frequency series from various sampling sources in the Krill Fishery Report. The Working Group also noted the importance of taking account of sample size when generating composite length-frequency distributions.

4.12 The Working Group noted the recent paper (Fuentes et al., 2016) indicating that suspended particles released from glacial melting being ingested by krill may be the cause of krill stranding and mass mortality, and suggested the importance of data collection on krill length-frequency distribution from stranded krill to monitor the effect of glacier melting on the krill population into the future. ‘Krill spill’ (i.e. undigested krill spilt by returning foragers in penguin colonies) might also be a useful source of length-frequency distribution information, and an alternative to stomach lavage (WG-EMM-2018 report, paragraphs 4.14 to 4.16).

4.13 WG-EMM-2019/P03 and 2019/P04 presented the results of stable isotope studies of adult krill in the austral autumn and winter. In both studies $\delta^{15}N$ values were strongly associated with krill size, indicating increased carnivory in larger animals, especially in winter. Carnivory was also higher in the South Shetland Islands than the Bransfield Straight and might be associated with feeding closer to shore. At South Georgia, size differences in $\delta^{13}C$ in June suggest lower feeding success in larger animals at this time. Variation in $\delta^{13}C$ occurred only between April and May in Subareas 48.1 and 48.2 suggesting an increase in primary production in autumn.

4.14 The Working Group welcomed this additional information on variability in the trophic status of krill, which corresponds with previous studies showing a switch from filter feeding to predatory behaviour and corresponding dietary switching from diatoms to zooplankton as they grow, including winter cannibalism at South Georgia, which could be one of the important overwintering strategies under food-poor environments (Nishino and Kawamura, 1994). Cannibalism has also regularly been observed for krill in captivity. It was further noted that analysis of individual body parts might provide additional information about recent versus longer-term feeding patterns and $\delta^{13}C$ values may be useful to indicate latitudinal movement.

4.15 WG-EMM-2019/20 presented maps of egg, larval, juvenile and adult life stages of Antarctic krill in Area 48. The distribution of eggs, nauplii and metanauplii indicated that spawning is most intense over the shelf and shelf slope. Calyptope and furcilia larvae were concentrated further offshore, mainly in the southern Scotia Sea and juveniles occurred over shelves along the Scotia Arc. Contrasts between early and late season suggests habitat partitioning with juveniles moving on-shelf while adults move off-shelf.

4.16 WG-EMM-2019/21 presented the results of a study which contrasts models of krill transport to Subarea 48.2 with and without ice-associated behaviour in addition to simple krill advection on ocean currents. Models which included ice-associated behaviour permitted transport from much of the northern Antarctic Peninsula and reduced retention time on the South Orkney Plateau due to rapid ice-associated off-shelf transport.

4.17 The Working Group noted these two papers and discussed the relative contribution of movement versus differential survival to the observed distributions, recognising that both may play a role. The contrast between model results with and without ice-associated behaviour highlighted the differences that behaviour might make to krill distribution, and it is likely that models which represent krill as exclusively passive drifters are insufficient to explain patterns observed. The success of krill in an environment in which food sources are patchily distributed suggests that behavioural interactions with food sources are also an important influence on distribution. Further work on the behaviour and physiology of krill will be useful to help identify the underlying mechanisms and to improve the utility and interpretation of models.

4.18 WG-EMM-2019/P01 presented a model of the potential flux of particulate organic carbon originating from Antarctic krill in the marginal ice zone. Krill swarming behaviour could result in carbon export to depth through their rapid exploitation of phytoplankton blooms and bulk egestion of rapidly sinking faecal pellets. The model results suggested a seasonal export flux of 0.039 giga-tonnes of carbon across the Southern Ocean marginal ice zone, corresponding to 17–61% of current satellite-derived export estimates for this zone. Thus krill may be important contributors to the Southern Ocean carbon sink.

4.19 The Working Group noted WG-EMM-2019/P01 which showed that krill make an important contribution to the global carbon cycle. It recommended that the Scientific Committee note this fact and promote the recognition of the role of krill in global and regional biogeochemical models.

4.20 WG-EMM-2019/P02 presented evidence of climate-related change in the Antarctic krill population in the southwest Atlantic based on analysis of density (number per $m^2$) and length-frequency data from scientific netting in the 1920s and 1930s and from 1976 to 2016. The results showed a poleward contraction in distribution associated with sharp changes in density north of 60°S which became less sharp further south. They also showed an increase in mean length affecting most latitudes and a relationship between recruitment and the Southern Annular Mode (SAM). Together, the results suggested that climate-driven changes in recruitment have restructured the krill population spatially and demographically since 1976.

4.21 WG-EMM-2019/28 reviewed evidence of change in indices of density and availability to predators. While many of these indices showed negative change, there was no direct evidence of a change in biomass. The paper presented power analyses of annual biomass indices from acoustic surveys in Subareas 48.1 and 48.3. It demonstrated that because these data series are relatively short and have high interannual variability, they have low power to determine whether systematic change has occurred, thus, the assumption that the krill stock has been stable since the 1980s might be inappropriate.

4.22 The Working Group welcomed these studies which evaluate indices of krill stock status and recognised that long-term information on large-scale biomass is not available. Furthermore, most of the available environmental and biological datasets have high levels of interannual variability, meaning that signals of change may take many decades to emerge from the noise. The high level of variability in the available indices of krill stock status emphasised the need for regular monitoring of krill biomass to inform management of the krill fishery. The Working Group also noted a discontinuity in scientific net-based length-frequency data around 2004.

4.23 Dr Ichii reminded the Working Group that annual biomass indices from acoustic surveys in a 10 640 $km^2$ survey box in Subarea 48.3 showed no evidence of change in krill biomass between 1997 and 2013 (Fielding et al., 2014).

4.24 The Working Group recognised that acoustic surveys generate more information than a single biomass or density estimate per year. In particular, they provide information on the distribution of krill within the survey area. Characteristics of this distribution, such as the availability of high-density swarms, might have a stronger influence than mean density on ecological interactions.

4.25 The Working Group noted that observed change and variability in krill populations might be the result of multiple impacts, including those of fishing, which require additional investigation.

## Krill life-history parameters and population models

4.26 WG-EMM-2019/45 outlined the promise and the challenges of the krill ageing method using their eyestalks to make a significant contribution to the objectives of CCAMLR, highlighting some critical issues that need to be addressed before the method can be used reliably by the krill research community.

4.27 The Working Group stressed the urgency of standardising such a method as information on krill age is fundamental to establishing an accurate growth curve and to calculate a recruitment index; the parameters for a GYM to estimate a sustainable yield ($\gamma$).

4.28 The authors of WG-EMM-2019/45 clarified that using known-age krill is essential for calibrating the method, which is planned to be provided by the Australian Antarctic Division and/or Port of Nagoya Public Aquarium.

4.29 The Working Group welcomed this initiative and recognised the importance of the application of the method to the field samples, and recommended that the Scientific Committee identify resources that could be used to provide a workshop to bring together laboratories from different Member nations to conduct interlaboratory calibrations much like the ageing workshops that were conducted for toothfish in the mid-1990s, and asked the authors to develop draft terms of reference and a budget for the workshop for the Scientific Committee to consider.

### Krill predator biology, ecology and population dynamics

4.30 WG-EMM-2019/33 reported on the existence of seasonal fish migrations into a krill hotspot through the analysis of acoustic mooring data north of the South Orkney Islands. The authors highlighted the potential for daytime acoustic estimates of krill to be confounded by the presence of planktivorous fish that exhibit similar backscattering levels. The occurrence of a deeper night-time scattering layer, indicative of vertically migrating fish, may serve as an indicator of potential bias of daytime estimates of krill.

4.31 The Working Group agreed that WG-EMM-2019/33 may be relevant to the Working Group on Fish Stock Assessment (WG-FSA) in the context of fish stocks recovering from overharvesting, and requested it be submitted to the next WG-FSA meeting for consideration.

4.32 WG-EMM-2019/34 demonstrated the use of moored echosounder data to identify air-breathing predators' diving activity just north of the South Orkney Islands. Using automated image recognition, the authors processed a one-year acoustic dataset to detect clear patterns in diving behaviour at short-term (diurnal) and longer-term (seasonal) time scales. However, at these timescales the authors could not detect a relationship between pelagic backscatter and diving activity in the vicinity of the mooring.

4.33 The Working Group agreed that this method would be valuable to improve understanding of how predators interact with krill swarms, and provide additional context to similar acoustic data collected by fishing vessels. The Working Group further agreed that environmental effects such as the presence of sea-ice over the mooring during winter should be considered when interpreting acoustically derived patterns of predator diving.

4.34 WG-EMM-2019/49 identified spatio–temporal overlap between the fishery for krill, breeding monitored penguins and non-breeding unmonitored male Antarctic fur seals. Tracking data covering the entire austral autumn and winter showed male fur seals moving into the Bransfield Strait before the fishery and occupying foraging grounds utilised by chinstrap penguins during the latter stages of breeding and as chicks fledged. The authors recommended that the potential competitive interactions between numerically abundant male Antarctic fur seals and monitored penguin species should be considered when interpreting penguin monitoring indices, particularly those relating to fledging.

4.35 The Working Group agreed that male Antarctic fur seals should be considered as important predators of krill in this area, although the difficulty in estimating abundance makes developing spatially resolved consumption estimates challenging. Furthermore, it was acknowledged that it would be difficult to detect an impact of fishing on this demographic given the polygynous mating system in Antarctic fur seals.

4.36 WG-EMM-2019/67 presented the distribution and areas of mixing of two stocks of humpback whales (Western and Eastern Australian stocks or 'D' and 'E1' stocks) in the Indo–Pacific region of Antarctica (Division 58.4, Subareas 88.1, 88.2, south of 60°S). Using genetic markers and genetic samples from both low (winter) and high (summer) latitudes, the authors demonstrated that the geographical boundaries of the IWC Management Areas broadly correspond to the boundaries of biological stocks, although there is some evidence of stock mixing in the eastern parts of Area III (Subarea 58.4) and Area V (Subarea 88.1). The data also suggested that both stocks do not distribute in Area VI (Subarea 88.2) in summer. Additional analyses considering a finer geographical scale in the Antarctic are planned. The authors therefore advised caution in attributing abundance estimates in Area VE (160°E–170°W) (Subarea 88.2) solely to the eastern Australian humpback stock.

4.37 The Working Group welcomed the study and acknowledged that in light of the results, linking abundance estimates of cetaceans at feeding grounds with breeding ground estimates would be important for ensuring appropriate risk assessment updates into the future. The Working Group further noted that differences in the abundance and distribution of krill at the feeding grounds may be setting the different carrying capacities of the two stocks.

4.38 The Working Group discussed WG-EMM-2019/10 and additional analysis submitted as a presentation to Agenda Item 4.3. The paper spatially and temporally matched pygoscelid penguin foraging areas with 37 years of annual fishing catch and SAM index values within a modelling framework to assess corresponding penguin population change rates. The paper showed significant decreases in population of chinstrap penguins in high catch years. The paper concluded that there is likely an additional negative stress for penguins from the increased concentration of krill fishing, and emphasised priority areas of conservation like the proposed D1MPA.

4.39 The Working Group congratulated the authors and agreed that exploring additional modelling parameters may strengthen the analysis presented in WG-EMM-2019/10, including regional concentration of sea-ice or colony-specific conditions. The Working Group noted both the danger of over-simplifying models (e.g. Melbourne-Thomas et al., 2013), and the need for an upper limit to the number of parameters for a population model.

4.40 The Working Group noted that, when identifying the effects of fishing on predators, differentiating between correlation and causation is important. The Working Group further agreed that fishing and non-fishing reference areas or integrated models could be established to more directly measure the effects of fishing. The Working Group drew attention to previous discussions about the potential for krill vessels to disrupt swarming behaviour (paragraph 2.5). However, the Working Group recalled that previously submitted acoustic data from fishing vessels indicate limited effects on swarm densities and thickness. The authors of WG-EMM-2019/10 offered to incorporate any provided acoustic data into their modelling.

4.41 The Working Group noted that two separate modelling approaches using different assumptions (WG-EMM-2019/10 and 2019/11) came to the same conclusions regarding probable impacts of concentrated krill fishing on the penguin populations and emphasised the need for precautionary management approaches. The Working Group agreed that WG-EMM-2019/10 and 2019/11 demonstrate that krill fishing at current levels and concentration in the Bransfield and Gerlache Straits are likely to have had a negative effect on localised predator populations in years with unfavourable environmental conditions. The Working Group further noted that the exact temporal and spatial scale of that impact is unknown and requires further study.

4.42 The Working Group emphasised the importance of Members working collaboratively to assess the best available data to better understand fishery–predator interactions. The Working Group drew attention to the value of empirical models for interpreting the best science in a precautionary approach.

4.43 The compendium of seven published papers in WG-EMM-2019/72 was discussed by the Working Group together, as they all related to comparing levels of health threats to pygoscelid penguins along the WAP. The paper demonstrated significant increases in a variety of health stress indicators with increasing latitude, including: humoral and immune system indicators, parasites, stress levels and trace contaminants. The authors suggested that such information about the spatial distribution of threatening processes to penguins may be useful for the planning of the D1MPA.

4.44 The Working Group highlighted the importance of such indicators of environmental stress to inform risk assessments of penguins and other krill predators. The Working Group agreed that the outputs of WG-EMM-2019/72 could be integrated into D1MPA planning. Additionally, the Working Group stressed that demonstrated variable impacts along latitudinal gradients such as these, highlight the need to distribute the krill catch in space and time.

4.45 WG-EMM-2019/35 Rev. 1 summarised cetacean observations collected in Subareas 48.1 and 48.2 on board the Ukrainian vessel *More Sodruzhestva* from December 2018 to January 2019. Species and behaviour were recorded from 66 sightings of baleen whales totalling 207 minke whales and 59 humpback whales. Behaviours were similar, although minke whales were more often observed feeding and humpback behaviour was more diverse, including nursing and breaching events.

4.46 The Working Group noted that even with relatively limited spatial and temporal coverage in this survey, abundance and photo ID data were collected that contribute to describing the spatial and temporal distribution of cetaceans and the possibility of re-sighting.

4.47 The Working Group discussed WG-EMM-2019/68 which outlined a Japanese research plan to study the abundance/abundance trends and stock structure/movement of large whales in the Indo–Pacific Southern Ocean (JASS-A) (Subareas 48.6, 58.4, 88.1, 88.2, south of 60°S). The study was designed to align with previous studies including JARPA/JARPA-II and NEWREP-A, and will feature only non-lethal sampling. JASS-A is planned for the next eight years, and also includes secondary objectives related to oceanographic and marine debris surveys, use of genetic data for abundance estimates and feasibility studies on non-lethal techniques for whale research. The first survey will be conducted in the western part of IWC management Area III (0–35°E) (Subarea 48.6) in 2019/20. JASS-A welcomes participation of external scientists in both field and analytical works, following established protocols for collaboration.

4.48 The Working Group welcomed the undertaking from Japan that data from the proposed marine debris monitoring data in WG-EMM-2019/68 will be submitted to the Secretariat.

4.49 The Working Group highlighted the value of the cetacean observation data that were collected during multiple 2019 research surveys (WG-EMM-2019/07, 2019/08, 2019/22, 2019/23, 2019/24, 2019/27, 2019/35 Rev. 1, 2019/38, 2019/46, 2019/67, 2019/68, 2019/80). The Working Group noted the increase in papers submitted to WG-EMM this year assessing the abundance and distribution of whales and acknowledged that this represented increasing consideration within WG-EMM of their role in the ecosystem as consumers of krill.

4.50 In order to assess data availability for cetacean studies, the Working Group invited Members to contribute available metadata describing data that could be used for current and future issues with consultation and permission of data managers as appropriate. The Working Group established its initial priorities as to:

(i) consolidate the available data for the Area 48 risk assessment layer, and more broadly, for evaluation of the impact of krill fisheries on cetaceans

(ii) agree on standard methods to be used during future cetacean observations to facilitate combining datasets for future analyses (e.g. considering IWC protocols for line-transect monitoring)

(iii) expand the spatial coverage of cetacean data available to WG-EMM, particularly to areas outside of Area 48

(iv) discuss the collection of data on cetacean behaviour.

4.51 The Working Group noted that the important marine mammal areas (IMMAs) program (WG-EMM-2019/80) could be considered by WG-EMM to support management of marine living resources, as they have been developing a science-based approach in an area of interest for CCAMLR. Further, the Working Group agreed that a mechanism to merge current risk assessment or spatial planning efforts with emerging IMMA data layers could be considered by the Scientific Committee. Finally, the Working Group encouraged Members with photo ID data to use existing science platforms currently in use by Antarctic scientists, such as Happy Whale (https://happywhale.com).

4.52 In order to facilitate efficiency of the Working Group and its cetacean related collaboration with external organisations, the Working Group requested the Scientific Committee to provide advice and an endorsement to proceed with the following potential steps forward: (i) contact existing organisations with pre-existing datasets and ongoing work that may provide natural collaborations or analytical advice such as the International Whaling Commission Southern Ocean Research Partnership (IWC-SORP) or the IWC-SC, and (ii) appeal to appropriate Scientific Committee on Antarctic Research (SCAR) bodies that could potentially provide both data and scientific advice directly to WG-EMM such as the SCAR Expert Group on Birds and Marine Mammals (EG-BAMM).

## Ecosystem monitoring and observation

### CEMP monitoring

5.1 WG-EMM-2019/04 detailed CEMP data submissions for the 2018/19 monitoring season and an update to the Area 48 spatial analysis using combined standardised indices (CSIs). It was noted that the e-forms and CEMP database had been updated intersessionally following recommendations made at WG-EMM-18, to facilitate submission of krill length data collected from predator diets, as well as standardised breeding population size data collected at sub-optimal times (WG-EMM-2018 report, paragraphs 4.4 to 4.6).

5.2 The Secretariat informed the Working Group that Australia had registered eight new CEMP sites from Mac Robertson Land, Wilkes Land and Princess Elizabeth Land, and had submitted breeding success data collected from camera monitoring at these sites prior to WG-EMM-2019. The Working Group thanked Australia for its work to expand monitoring efforts and increase the spatial range of data submitted to the CEMP database.

5.3 The Working Group recommended the relevant CSIs be included in the annual Krill Fishery Report for Area 48. It also recommended that future analyses look at individual parameters by sites in addition to the multivariate analysis to explore emerging temporal trends.

5.4 The Working Group noted inconsistencies in data collection for some sites where logistics of data collection are more complicated, such as Laurie Island, and discussed the importance of continuing data collection at long-established CEMP sites with historical data series. The Working Group noted that Laurie Island was an important CEMP site to measure predator performance in relation to krill variability, and expanding the camera network to this site may assist with consistent data collection.

5.5 The Working Group noted that there was a positive relationship between the krill densities in the time series in the South Orkney Islands in WG-EMM-2019/69 and the CSIs from the CEMP monitoring at both Signy and Laurie Islands (WG-EMM-2019/04).

5.6 WG-EMM-2019/36 Rev. 1 analysed Adélie penguins' response to unmanned aerial vehicles (UAVs) at Cape Hallett in the Ross Sea region, as a response to Members' concerns that UAVs used for monitoring purposes may have negative side effects and disturbances on the colony. Vertical and horizontal flights for UAVs (using quadcopters and hexacopters) were flown at four specific altitudes, with behavioural response of the penguins categorised and recorded. Based on the behavioural response from visual approaches and noises by UAVs, it was suggested that minimum flight altitudes be set to 50 m for quadcopters and 100 m for hexacopters.

5.7 The Working Group thanked Dr J.-H. Kim (Korea) and others for their efforts to improve understanding surrounding the effects of UAV technology on penguin behaviour and welcomed the discussion of new methodologies that could minimise disturbance from monitoring while increasing data collection.

5.8 The Working Group considered how data collected using UAV technology might be incorporated into CEMP standard methodology and suggested that noise and size characteristics of the specific device used, rather than specification to a particular product, would be easier to develop into standard methodology.

5.9 The Working Group noted the importance of conducting work to support policy development in regard to emerging technologies that can be used in monitoring of predators and encouraged further work to develop standard methods to enable submission of data collected using drones. The Working Group also noted the recent agreement by the Antarctic Treaty Consultative Meeting (ATCM) of environmental guidelines for operation of remotely piloted aircraft systems (RPAS) in Antarctica (ATCM Resolution 4, 2018).

5.10 WG-EMM-2019/44 reported on the final stage of the CEMP Special Fund project for 'Developing an image processing software tool for analysis of camera network monitoring data' that was initiated with support from the CEMP Fund in 2015/16. The software, which has been updated since it was first presented in 2015 (WG-EMM-2015 report, paragraphs 2.181 and 6.8) with additional image-processing, data-processing and data-reporting features that, combined with the new R code written to reformat generalised output tables for specific CCAMLR needs, will allow for a seamless transition from image processing to estimation of CEMP parameters consistent with recently agreed changes to estimation methods and CEMP data e-forms. The Seabird & Penguin Population Dynamics Camera Analysis & Monitoring Software (SPPYCAMS) has been made available for use by the CCAMLR community (https://data.aad.gov.au/aadc/sppycams).

5.11 The Working Group thanked Dr C. Southwell (Australia) and others involved in the development of SPPYCAMS for their collaborative effort to complete this project and noted that the updated software would assist in the timely delivery of CEMP data to the Secretariat.

5.12 The Working Group noted that the CEMP Special Fund has funded several projects resulting in advances to monitoring work and is a useful mechanism to develop monitoring efforts and to enhance cooperation with CEMP. The Working Group encouraged the submission of proposals to the CEMP Special Fund, noting that the Fund provides opportunities to increase the number of CEMP sites and to enable other Members to begin their own monitoring programs.

5.13 WG-EMM-2019/59 and 2019/60 reported on monitoring activities at Galindez Island for gentoo penguins, including the CEMP camera data validation experiment as well as data collected in relation to behaviour and population dynamics during the 2018/19 season.

5.14 The Working Group considered the importance of conducting work to improve validation estimates arising from variability between camera-sourced data and visual-sourced data. The Working Group noted that the variability reported in WG-EMM-2019/59 was consistent with previously published results (Hinke et al., 2018) but that the ongoing validation work was critical for understanding the accuracy of results from camera sites where validation work is not possible.

5.15 The Working Group thanked Dr G. Milinevskyi (Ukraine) for his presentation and work to expand data collection at the Ukraine monitoring sites. The Working Group noted that Galindez Island is the southernmost CEMP site on the Antarctic Peninsula and highlighted the importance of continuing monitoring at this site. The Working Group noted that the biological data, including penguin population dynamics census, collected on a year-around basis at Vernadsky Station area, and organised in an accessible database, will be useful for monitoring ecosystem status and changes.

### CEMP Special Fund

5.16 The Chair of the CEMP Special Fund, Dr Santos, presented updates to the CEMP Special Fund procedures and informed the Working Group that a call for applications for funding will be sent out in July via an SC CIRC, with applications to close in August.

5.17 The Working Group endorsed the changes to the CEMP Special Fund procedures, which included incorporating the priority to maintain ongoing monitoring programs within the scope of the assessment procedure for project proposals.

5.18 The Working Group highlighted the success of the CEMP camera monitoring network, financed by the CEMP Special Fund, which has enabled several Members to either initiate or sustain monitoring efforts at CEMP sites, and noted that ongoing expansion and maintenance of the network will continue to increase capacity and engagement in CEMP.

5.19 The Working Group agreed that developing a dedicated mechanism of funding to support the camera monitoring network (e.g. to assist in costs of repairs, battery replacements) through the CEMP Special Fund would enable maintenance and expansion of these important monitoring programs and facilitate increased participation by interested Members. The Working Group recommended that the Scientific Committee support such a mechanism, noting that a simple request form submitted to the Secretariat may be a suitable approach which could be included in the administrative processes of the CEMP Special Fund.

Other monitoring data

5.20 WG-EMM-2019/37 described methods to engage citizen scientists in searching for Weddell (*Leptonychotes weddellii*) and crabeater (*Lobodon carcinophagus*) seals on satellite images, and reported that the false positive rate was high (67%) and false negative low (1.7%). This approach is proposed to further the sampling of potential habitats and reduce the search time for seal presence. Weddell seals seem to occupy less than 1% of habitat available to them.

5.21 The Working Group noted that new technologies may produce huge datasets. The development of machine learning techniques, and the use of citizen science approaches, may help increase research capacity by processing emerging datasets more quickly, and may help raise awareness of the work of CCAMLR.

5.22 WG-EMM-2019/38 provided a preliminary report on the research activities undertaken by the *Tangaroa* between 8 January and 16 February 2019. Researchers undertook a multidisciplinary research survey to collect environmental and biological data, principally from the seabed, in the eastern area of the continental slope.

5.23 The Working Group commented that such research observation efforts are extremely valuable to the objectives of CCAMLR, particularly as information for the Ross Sea region (RSR) MPA evaluation.

5.24 WG-EMM-2019/50 described the use of baited remote underwater video (BRUV) to study toothfish in areas where extractive methods cannot be used. A preliminary report on this project was presented at WG-FSA-2018 (WG-FSA-18/62). BRUVs were deployed from the fast-ice of McMurdo Sound and Terra Nova Bay as a tool to estimate abundance and length distribution of toothfish. Beyond toothfish, observations include the collection of data for various environmental factors such as depth, substrate and coverage of benthos. Various metrics are used as proxies for toothfish abundance.

5.25 The Working Group noted this method and suggested that future work may include the identification of benthic taxa and communities, protocols for identification of tagged fish and tracking fish approach angle with respect to smell plume to determine bait decay effect on abundance calculations.

5.26 WG-EMM-2019/51 Rev. 1 provided background information about mercury (Hg) cycling. It also summarised a geographical comparison of Hg levels in seawater, snow/snowmelt and biota. Results show that Hg levels in lichen and moss are 3–5 times higher in Terra Nova Bay compared to the South Shetland Islands. The paper also reported increasing levels of Hg in krill and krill predator tissues that were positively correlated with trophic position. Global change may modify the Hg cycling. This effect could be quantified with the monitoring of Hg concentration in the environment, which can be considered as an indicator of environmental health. Furthermore, the paper recommended adding Antarctic krill as a new CEMP species.

5.27 The Working Group agreed on the importance of tracking environmental Hg, but noted that the influence of volcanic activity and establishing baseline Hg levels by sampling ancient biological archives, like corals, may be considered in future work.

5.28 WG-EMM-2019/53 and 2019/54 described four different barcoding programs in the Southern Ocean. Two were conducted within the French Kerguelen exclusive economic zone (EEZ): a fisheries observer ID quality control study and a large-scale barcoding project of invertebrates collected during the POKER 4 cruise that will provide a molecular reference database for the area. The third project extended barcoding to mitogenomes for fish, and the fourth used standardised autonomous reef monitoring structures for micro-fauna colonisation study using metabarcoding in Terre Adélie. New sequencing approaches decrease costs and open new study opportunities for multiplex barcoding, mitogenome sequencing and metabarcoding. These projects will provide reference sequences for future projects such as environmental DNA studies or diet identification. The Working Group noted the remarkable amount of work done and congratulated the authors for their significant effort.

5.29 WG-EMM-2019/62 and 2019/64 reported on research projects conducted on board the *More Sodruzhestva* during the 2019 Area 48 Survey when the vessel continuously recorded various physical and biological parameters, including phytoplankton and mesozooplankton from station 1735 of the survey. Additionally, persistent pollutants in the water column near Vernadsky Station were monitored using passive samplers. The baseline dataset accumulated during this survey will be valuable in understanding the effects of climate change in the area. Furthermore, a bacterial metagenomics study is planned.

5.30 The Working Group commended the collaborative and multifaceted nature of the Ukrainian research efforts this year (WG-EMM-2019/61) and reflected that it has resulted in an increase of Ukrainian engagement in Antarctic research and contribution to WG-EMM.

5.31 WG-EMM-2019/65 reported on a census of Antarctic fur seal pups from the San Telmo Islands in December 2018 using a medium-range, vertical take-off and landing (VTOL) drone. The corrected census highlighted a dramatic decrease in the fur seal population at San Telmo Islands (90% since 1997). The paper concluded that the Antarctic fur seal population in the South Shetland Islands should be reassessed.

5.32 The Working Group noted that VTOLs provide a minimally invasive, inexpensive and accurate (error rates <2%) survey tool for Antarctic predators, including ice seals. The Working Group discussed how leopard seal predation is negatively affecting Antarctic fur seal populations in this area, but is unlikely to have caused the regional decrease of penguin populations.

### Review of CCAMLR research and monitoring design and implementation

5.33 WG-EMM-2019/57 outlined components to be considered in further refining CCAMLR's management of the krill fishery, including:

(i) can fishery at its present level really affect krill resources and the status of populations of dependent predators and, if so, where, in what spatial–temporal scales and under what conditions?

(ii) development of scientifically based indicators of the status of dependent predators. After how many years can response of such indicators to the impact of the fishery be revealed?

(iii) research on ecosystem and competitive relationships between dependent predator species, instead of the proposed approach based on consideration of the penguin species only

(iv) development of scientifically based criteria and diagnostics to assess the possible ecosystem impact of the fishery, taking into account the mixed effects of fishing, environmental variability (or climatic changes) and the competitive relationship between predator species

(v) development of target points for the status of populations of dependent predators and decision rules on the krill fishery management, taking into account these target points.

5.34 Dr Kasatkina further noted that CEMP, acoustic survey and fishery data should be combined to address these components, and that changes in predator populations and krill availability around South Georgia and the Bransfield Strait provided ‘natural experiments’ that could be used to understand the ecosystem impact of the krill fishery and hence likely responses to the fishery. She also noted that the suggested candidate data provide the possibility to develop time series data for the further integrated analysis to understand whether there is only a spatial overlap between the predators and the fishery or if this is a functional overlap.

5.35 The Working Group noted that the outcomes of the focus topic (Agenda Item 2) had reached similar conclusions to the authors of WG-EMM-2019/57 on the key components that need to be addressed to provide revised management advice for the krill fishery in 2021. The Working Group noted that work in several papers presented at the current meeting specifically addressed many of these components (paragraphs 2.3, 2.4, 3.42, 3.45 and 4.41). It encouraged Members to continue such analyses to further enhance understanding of key processes that may impact on the krill stock and dependent predators, including fishing and environmental variability. It further noted that the relative importance of different processes was likely to be highly dependent on spatio–temporal scales, and that long-term datasets were critical to interpreting observations.

## Spatial management

### New Antarctic Specially Protected Area (ASPA) proposals

6.1 The Working Group considered draft management plans for new Antarctic Specially Protected Areas (ASPAs) at the Rosenthal Islands, Anvers Island, Palmer Archipelago, proposed by the USA (WG-EMM-2019/01) and Inexpressible Island and Seaview Bay, Ross Sea, proposed by China, Italy and Korea (WG-EMM-2019/40).

6.2 Recalling previous occasions on which it had discussed draft ASPA proposals (e.g. WG-EMM-2012 report, paragraph 3.7), the Working Group noted that prior approval from the Commission is required for the adoption of ASPAs: (i) in which there is actual harvesting or potential capability of harvesting of marine living resources which might be affected by site designation, or (ii) for which there are provisions specified in a draft management plan which might prevent or restrict CCAMLR-related activities (ATCM Decision 9, 2005). The Working Group agreed that it would restrict its advice to consideration of these points, but noted that further clarification could be sought from the Scientific Committee on the process for engagement with the ATCM on the development of ASPAs, if required.

6.3 The Working Group noted that the proposed ASPA at the Rosenthal Islands lies within the existing Southwest Anvers Island Antarctic Specially Managed Area (ASMA), which includes the Palmer long-term ecological research (LTER) study area. The primary reasons for designation of the area are its large and diverse colonies of breeding birds which are of exceptional ecological and scientific interest, its rarely visited and almost pristine condition, and its potential role as a reference area for comparisons with localities that have been affected by human activities. The marine component of the proposed ASPA extends up to 1 km seaward from the outer shores of the Rosenthal Islands, and to a maximum depth of less than 100 m.

6.4 Dr Zhao suggested that the proponents could consider providing further details on the link between the marine and terrestrial environments and the characteristics of the marine component to facilitate consideration of the inclusion of a marine component in the proposal.

6.5 The Working Group noted the importance of the Rosenthal Islands as a minimally impacted reference area of exceptional scientific interest.

6.6 The Working Group agreed that there is currently no harvesting in the Rosenthal Islands and the area is not of interest for harvesting activities, therefore it recommended approval of the draft management plan for a new ASPA in this area by the Scientific Committee.

6.7 In considering the proposed ASPA at Inexpressible Island, the Working Group noted that this area contains a distinctive ecosystem hosting one of the oldest known colonies of Adélie penguins and an important breeding site for south polar skuas, and is listed as an Important Bird Area (IBA). The area is adjacent to the Terra Nova Bay polynya, and is a reference site allowing comparison with nearby areas for studies on the effect of sea-ice dynamics on the ecosystem. The marine component of the proposed ASPA extends less than 1 km from the coast, and does not exceed 50 m in depth.

6.8 The Working Group noted the importance of the unique ecosystem at Inexpressible Island for ongoing, comparative scientific research.

6.9 The Working Group agreed that there is currently no harvesting at Inexpressible Island and the area is not of interest for harvesting activities, therefore it recommended approval of the draft management plan for a new ASPA in this area by the Scientific Committee.

6.10 Dr L. Krüger (Chile) indicated that Chile intends to submit a revised management plan for ASPA No. 146, South Bay, Doumer Island, Palmer Archipelago, for consideration at WG-EMM-2020, with updated information from scientific research conducted in the area.

MPA research and monitoring

6.11 WG-EMM-2019/77 described updates made by the Secretariat to the proposed data structure and implementation of the MPA Research and Monitoring Plan (RMP) Project List database. This forms part of the CCAMLR MPA Information Repository (CMIR), which will allow Members to interact with RMPs, including project lists. Updates to the database structure have been made based on recommendations from the Workshop on Spatial Management (WS-SM-2018), and following analysis of the common elements of existing RMPs. The Secretariat informed the Working Group that it would continue to develop elements of the CMIR and would update Members on progress intersessionally.

6.12 The Working Group thanked the Secretariat for its work in developing this important resource, which will help to increase transparency and accessibility of data, particularly as further information is generated through developing RMP activities. The proponents of the Weddell Sea MPA (WSMPA), D1MPA and the South Orkney Island southern shelf (SOISS) MPA indicated that they would work with the Secretariat in the intersessional period to provide links to relevant data layers and to populate the Project List database.

6.13 WG-EMM-2019/08 described research on habitat use of Type C killer whales (*Orcinus orca*) in the Ross Sea, which revealed discrete, largely non-overlapping areas of restricted search (ARS) along the coastline, indicating possible feeding grounds. The Working Group congratulated the authors, noting that this type of predator foraging data, especially for killer whales, is difficult to obtain, and agreed that this is a valuable contribution to the RSRMPA RMP. The Working Group further noted that this project is a good example of work to be included in developing the CMIR.

6.14 The Working Group considered WG-EMM-2019/31, outlining a revised draft RMP for the SOISS MPA. This draft plan takes account of recent work and general recommendations by the Scientific Committee on the development of RMPs, and sets out research and monitoring topics that address questions relevant to the specific MPA objectives. The draft plan also includes a Project List with information on completed and underway research activities, and details of relevant datasets, including (i) baseline data used in the designation of the MPA, and (ii) additional data available subsequent to the adoption of the MPA. Further information, including an updated MPA Report, will be provided to the Scientific Committee as part of the MPA review scheduled to be undertaken in 2019.

6.15 The Working Group welcomed this update, recalling that WS-SM-2018 had provided useful recommendations on the presentation of RMPs. It suggested that additional information on research fishing in Subarea 48.2, krill catch distribution and cetaceans could be added to the list of relevant data in Annex 1 of the RMP. In considering the role of this MPA as a reference area, the Working Group also noted that further information on the requirements for comparison with other areas in Domain 1 would be useful. However, it noted that this is not the only objective of the SOISS MPA, and that signals of change may not be evident over short time periods.

6.16 Dr Kasatkina suggested that the proposed two indicator species would not be sufficient for monitoring and assessing the effectiveness of MPAs in terms of marine ecosystem and biodiversity. Dr Kasatkina noted that additional indicator species would be needed and these indicators would be accompanied by their characteristics at the time of the establishment of the MPA.

6.17 The Working Group considered WG-EMM-2019/14, the Report of the Workshop on data and modelling issues relevant to the planning of a potential MPA east of the zero meridian in the Weddell Sea (Maud). The workshop objectives were: (i) to discuss the available data, gaps in data and future priorities for data collection, including ways to openly share existing and new data, and (ii) to decide on a candidate list of realistic modelling options to support a scientifically sound future MPA proposal appropriate to the available data and scientific knowledge. The workshop considered and discussed the current understanding of ecosystem connectivity and ecoregion representativeness within and beyond the Maud area, and candidate analytical tools to consider ecoregions and potential connectivity.

6.18 The Working Group welcomed progress towards the development of an MPA in the Maud region, which includes important bioregions that are not present elsewhere in the Convention Area. It discussed the use of different modelling options in the development of MPAs, noting that appropriate options could be selected based on the characteristics of different regions.

6.19 Dr Kasatkina noted that future further information on dominant fish species and krill would be useful for planning an MPA in the Maud region to designate areas for protection and potential fishing activity in the frame of this MPA.

6.20 WG-EMM-2019/71 outlined a study on connectivity patterns along the Antarctic Circumpolar Current (ACC) in the sub-Antarctic region. The review aimed to characterise dynamical mechanisms structuring primary production and trophic hotspots at a regional scale, and cross-boundary dispersal patterns of water between and beyond island groups. Methods such as Lagrangian tools and observations from high-resolution remote sensing provide new approaches for identifying physical connectivity pathways structuring the pelagic ecosystem, and could be integrated in ongoing pelagic spatial planning activities for the eastern sub-Antarctic region.

6.21 The Working Group noted the development of these techniques in linking physical ocean processes to ecological dynamics at various trophic levels, will be useful in identifying areas of importance at smaller spatial scales and understanding connectivity between regions.

6.22 Dr Lowther noted that a scientific experts workshop will be held in Cape Town from 26 to 30 August 2019 to examine pelagic connectivity across the sub-Antarctic region.

6.23 WG-EMM-2019/80 described recent work by an IUCN SSC/WCPA Joint Task Force on Marine Mammal Protected Areas (MMPA Task Force) to identify IMMAs. These areas are defined as 'discrete portions of habitat, important to marine mammal species, that have the potential to be delineated and managed for conservation'. An experts workshop held by SCAR in 2018 identified candidate IMMAs based on criteria including vulnerability, distribution and abundance, key life-cycle areas, distinctiveness and diversity. The next stage of the process will be to finalise the candidate IMMAs based on peer review by an expert panel.

6.24 The Working Group noted the development of this work, particularly in the context of its other work on cetaceans (paragraphs 2.39, 4.37, 4.45 to 4.52) and looked forward to the presentation of the IMMA scientific protocol at the Scientific Committee meeting in 2019. The Working Group noted that IMMAs are designed to inform policy makers about general management and conservation processes.

## D1MPA

6.25 Dr Santos informed the Working Group that during this intersessional period the D1MPA proponents have been working with Members to progress the development of a D1MPA proposal in line with a comprehensive krill fisheries management approach. This has included an informal meeting with colleagues from Norway (report shared with the D1MPA Expert Group), participation in krill fishery management discussions during this Working Group meeting and at the Workshop on Krill-fishery Management for Subareas 48.1 and 48.2 (WG-EMM-2019/25 Rev. 1). In all these processes, similarities have been observed, and the proponents are working towards consolidating them in a single vision. In order to progress to a revised version of the proposal, Members with outstanding issues are invited to provide their comments to the proponents.

## Data analysis supporting spatial management approaches in CCAMLR

6.26 WG-EMM-2019/05 described WSMPA data layers that have been deposited with the data repository PANGAEA. The following DOIs link to the corresponding datasets:

(i) Flying seabird and penguins: https://doi.org/10.1594/PANGAEA.899520
(ii) Demersal and pelagic fishes: https://doi.org/10.1594/PANGAEA.899591
(iii) Pelagic regionalisation approach: https://doi.org/10.1594/PANGAEA.899595
(iv) Seals: https://doi.org/10.1594/PANGAEA.899619
(v) Zoobenthos: https://doi.org/10.1594/PANGAEA.899645
(vi) Zooplankton: https://doi.org/10.1594/PANGAEA.899667.

6.27 The Working Group agreed that the interlinkage of such data from MPA developments through the CMIR (see WG-EMM-2019/77) using the relevant DOIs would be appropriate.

6.28 The Working Group considered two papers on the development of a marine area for protection at the Argentine Islands. WG-EMM-2019/19 described acoustic and underwater studies of the seabed off the Argentine Islands, continuing observations that have been made at a network of marine sites since 2012. WG-EMM-2019/63 outlined progress on the development of small-scale MPAs in the Argentine Islands Archipelago. Dr Milinevskyi confirmed that Ukraine intends to propose the designation of long-term environmental monitoring sites around the Argentine Islands, including relevant CEMP sites, as a new ASPA under the provisions of the Environmental Protocol to the Antarctic Treaty.

6.29 The Working Group encouraged the continuation of data collection and the further development of an ASPA proposal in the Argentine Islands Archipelago, which was highlighted as an important area in the D1MPA planning process.

6.30 WG-EMM-2019/48 described the recent Norwegian cruise to Kong Håkons VII Hav. The study area was the ocean south of 65°S east of 0° meridian and 13.5°E, with a focus on Astrid Ridge, and the cruise included work packages on bird and marine mammal observations, fish community, benthic mapping, zooplankton, primary production, oceanography, ocean carbon chemistry and ocean acidification. The Working Group recognised the importance of multidisciplinary cruises in regions where data are currently limited, and looked forward to receiving further results next year.

6.31 Dr Belchier noted that the UK had undertaken a physical oceanographic cruise (ANDREX II) to the east of the prime meridian at around the same time, which might provide additional information of interest for this region.

6.32 WG-EMM-2019/39 reviewed changes in environmental conditions of the Southern Ocean observed by satellites and data-assimilating models between 1981 and 2019. This data showed heterogenous patterns of environmental change across the Southern Ocean over the last four decades, including warming of the ocean surface north of the southern limit of the ACC and slight cooling to the south, and gradual loss of sea-ice in the Amundsen Sea and increasing sea-ice in the Weddell, Bellingshausen and Ross Seas.

6.33 The Working Group recognised the importance of such analyses in informing management strategies that are robust to the uncertainties produced by a changing climate. It noted that warming may not have occurred in some regions (e.g. Subareas 48.1 and 48.2) during recent decades, but that variability and unpredictability of environmental conditions are likely to increase across all regions. In addition, understanding the signals and impacts of change becomes more difficult at smaller scales, as highlighted by the recent Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) Krill Projections Workshop (WG-EMM-18/09, WG-EMM-2019/02 and paragraph 7.7).

6.34 WG-EMM-2019/20 on habitat partitioning in Antarctic krill, including spawning hotspots and nursery areas, and WG-EMM-2019/30, on the development of mIBAs for penguins in Antarctica, were also submitted under this agenda item, but were discussed in paragraphs 2.44, 4.15 and 2.41 and 2.42 respectively.

### VME data and spatial planning approaches

6.35 WG-EMM-2019/52 described a method to assess the probability of vulnerable marine ecosystem (VME) indicator species reaching the CM 22-07 trigger threshold given the number of hooks, number of specimens and average weight of specimens using sea pens collected from research block 5844b_2 as a case study.

6.36 The Working Group noted from this case study that even though this region has the highest by-catch of this taxon ever recorded in the Convention Area, the trigger level in CM 22-07 had not been reached and no VME risk area had been designated. In this instance, reducing the threshold limit by a factor of four would lead to areas of highest density being designated a risk area. Hence, the Working Group agreed that further exploration of taxa and/or morphology-specific trigger limits be evaluated. To expedite this work, it was noted that protocols to collect taxa-specific weights would assist, noting that as vessels collect VME by-catch data, any data collection protocol needs to be practical and easy to realise on board vessels with a minimum of technical training. For example, specimens from a bucket may be spread on a checkered mat and photographed so measurements and identifications can be made by a trained taxonomist, or using image analysis algorithms that are under development.

6.37 WG-EMM-2019/73 Rev. 1 described habitat suitability of the VME indicator species, *Ptilocrinus amezianeae*, over the Kerguelen Plateau in Divisions 58.5.1 and 58.5.2. The methods used, repeated boosted regression tree (BRT) helped identify areas suitable for *P. amezianeae*, some of which are already protected, and others such as areas in the northeast of the Kerguelen Plateau in Division 58.5.1, and William's Ridge which extends to the east beyond Division 58.5.2 into the Southern Indian Ocean Fisheries Agreement (SIOFA) area, are not. The Working Group noted that Australia was planning a research voyage to study the geomorphology of William's Ridge, including video transects along bathymetric gradients, and looked forward to confirming whether *P. amezianeae* is present in the area as predicted.

6.38 The Working Group agreed that modelling the habitat of VME taxa is useful to put by-catch observation in a broader context. It noted that VME taxa such as *Ptilocrinus*, which are likely to be relatively easy to recognise on the vessels, would be a good example of species to use to collect data to generate larger-scale species distribution models and identify areas of special interest. It is, however, necessary to check that the minimum number of occurrence data is available, across a suitable scale, to allow useful extrapolation and interpolation. The Working Group also noted that in any modelling approach, using a subset of data to 'train' the model, and comparing predictions into areas with data, was an important step in model evaluation. The Working Group discussed the relevance of predicting habitat suitability over unsampled areas and agreed that sampling outside the model area is ideal to ground truth such predictions.

6.39 The Working Group also noted that the Scientific Committee had considered a focus topic on VMEs be considered for WG-FSA-2019. The Working Group considered the possibility to discuss VMEs during WG-FSA-2019 in parallel to fish stock assessments and suggested that this could be done during the second week of WG-FSA.

6.40 The Working Group requested that the following topics be considered during the VME focus topic:

(i) procedures for developing taxon-specific thresholds for triggering move on rules and risk areas

(ii) revision and updates of exploratory fishing footprint estimates

(iii) case studies of best practice in modelling benthic biodiversity including species, assemblages and functional groups

(iv) identification of protocols for evaluating VME risk areas after they have been declared, such as camera surveys to establish nature and extent of VME indicators.

## Climate change and associated research and monitoring

7.1 The Working Group revisited WG-EMM-2019/22 with a presentation emphasising the complex hydrographic circulation patterns around the Antarctic Peninsula and the disparate patterns of impact on glacier melting rates and their indirect effects on levels of productivity between the northern and southern regions. The Working Group thanked the authors of the source papers (Cook et al., 2016; Moffat and Meredith, 2018), noting that circulation patterns influence the distribution of krill and can impact the development of egg and larval stages of krill and agreed that including considerations of physical hydrography was important when developing a krill fisheries management strategy. More studies are encouraged in the study area given its oceanographic and ecosystem complexity.

7.2 WG-EMM-2019/66 reported on the analysis of the international Southern Ocean continuous plankton recorder (CPR) survey data between 1971 and 2018. BRT models were used to investigate the relationships between the abundance of key zooplankton groups and their occurrences and environmental conditions. Analyses suggested that trends on the environmental suitability for copepods may lead to increased abundances between 0.59% and 0.83% per annum across the Southern Ocean but with variability across regions. In contrast, suitability for pteropods is predicted to decrease in the Ross Sea. Sub-Antarctic zooplankton communities have either remained stable or decreased over the study period, whereas Polar Frontal and southern sea-ice associated communities have expanded and decreased respectively. The authors place their results in the context of evaluating the conservation value of the RSRMPA against its specific objectives.

7.3 The Working Group acknowledged the value of assembling long-term datasets across large areas, particularly in highlighting the non-uniform reaction of zooplankton to climate change. The Working Group noted that there are additional modelling methods that could be applied to model the CPR data at the assemblage level (e.g. Hill et al., 2017), which is likely to provide additional context on how zooplankton is distributed and responds to environmental variability in the Southern Ocean.

7.4 WG-EMM-2019/74 reported on the extinction risk of Adélie, chinstrap and gentoo penguins under present-day and future environmental scenarios to identify the most endangered colonies. The extinction risk was estimated for twelve colonies from environmentally contrasting areas, such as the Antarctic Peninsula, Ross Sea and East Antarctica. Intraspecific competition as an endogenous process was identified as the most important driver of extinction probabilities across all colonies, while responses to climate change were more varied and related to local conditions. The authors showed that the most vulnerable Adélie penguin colonies are distributed along the South Shetland Islands on the Antarctic Peninsula and at Syowa Station in East Antarctica, and that for sub-Antarctic gentoo penguin colonies at Marion Island demographic predictions appeared to be governed by the SAM index.

7.5 The Working Group noted that while some colonies of penguins were predicted to decline, others have been observed to be increasing in numbers, in particular the presented at-risk areas for Adélie penguins at Syowa Station contrasting with observed increases in population sizes over the preceding three decades. The Working Group agreed that migration to new areas and decreasing demographic trends in others may be parallel processes. The Working Group further agreed that studies such as these are useful to highlight to the Scientific Committee the implications of climate change in its work. The Working Group also noted that, given the different responses of Adélie penguin populations in the eastern and western Antarctic Peninsula, and the remaining large colonies that are still being observed in areas near the northern tip of the Peninsula, it is important to consider an extra level of protection to that area.

7.6 The Working group discussed WG-EMM-2019/P02 (paragraph 4.20) in the context of the climate change influence on the whole structure of the Antarctic ecosystem, including krill stocks, noting that the paper provides a graphical summary of potential effects. The Working Group agreed that the presentation of scientific data from the paper was useful and is well summarised. The Working Group noted that there is ongoing debate on trends in net-based estimates of krill density (e.g. Cox et al., 2019; Hill et al., 2019). The Working Group advised that efforts should be focused on collating all available information and providing balanced summaries. The Working Group further agreed that the climate change associated risks to krill and the ecosystem it supports emphasise the need for precautionary management of the krill fishery.

7.7 WG-EMM-2019/02 highlighted recent ICED research and activities on Southern Ocean ecosystems and changes, focusing on areas of interest to CCAMLR and joint ICED–CCAMLR activities, and suggested ways to continue to strengthen the links between ICED and CCAMLR. The Working Group encouraged CCAMLR involvement in relevant ICED activities to jointly identify, prioritise and address key scientific issues with respect to the management of Southern Ocean ecosystems in the face of changes being observed and expected.

7.8 The Working Group welcomed the updated activities of ICED and expressed interest in seeing the published results from the joint ICED–CCAMLR workshop held in 2018. The Working Group agreed that communicating to ICED the outcomes of WG-EMM-2019 in terms of developing a krill fisheries management strategy would be useful, highlighting areas where ICED can contribute, for example (i) developing data layers for the risk assessment in the context of climate change, (ii) time frames and scales for climate change information to be included in a krill stock assessment. In this context, the Working Group also welcomed the continuing collaboration between ICED and SKAG to ensure the potential for the duplication of work between the two groups was minimised.

7.9 Dr Santos highlighted that the proponents of the D1MPA had considered climate change in the design of the MPA model and incorporated the impacts of climate change as key priorities for research. The proponents would continue to work with ICED to develop research priorities for the D1MPA RMP.

## Other business

8.1 The Working Group considered the discussion by WG-SAM-2019 on the crab research results (WG-SAM-2019 report, paragraphs 6.101 to 6.111), and noted that 45 pots were lost during operations, as well as a further 30 damaged. The Working Group considered the potential impacts of these pots as abandoned, lost, or otherwise discarded fishing gear (ALDFG), and the effect they may have on the benthos and seabed area, as well as the potential for ghost fishing into the future.

8.2 The Working Group noted that previous fishing activities targeting toothfish using pot fishing gear were required to use biodegradable netting panels to minimise impacts on the environment in the case that pots were lost, and requested clarification from Russia on the materials used for their pots.

8.3 Dr Kasatkina noted that the report on implementation of the Russian research program was provided to WG-SAM and highlighted that each pot was equipped by special biodegradable cotton netting panels (WG-FSA-18/32 Rev. 1, Figure 3).

8.4 The Working Group further noted the discussion at SC-CAMLR-XXXVII (SC-CAMLR-XXXVII, paragraph 4.3) which recommended that the crab research proposal proceed with the use of benthic cameras to document and examine the impact of pots on benthic habitats. The Working Group highlighted the importance of having an agreed approach for research to proceed and strongly recommended that cameras are used to assess impacts on the ecosystem.

8.5 Dr Kasatkina clarified that benthic cameras were not obtained in time for use during the research trip, but that Russia would endeavour to implement all the recommendations made at

WG-FSA-2018 (WG-FSA-2018 report, paragraphs 4.210 to 4.217) and SC-CAMLR-XXXVII (SC-CAMLR-XXXVII, paragraph 4.3) for this next season, including any new recommendations made at WG-FSA-2019. Dr Kasatkina further noted that the research represented a pilot program on the investigation of crab biology and spatial distribution, and that the number of by-catch species was very small, that the total weight of by-catch of Antarctic toothfish (*Dissostichus mawsoni*) was 434 kg from a catch limit of 5 tonnes and the total weight of the retained catch of targeted crabs was 569 kg for the catch limit of 500 tonnes.

## Future work

9.1 The Working Group agreed that a clear priority for its future work was to implement the workplan for the krill fishery management as described in paragraph 2.62 according to the timelines in Figure 1.

9.2 The Working Group agreed that having a one-week focus topic on the krill fishery management strategy had allowed it to make significant progress and recommended that the meeting follow a similar schedule in 2020.

9.3 The Working Group noted that this structure and scheduling of the meeting provided flexibility in the attendance of relevant experts and requested that the Secretariat provide a means for attendees registering for the meeting to indicate whether they would be attending all or part of the meeting as this would greatly assist the meeting coordinators and the hosts in preparing facilities and support for the meeting.

9.4 The Working Group recognised that there had been a number of proposals for additional workshops/focus topics over the next 12–18 months and requested the Scientific Committee find a mechanism that would allow the tasks outlined to be included, to the extent possible, within the existing time commitment of the intersessional meetings of the Scientific Committee.

9.5 The Working Group also noted the need to develop sustained funding streams for the work required to deliver and maintain the krill fishery management strategy. This is likely to include, but not be limited to, the use of the CEMP Fund and the General Science Capacity Fund.

9.6 The Working Group encouraged those with an interest in proposing additional workshops/focus topics to submit terms of reference for those meetings to the Scientific Committee in order that it can coordinate the work required.

## Advice to the Scientific Committee and its working groups

10.1 The paragraphs containing the advice of the Working Group to the Scientific Committee (and its working groups) are summarised below; these advice paragraphs should be considered along with the body of the report leading to the advice:

(i) outcomes of a Workshop on Krill-fishery Management for Subareas 48.1 and 48.2 (paragraph 2.2)

(ii) prioritisation of the work required for the development of a management strategy for the krill (paragraphs 2.20 and 2.38)

(iii) request to SG-ASAM to prioritise estimation of krill biomass and associated confidence intervals on the subarea scale (paragraph 2.21)

(iv) focus topic for WG-EMM-2020 on data standards for use in risk assessment layers (paragraph 2.25)

(v) operational considerations and catch reporting frequency for the krill fishery (paragraphs 2.36 and 3.5)

(vi) summary of advice to the Scientific Committee on the development of a preferred option for the management of the krill fishery in Area 48 (paragraphs 2.60 to 2.64)

(vii) use of net monitoring cables (paragraph 3.12)

(viii) continuous trawl catch recording (paragraph 3.19)

(ix) proposed workshop on priorities for data collection, information sharing and overall tasking for observers in the krill fishery (paragraph 3.38)

(x) proposed workshop on krill ageing methods standardisation (paragraph 4.29)

(xi) collaboration with external organisations on cetaceans (paragraph 4.52)

(xii) use of the CEMP Special Fund to support to the camera monitoring network (paragraph 5.19)

(xiii) ASPA proposal reviews (paragraphs 6.6 and 6.9)

(xiv) VME Focus Topic at WG-FSA-2019 (paragraphs 6.39 and 6.40)

(xv) a mechanism to allow additional tasks to be completed in intersessional workshops and focus topics (paragraph 9.4).

## Adoption of the report and close of the meeting

11.1 At the close of the meeting Dr Cárdenas thanked all participants for their positive engagement in the meeting and the rapporteurs for their great work in preparing the report including the careful consideration of some sensitive discussions. He also thanked the Secretariat for their support prior to and during the meeting. Dr Cárdenas thanked the local MNHN hosts, in particular Mr Jonathan Blettery who had provided fantastic support that had ensured the smooth running of meeting.

11.2 Dr Cárdenas also thanked the Commission for the agreement in 2018 to support the funding of conveners to Working Groups and he was delighted to have been the first convener to be supported in this way.

11.3 On behalf of the Working Group, Dr Zhao congratulated Dr Cárdenas on his first meeting as convener being a very productive working group meeting that had also provided very clear advice on the management of the krill fishery. He also thanked Dr Cárdenas for facilitating the diverse engagement in plenary discussions and in subgroups that had engendered a strong spirit of cooperation.

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Table 1: Action plan to develop advice to enable revision of Conservation Measure (CM) 51-07. This and subsequent tables are designed to outline the process whereby the Scientific Committee may provide advice on CM 51-07, as per SC-CAMLR-XXXVII, paragraph 13.2. The highest priority work areas identified sit within the remit of WG-EMM, however, other elements are also important and can be worked on in parallel. Members/groups are proposed coordinators for work, but all Members are welcome to contribute to progressing work. Detailed work plans for the highest-priority elements are provided in Tables 2 to 8. CEMP – CCAMLR Ecosystem Monitoring Program; AMLR – US Antarctic marine living resources program; NEMO – Nucleus for European Modelling of the Ocean; ROMS – Regional Ocean Modeling System; SKAG – SCAR Krill Action Group; MSE – Management strategy evaluation.

| Action | Priority | Timeframe | Spatial scale | Temporal scale | Data input | Coordinating Members/groups | Scientific Committee body reviewing |
|---|---|---|---|---|---|---|---|
| Updated time series of biomass estimates of krill | Highest | WG-EMM-2021 | Area, subarea and fishing grounds | Interannual | Synoptic surveys, industry and AMLR transects, sail buoy and glider missions | Norway, USA, China (48.1, 48.2, 48.4) UK (48.3) | SG-ASAM, WG-EMM, WG-SAM |
| Estimate of krill flux | Medium | | Fishing grounds | Monthly | Industry and AMLR transects, moorings, sail buoy and glider missions, NEMO and ROMS outputs | Norway, USA, UK, Russia | SG-ASAM, WG-EMM, WG-SAM |
| Preliminary risk assessment including predator, krill and by-catch data layers | Highest | WG-EMM-2021 | Area, subarea and fishing grounds | Seasonal | Predator tracking, at-sea observations, expert opinion (fish and squid) | UK (predator layers), Norway, SKAG (krill life stages) | WG-EMM-2020 |
| Review CEMP to ensure effective coverage of fished and non-fished areas, and development of indices for rapid assessment of predator responses | Medium | | Area, subarea | Seasonal | CEMP observations, camera and tracking data | All | WG-EMM |
| Develop a harvest strategy for krill fishing, including catch limits and spatial distribution of catch | Highest | WG-EMM-2021 | Area, subarea | Interannual | Biomass estimates, stock assessment, risk assessment, ecosystem models, fleet dynamics, MSE | All | WG-EMM, WG-SAM, WG-FSA |
| Recommendations for process to develop scientific basis for revision of CM 51-07 | Highest | SC-CAMLR-38 | Area, subarea | Interannual | Biomass estimates, stock assessment, risk assessment, ecosystem models, fleet dynamics, MSE | All | SC-CAMLR |

Table 2: Work plan for GYM reparameterisation. LTER – US long-term ecological research program; AMLR – US Antarctic marine living resources program; BAS – British Antarctic Survey; MODIS – Moderate resolution imaging spectradiometer; SST – sea-surface temperature; POC – particulate organic carbon; VB – von Bertalanffy; AUS – Australia; UK – United Kingdom; USA – United States of America

| GYM parameter | Spatial Scale | Information (e.g. relevant papers) | Data series | Method for parametrisation | Responsible Members/groups |
|---|---|---|---|---|---|
| Recruitment | 48.1 | Kinzey et al., 2013, 2015, 2019, | LTER, AMLR, combined German-US regional survey, predator diets, fishery data German cruise | E.g. extract <40 mm krill as recruits, at monthly scale. | Secretariat and external data contribution |
| | 48.2 | Thanassekos et al., 2014 | Norway 2009, AMLR survey in 2008, BAS penguin diet, fishery observer data | Check the size range of age-1 with growth models (subarea dependent). | |
| | 48.3 | | BAS Western core box survey series, penguin, fur seals, fish diet, fishery observer | | |
| | 48.4 | | No time series available, only occasional net data in 2000, 2008 and 2019 synoptic surveys | To be informed by recruitment series from Subareas 48.1, 48.2 and 48.3. | |
| Growth | 48.1<br>48.2<br>48.3<br>48.4 | Atkinson et al., 2006, Constable and Kawaguchi, 2017 | Use LTER krill length data as a base case to reality check/performance check the seasonal growth model.<br>Chlorophyll from MODIS or Aquarius (level 4).<br>SST: optimally interpolated dataset (e.g. less than 20 km) | Simulate growth using available growth model that can handle environmental factors (e.g. Atkinson et al., 2006, Constable and Kawaguchi, 2017) by using climatology of seasonal temperature and chlorophyll (possibly POC) at subarea scale, weighted by krill distribution, and determine parameters for seasonal VB that approximates these patterns. | Secretariat, UK, AUS |
| Mortality | 48.1<br>48.2<br>48.3<br>48.4 | Kinzey et al., 2013, 2015, 2019; Murphy and Reid, 2001 | | Estimate M<br>Seasonal variation<br>(Scaling of season to be informed by risk assessment group outcome) | Secretariat, USA |

Table 3: Actions to combine risk assessment and biomass estimates to evaluate and revise the krill harvest strategy in Area 48. GYM – generalised yield model; AUS – Australia; CHL – Chile; CHN – China; KOR – Republic of Korea; NOR – Norway; UK – United Kingdom; USA – United States of America; UKR – Ukraine; ARK – Association of Responsible Krill harvesting companies.

| Action | Inputs | Priority | Coordinating Members/groups |
|---|---|---|---|
| Recompile GYM model in open-source code | Current GYM functions | High | AUS, Secretariat |
| Collate best estimates of growth, recruitment and natural mortality, and variability at subarea scales | Existing studies of parameter estimates e.g. Atkinson et al., 2006, Constable and Kawaguchi, 2017, Kinzey et al., 2013, 2015, 2019, AMLR time series, catch and length from research and fishery hauls, productivity and source-sink relationships between subareas | High | USA, NOR, UK, AUS |
| Evaluate alternative implementation of decision rules, e.g. short-term projections with regular biomass updates | GYM or other assessment model with updated parameters | High | USA, UK |
| Update estimate(s) of gamma (γ, biomass exploitation rate) for krill in Subareas 48.1–48.4 | GYM or other assessment model with updated parameters | High | USA, NOR, UK, AUS |
| Estimate of area and subarea catch limits | Subarea and area biomass estimates, subarea and area gamma estimates | High | UK, USA, NOR |
| Estimate risk associated with catch distribution scenarios | Estimate of area and subarea distribution of catches, risk assessment populated with key predator layers | High | UK, AUS |
| Canvas expectations of the fishing industry of size and variation in fishery yields | Discussions with industry stakeholders | Medium | ARK, NOR, CHN, CHL, UKR, KOR |
| Evaluate current fishery reporting and closure mechanisms under future harvest scenarios | Catch limit and fleet size scenarios | Medium | Secretariat |

Table 4: Priority elements and timeline to progress the estimation of krill biomass for use in a stock assessment.

| Action | 2019 | 2020 | 2021 | 2022+ |
|---|---|---|---|---|
| Updated time series biomass estimate of krill | | | | |
| Large-scale survey krill density (e.g. Area 48) | Data validation and biomass estimate (SG-ASAM), taking into account recommendations from WG-EMM-2019 | Refine biomass estimates as necessary, taking into account recommendations from SC-CAMLR-38. | | Identify recommended frequency of large-scale survey<br>Evaluate how these surveys can be made more robust. |
| Subarea survey krill density (e.g. Subareas 48.1, 48.2, 48.3) | Compilation of existing data and comparison of methods (WG-EMM-2019, SG-ASAM-2019) | New data contribution (SG-ASAM). | New data contribution (SG-ASAM). | New data contribution (SG-ASAM) |
| Transect-scale krill density by fishing vessels (data from one or more CCAMLR-nominated transect collected within a fishing season) | First density estimates (SG-ASAM-2019) | New data contribution (SG-ASAM).<br>Method development for inclusion in subarea stock assessment | New data contribution (SG-ASAM).<br>Analysis for subarea stock assessment | New data contribution (SG-ASAM).<br>Implementation in subarea stock assessment |
| Fishing-area scale data | | New data contribution (SG-ASAM)<br>Method development and analysis for biomass estimation | New data contribution (SG-ASAM)<br>Method evaluation | New data contribution (SG-ASAM)<br>Method recommendation |
| Coherent biomass estimates (primarily based on large-scale and subarea survey scale time series biomass) | | SG-ASAM-2020 or a dedicated workshop on subarea biomass estimation method | WG-SAM/WG-EMM evaluation of the biomass estimation method and the first subarea biomass estimate | |

Table 5: List of available acoustic data for krill biomass estimation in Area 48 to be submitted to SG-ASAM-2019.

| 2019 Area 48 survey | | |
|---|---|---|
| **Member** | **Vessel** | **Contact** |
| Norway | *Kronprins Haakon* | Gavin Macaulay, gavin.macaulay@hi.no |
| | *Cabo de Hornos** | Gavin Macaulay, gavin.macaulay@hi.no |
| UK | *RRS Discovery* | Sophie Fielding, sof@bas.ac.uk |
| China | *Fu Rong Hai* | Xinliang Wang, wangxl@ysfri.ac.cn |
| Ukraine | *More Sodruzhestva* | Victor Podgorny, pvv04111970@i.ua |
| Korea | *Kwang Ja Ho* | Seok-Gwan Choi, sgchoi@korea.kr |
| Subarea krill survey | | |
| **Subarea** | **Member** | **Contact** |
| 48.1 | USA | George Watters, george.watters@noaa.gov |
| | Peru | George Watters, george.watters@noaa.gov |
| | Germany | George Watters, george.watters@noaa.gov |
| | China | Xinliang Wang, wangxl@ysfri.ac.cn |
| | Korea | Seok-Gwan Choi, sgchoi@korea.kr |
| 48.2 | Norway | Gavin Macaulay, gavin.macaulay@hi.no |
| | USA | George Watters, george.watters@noaa.gov |
| | Russia | Svetlana Kasatkina, ks@atlantniro.ru |
| 48.3 | UK | Sophie Fielding, sof@bas.ac.uk |
| | Russia | Svetlana Kasatkina, ks@atlantniro.ru |

* Chilean-flagged vessel conducted the survey for the Association of Responsible Krill harvesting companies (ARK).

Table 6: Metadata requirements for krill biomass time series.

| Variable | Unit/format | Description |
|---|---|---|
| Year | YYYY | The year the survey took place. If the survey took place over a split year (e.g. December to January), please use the starting year |
| Month | MON | The month the survey took place. If the survey took place over multiple months (e.g. January to March), please use starting month |
| Vessel | Free text | Name of vessel or unique maritime call sign |
| Contributor | Free text | Country who conducted the survey and/or person who analysed the data |
| Subarea | 48.1, 48.2, 48.3, 48.4 | CCAMLR subarea where survey was undertaken |
| Survey name | Free text | Name of survey during which estimate made, e.g. CCAMLR-2000 Survey |
| Density estimate | g $m^{-2}$ | Estimate of krill density in g $m^{-2}$ for the survey/stratum |
| CV of density estimate | % | Estimate of CV of the krill density estimate |
| CV estimation method | Free text | Explanation of method used to derive CV estimate of survey |
| Survey area | $km^2$ | Area survey represents in $km^2$ |
| Echosounder model | Free text | Manufacturer and model of echosounder used to collect data |
| Frequency used for biomass estimate | kHz | Frequency used to collect acoustic backscatter converted to krill density |
| Other frequencies available | kHz | Other frequencies of acoustic backscatter collected using the same echosounder |
| Method used for target identification | List | Method used to identify krill targets in the acoustic data, allows for no identification, manual identification, dB-difference (variety of frequency combinations) and swarm-based identification |
| dB-difference window | List | Indicate dB-difference window used if applicable |
| TS model used | List | Indicate TS model used to convert NASC to krill density. Allows for Greene et al., 1991, simplified SDWBA parameterised using (11, 4) orientation or full SDWBA parameterised using (–20, 28) orientation (SG-ASAM-2010). New conversions can be added. |
| Depth range integrated | m | Depth range (m) over which data was integrated |
| Time of day sampled | List | Identifies data collected solely during daytime, solely during night time, or both |
| Stratum name | Free text | Stratum name if used |
| Survey design description | Free text | Design of survey, e.g. parallel vs random transects; methods for data processing, etc. |
| Reference | Free text | If the data is published, provide full citation information on the paper or book |

Table 7: Priority data layers (potential data providers are identified in parentheses) and time line to progress a risk assessment in Area 48. ARG – Argentina; AUS – Australia; BRA – Brazil; CHL – Chile; CHN – China; ESP – Spain; FRA – France; GER – Germany; JPN – Japan; KOR – Republic of Korea; NOR – Norway; POL – Poland; UKR – Ukraine; UK – United Kingdom; USA – United States of America; URY – Uruguay; IWC-SORP – International Whaling Commission - Southern Ocean Research Program; MEOP – Marine Mammals Exploring the Oceans Pole to Pole; RATTD – Retrospective Analysis of Antarctic Tracking Data; SG-ASAM – Subgroup on Acoustic Survey and Analysis Methods; SKAG – SCAR Krill Action Group.

| Action | 2019 | 2020 | Comments | Priority |
|---|---|---|---|---|
| Risk assessment data layers | Models complete | Models to do | | |
| Chinstrap penguins | | | | |
| Incubation (UK, NOR, CHL, USA) | 48.1, 48.2 | 48.1 | Tracking data | |
| Brood (UK, USA, KOR, JPN, CHL, NOR, ESP) | 48.1, 48.2 | 48.1, 48.4 | Tracking data | |
| Crèche (UK, USA, JPN, CHL, NOR) | 48.1, 48.2 | 48.1, 48.4 | Tracking data | |
| Fledging (USA, POL, ARG) | | 48.1 | Tracking data | High |
| Winter (UK, USA, ARG, POL) | | 48.1, 48.2 | Tracking data | High |
| Adélie penguins | | | | |
| Incubation (UK, USA, JPN, NOR, ESP) | | 48.1, 48.2 | Tracking data | |
| Brood (UK, USA, JPN, ESP, URY, NOR) | 48.1, 48.2 | | Tracking data | |
| Crèche (UK, USA, JPN, ARG, NOR) | 48.1, 48.2 | | Tracking data | |
| Non-breeders (NOR, ARG, POL) | | 48.1 | | |
| Fledging (USA, ARG) | | 48.1 | Tracking data | High |
| Winter (USA, UK, ARG) | | 48.1, 48.2 | Tracking data | High |
| Gentoo penguins | | | | |
| Incubation (NOR, CHL, UKR) | 48.1 | | Tracking data | |
| Brood (UK, USA, KOR, JPN, NOR, UKR) | 48.1, 48.2 | 48.3 | Tracking data | |
| Crèche (UK, USA, JPN, NOR, UKR) | 48.1, 48.2 | 48.3 | Tracking data | |
| Fledging (USA, ARG, UKR) | | 48.1 | Tracking data | High |
| Winter (USA, UK, ARG, POL) | | 48.1, 48.3 | Tracking data | High |
| Macaroni penguins | | | | |
| Incubation (UK, JPN) | 48.3 | 48.3 | Tracking data | |
| Brood (UK, JPN) | 48.3 | 48.3 | Tracking data | |
| Crèche (UK, JPN) | 48.3 | 48.3 | Tracking data | |
| Fledging (UK) | | | | |
| Winter (UK) | 48.2, 48.3 | | Tracking data | High |
| Pack-ice seals (UK, USA, ARG, AUS) | | 48.1, 48.5 | Tracking data, at-sea data | |
| Elephant seals (UK, USA, ARG, GER, AUS, FRA, MEOP, RAATD) | | 48.1, 48.2, 48.3 | Tracking data | |

(continued)

Table 7 (continued)

| Action | 2019 | 2020 | Comments | Priority |
|---|---|---|---|---|
| Antarctic fur seals | | | | |
| Female (UK, USA, NOR, ESP) | | 48.1, 48.2, 48.3 | Tracking data, at-sea data | |
| Male (UK, USA, NOR) | | 48.1, 48.2, 48.3 | Tracking data, at-sea data | High |
| Humpback whales* (BRA, USA, NOR, UK, ARG, GER, AUS, IWC-SORP) | 48.1 | 48.1, 48.2, 48.3, 48.4 | At-sea, tracking, catch history | High |
| Fin whales* (IWC-SORP, GER, AUS, ARG) | | 48.1, 48.2, 48.3, 48.4 | At-sea, tracking, catch history | High |
| Blue whales* (IWC) | | 48.1, 48.2, 48.3, 48.4 | Catch history | |
| Minke whale* (USA, ARG) | | 48.1 | Tracking data, at-sea data | |
| Flying seabirds (USA, NOR, UK) | | 48.1, 48.2, 48.3, 48.4 | Tracking data, at-sea data | |
| Fishing fleet dynamics (Secretariat, NOR, UK, CHN, AUS, ARK, CHL) | | 48.1, 48.2, 48.3, 48.4 | VMS, catch data, fishing masters, environmental data | High |
| Fish (USA, ARG, GER, UKR, UK, 2019 Area 48 Survey) | | 48.1, 48.2, 48.3 | Survey data, catch data, observer data | High |
| *Euphausia* species by-catch (Secretariat, 2019 Area 48 survey) | | 48.1, 48.2, 48.3 | Survey data, catch data | |
| Larval and juvenile fish by-catch (Secretariat, 2019 Area 48 Survey) | | 48.1, 48.2, 48.3 | Survey data, catch data | |
| *E. superba* stock (SG-ASAM) | | | | High |
| *E. superba* spawning areas (SKAG) | | 48.1, 48.2, 48.3, 48.4 | Survey data, observer data, KRILLBASE | High |
| *E. superba* nursery areas (SKAG) | | 48.1, 48.2, 48.3, 48.4 | Survey data, observer data, KRILLBASE | |

* Presence absence data for cetaceans may be feasible using passive acoustic devices.

Table 8: Tools and mechanisms required to advance the risk assessment for subdivision of the krill fishery catch in Area 48. UK – United Kingdom; TBA – to be announced; SKAG – SCAR Krill Action Group.

| Action | Primary tools | Mechanisms |
|---|---|---|
| Risk assessment (UK) | Compare R code implementation for the Risk Assessment | Make available to WG-EMM-2020 |
| Fishery dynamics | Behavioural models | Focus topic at WG-EMM-2020 to consider models for each data layer |
| Penguins, pack-ice seals, fur seals | Compare R code for implementing models each data layer; develop standard methods, including considerations of scale and associated limitations; data quality control | Focus topic at WG-EMM-2020 to consider models for each data layer |
| Cetacean data layers | Consideration of appropriate cetacean layers; develop standard methods, including considerations of scale and associated limitations; data quality control | Focus topic at WG-EMM-2020 to consider models for each data layer |
| Fish layers | Determine relevant species | WG-FSA-2019; generate support for multi-Member analyses of existing data; published review papers |
| Krill spawning and nursery layers | TBA | SKAG |

Table 9: Overview of vessel-based effort in the 2019 survey.

| Vessel | *Cabo de Hornos* | *RRS Discovery* | *Fu Rong Hai* | *Kronprins Haakon* | *Kwang Ja Ho* | *More Sodruzhestva* |
|---|---|---|---|---|---|---|
| Flag | Chile | United Kingdom | China | Norway | Korea | Ukraine |
| Type | Stern trawler | Research | Stern trawler | Research | Stern trawler | Stern trawler |
| Available echosounder frequencies (kHz) | 38, 120 | 70, 120, 200 | 38, 70, 120 | 18, 38, 70, 120, 200, 333 | 38, 120 | 120, 200 |
| Survey start | 16 Jan 2019 | 26 Jan 2019 | 05 Feb 2019 | 18 Jan 2019 | 08 Mar 2019 | 13 Dec 2018 |
| Survey end | 02 Mar 2019 | 07 Feb 2019 | 10 Feb 2019 | 15 Feb 2019 | 15 Mar 2019 | 18 Dec 2018 |
| Total transect distance (n miles) | 3 928 | 1 130 | 875 | 2 969 | 940 | 692 |
| Trawl type | Macroplankton trawl | RMT8+1 | Krill trawl | Macroplankton trawl | Krill trawl | Krill trawl |
| No. trawl stations | 68 | 14 | 10 | 59 | n/a | 8 |
| No. CTD stations | 68 | 20 | 57 | 48 | 48 | 8 |

Table 10: Summary of actions to address methodological differences between the 2000-CCAMLR Survey and the 2019 Area 48 Survey.

| Detail | Action | |
|---|---|---|
| dB-difference in 2000, swarms-based detection in 2019 | Compare dB-difference and swarms-based approach from 2019 data from ships with the relevant frequencies at SG-ASAM-2019 | |
| Differences in selectivity between commercial trawls, research trawls, and RMT8+1. If available, utilise other sources of krill LF in survey area and period | Analysis of 2019 krill catches from vessels presented to SG-ASAM-2019 | |
| Daylight acoustic transects in 2000, day and night transects in 2019 | Use moored echosounder data to evaluate day/night differences in krill backscatter close to the surface | |
| One vessel surveyed approx. 1 month before the others | Consider using current models to assess the effect of an extended survey period | |
| Allocation of krill length distributions to backscatter data | Clustering in 2000 | Sensitivity analysis of the effect of varying krill lengths on biomass estimates |

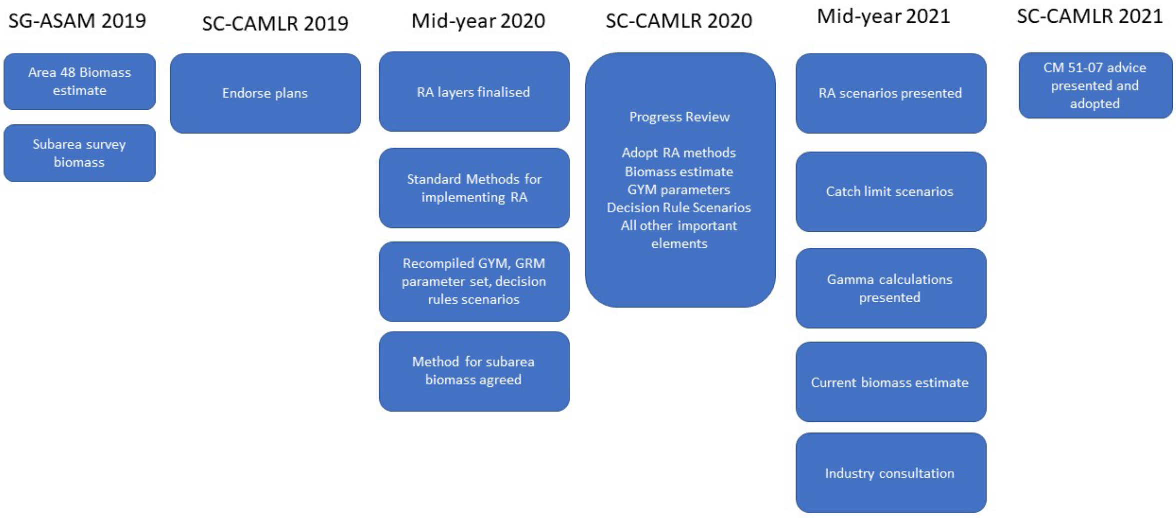


Figure 1: Timeline for progression priority elements identified in Table 1.

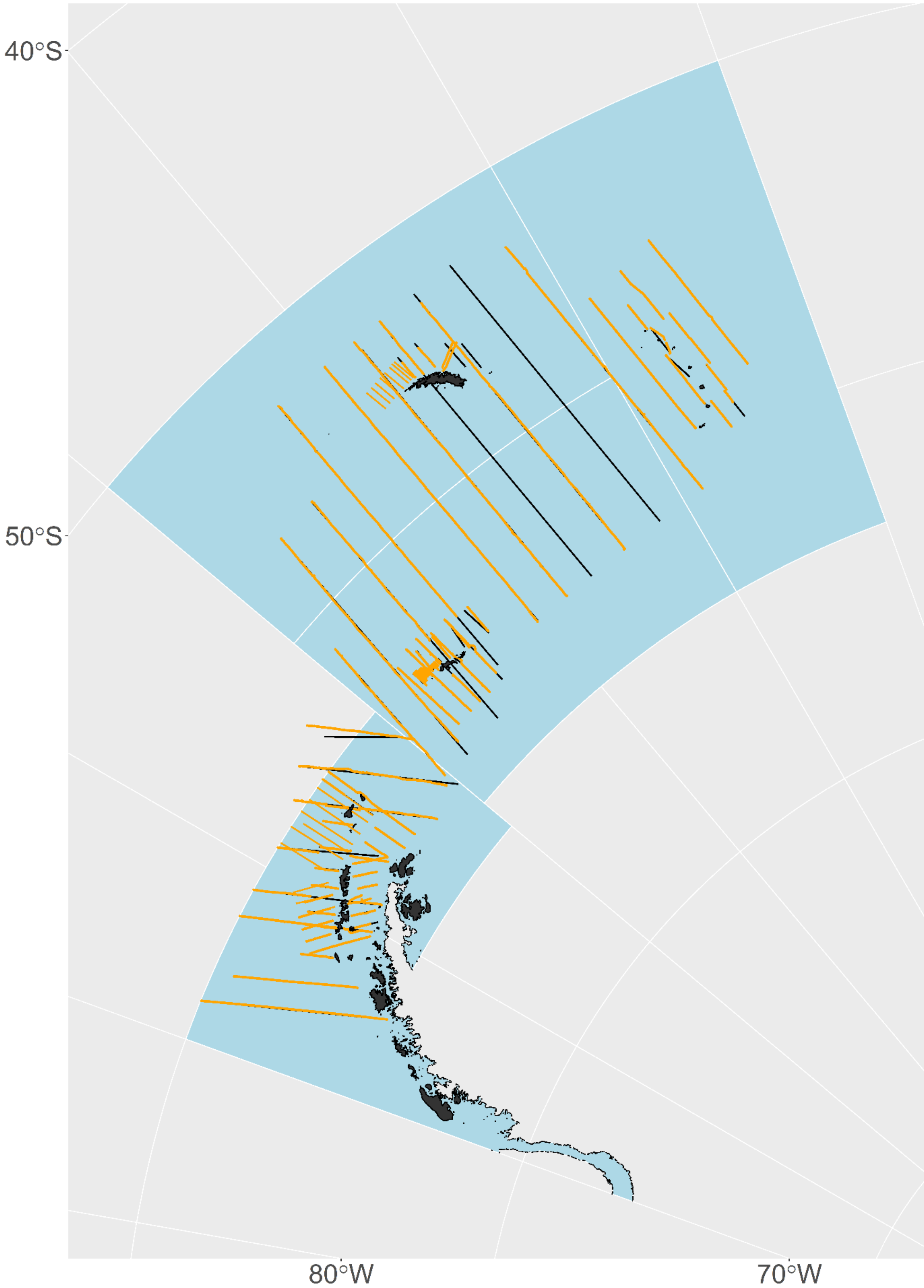


Figure 2: Occupied (orange) and unoccupied (black) transects for the 2019 survey.

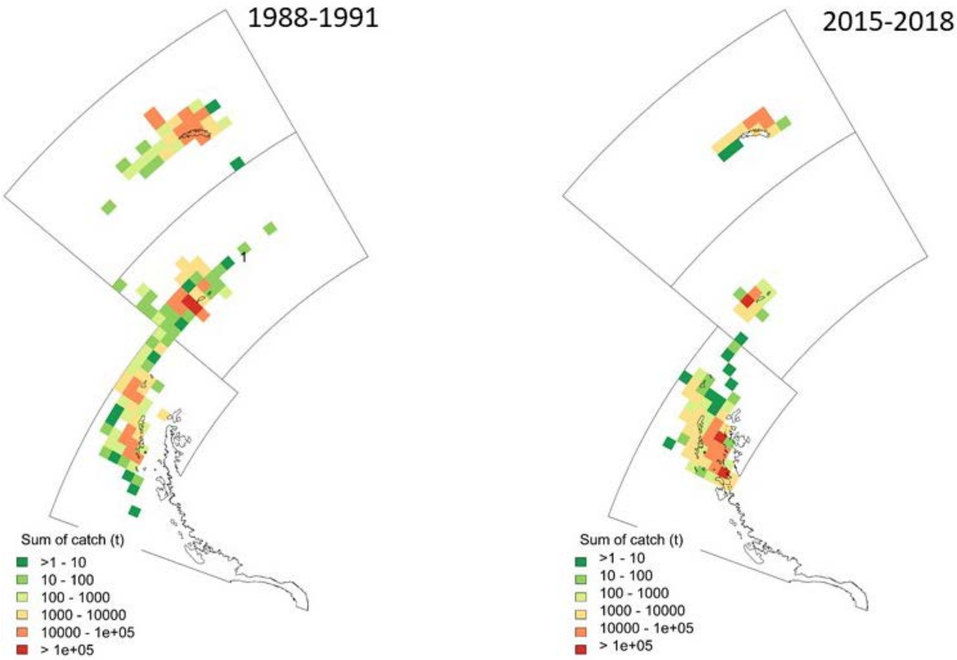


Figure 3: Distribution of krill catches in Subareas 48.1, 48.2 and 48.3 during the periods 1988–1991 and 2015–2018.

Appendix A

## List of Participants

Working Group on Ecosystem Monitoring and Management
(Concarneau, France, 24 June to 5 July 2019)

| | |
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# Agenda

Working Group on Ecosystem Monitoring and Management
(Concarneau, France, 24 June to 5 July 2019)

1. Introduction

    1.1 Opening of the meeting
    1.2 Adoption of the agenda and appointment of rapporteurs, proposed schedule for the meeting

2. Focus Topic on krill fishery management

    2.1 Data layers for risk assessment of spatial and temporal distribution
        2.1.1 2019 multinational synoptic large-scale krill survey

    2.2 Risk-assessment for the krill fishery
    2.3 Development of a preferred option for the management of the krill fishery in Area 48
    2.4 Advice to the Scientific Committee on the management of the krill fishery in Area 48

3. Krill fishery

    3.1 Fishing activities (updates and data)
    3.2 Scientific observation
    3.3 CPUE and spatial dynamics
    3.4 Fishing vessel surveys

4. Krill-based ecosystem interactions

    4.1 Krill biology, ecology and population dynamics
    4.2 Krill life-history parameters and population models
    4.3 Krill predator biology, ecology and population dynamics

5. Ecosystem monitoring and observation

    5.1 CEMP monitoring
    5.2 Other monitoring data
    5.3 Review of CCAMLR research and monitoring design and implementation

6. Spatial management

    6.1 Data analysis supporting spatial management approaches in CCAMLR
    6.2 Integration of existing measures in spatial management approaches
    6.3 VME data and spatial planning approaches

7. Climate change and associated research and monitoring

8. Other business

9. Future work

10. Advice to the Scientific Committee and its working groups

11. Adoption of the report and close of the meeting.

Appendix C

## List of Documents

Working Group on Ecosystem Monitoring and Management
(Concarneau, France, 24 June to 5 July 2019)

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| WG-EMM-2019/01 | A Proposal for a new Antarctic Specially Protected Area (ASPA)<br>P. Penhale |
| WG-EMM-2019/02 | Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) programme: a report on recent joint activities and links between ICED and CCAMLR<br>R.D. Cavanagh, N.M. Johnston and E.J. Murphy |
| WG-EMM-2019/03 | Proposal for a krill biomass survey for krill monitoring and management in CCAMLR Division 58.4.2-East<br>S. Kawaguchi, M. Cox, N. Kelly, L. Emmerson and D. Welsford |
| WG-EMM-2019/04 | CEMP 2018/19 data and updated spatial analysis of Area 48<br>Secretariat |
| WG-EMM-2019/05 | Weddell Sea MPA data layers have been deposited with the data publisher PANGAEA<br>K. Teschke, H. Pehlke and T. Brey |
| WG-EMM-2019/06 | Reporting procedures for the continuous fishing method<br>F. Grebstad |
| WG-EMM-2019/07 | Report from a krill- focused survey with RV *Kronprins Haakon* and land-based predator work in Antarctica during 2018/19<br>B. Krafft, K. Bakkeplass, T. Berge, M. Biuw, J. Erices, E. Jones, T. Knutsen, R. Kubilius, M. Kvalsund, U. Lindstrøm, G.J. Macaulay, A. Renner, A. Rey, H. Søiland, R. Wienerroither, H. Ahonen, J. Goto, N. Hoem, M. Huerta, J. Höfer, O. Iden, W. Jouanneau, L. Kruger, H. Liholt, A. Lowther, A. Makhado, M. Mestre, A. Narvestad, C. Oosthuisen, J. Rodrigues and R. Øyerhamn |
| WG-EMM-2019/08 | Habitat use of type – C killer whales (*Orcinus orca*) in the Ross Sea, Antarctica<br>G. Lauriano, E. Pirotta, T. Joyce, R. L. Pitman and S. Panigada |
| WG-EMM-2019/09 | Analysis of the Chilean operation in the Antarctic krill fishery, years 2017/18<br>P.M. Arana and R. Rolleri |

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| WG-EMM-2019/10 | Pygoscelid penguins vulnerabilities to spatio-temporal changes of the krill fisheries in the Antarctic Peninsula<br>L. Krüger, F. Santacruz, L. Rebolledo and C. Cárdenas |
| WG-EMM-2019/11 | Long-term observations from Antarctica demonstrate that mismatched scales of fisheries management and predator–prey interaction lead to erroneous conclusions about precaution<br>G.M. Watters, J.T. Hinke and C.S. Reiss |
| WG-EMM-2019/12 Rev. 1 | Update of the activities of the SCAR krill action group (SKAG) since last year's WG-EMM<br>B. Meyer and C. Reiss |
| WG-EMM-2019/13 | Glider-based estimates of Antarctic krill in Bransfield Strait, and the West shelf off Livingston Island, Antarctica<br>C. Reiss, A. Cossio, G. Cutter, J. Walsh and G. Watters |
| WG-EMM-2019/14 | Report of the Workshop on data and modelling issues relevant to the planning of a potential Marine Protected Area (MPA) east of the zero meridian in the Weddell Sea (MAUD)<br>Delegation of Norway |
| WG-EMM-2019/15 | Development of an acoustic sensor to estimate catch directly from the trawl during continuous krill harvesting<br>O.R. Godø, B. Krafft and F. Grebstad |
| WG-EMM-2019/16 | Trials with net monitoring cable during the 2017/18 and 2018/19 seasons onboard FV *Saga Sea*<br>O.R. Godø |
| WG-EMM-2019/17 | Supporting industry sustainability and CCAMLR monitoring with Sailbuoy operations<br>R. Øyerhamn, O.R. Godø and A. Lowther |
| WG-EMM-2019/18 | Empirically-driven feedback management incorporating multi-scale risk assessment and an experimental framework to facilitate adaptive improvement<br>A.D. Lowther, B. Krafft, O.R. Godø, C. Cardenas, X. Zhao and O.A. Bergstad |
| WG-EMM-2019/19 | Acoustic and underwater survey of the Argentine Islands (West Antarctic) water area for development of network of testing sites in the summer season of 2019<br>A. Utevsky, D. Smyrov, E. Sinna, M. Shrestha and S. Utevsky |

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| WG-EMM-2019/20 | Habitat partitioning in Antarctic krill: spawning hotspots and nursery areas<br>F. Perry, A. Atkinson, S.F. Sailley, G.A. Tarling, S.L. Hill, C.H. Lucas and D.J. Mayor |
| WG-EMM-2019/21 | The importance of sea ice association of Antarctic krill for transport and retention in the South Orkneys region: a modelling study<br>S.E. Thorpe, E.F. Young, E.J. Murphy and A.H.H. Renner |
| WG-EMM-2019/22 | Considerations about managing the krill fishery at small spatial and temporal scales<br>P.N. Trathan, V. Warwick-Evans and E. Young |
| WG-EMM-2019/23 | Developing layers for a Risk Assessment for Subarea 48.1 using data from at-sea sightings<br>V. Warwick-Evans, L. Dalla Rosa, E. Secchi, E. Seyboth, N. Kelly and P.N. Trathan |
| WG-EMM-2019/24 | Developing a Risk Assessment for Subarea 48.1 using tracking data<br>V. Warwick-Evans, A. Friedlaender, J.T. Hinke, N. Kokubun, J.H. Kim and P.N. Trathan |
| WG-EMM-2019/25 Rev. 1 | Report from the Workshop on Krill-fishery Management for Subareas 48.1 and 48.2<br>G. Watters and P. Trathan |
| WG-EMM-2019/26 | The Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD) database: a tool for helping stakeholders monitor penguin population trends in Antarctica<br>G.R.W. Humphries, P. Trathan, R. Naveen, C. Che-Castaldo and H.J. Lynch |
| WG-EMM-2019/27 | Density and abundance estimates of baleen whales recorded during the 2019 DY098 cruise in the Scotia Sea around South Georgia and the South Sandwich Islands<br>M. Baines, M. Reichelt, C. Lacey, S. Pinder, S. Fielding, N. Kelly, E. Murphy, P. Trathan and J.A. Jackson |
| WG-EMM-2019/28 | Advances are urgently needed in providing regular estimates of krill stock status based on the available data<br>S. Hill, J. Hinke, N. Ratcliffe, P. Trathan and G. Watters |
| WG-EMM-2019/29 | Evidence of change to the environment, ecosystem and fishery within Area 48 indicates the need for continued precaution<br>S. Hill and A. Atkinson |

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| WG-EMM-2019/30 | Towards the development of Marine Important Bird and Biodiversity Areas (mIBAs) for penguins in Antarctica – an update on progress<br>J. Handley, M.-M. Rouyer, L. Pearmain, V. Warwick-Evans, P. Trathan and M.P. Dias |
| WG-EMM-2019/31 | Draft Research and Monitoring Plan for the South Orkney Islands Southern Shelf Marine Protected Area (MPA Planning Domain 1, Subarea 48.2)<br>S.M. Grant and P.N. Trathan |
| WG-EMM-2019/32 | Using stationary acoustic platforms to assess precision and accuracy of acoustical krill surveys<br>T. Klevjer, G. Skaret and B.A. Krafft |
| WG-EMM-2019/33 | Annual migrations of pelagic fish stocks into a krill hotspot<br>T. Klevjer |
| WG-EMM-2019/34 | Detection of predator dive patterns from stationary echosounder data<br>T. Klevjer and G. Skaret |
| WG-EMM-2019/35 Rev. 1 | Preliminary results on the observations of cetaceans in the CCAMLR Statistical Subareas 48.1 and 48.2<br>K. Vishnyakova and L. Pshenichnov |
| WG-EMM-2019/36 Rev. 1 | Adélie penguins' response to unmanned aerial vehicle at Cape Hallett in the Ross Sea region, Antarctica<br>J.-H. Kim, Y.-S. Kim, J.-W. Jung, W.Y. Lee, H.-C. Kim, J.H. Kim, H. Chung and H.C. Shin |
| WG-EMM-2019/37 | Engaging 'the crowd' in citizen science and remote sensing to learn about habitat affinity of two Southern Ocean seals<br>M.A. LaRue, D.G. Ainley, J. Pennycook, K. Stamatiou, M. Dozier, J. Saints, L. Sales, N. Nur, S. Stammerjohn and L. Barrington |
| WG-EMM-2019/38 | Ross Sea Environment and Ecosystem Voyage 2019<br>R.L. O'Driscoll, D. Bowden and M.H. Pinkerton |
| WG-EMM-2019/39 | Change in environmental conditions of the Southern Ocean observed by satellites and data-assimilating models between 1981 and 2019<br>M. Pinkerton |
| WG-EMM-2019/40 | A Proposal for a new Antarctic Specially Protected Area (ASPA) at Inexpressible Island and Seaview Bay, Ross Sea<br>Delegations of China, Italy and the Republic of Korea |

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| WG-EMM-2019/41 | Exploring trends of the krill fishery indicators among the NWAP D1MPA zones in the Subarea 48.1<br>F. Santa Cruz, L. Krüger, L. Rebolledo and C. Cárdenas |
| WG-EMM-2019/42 | Cruise report of multidisciplinary ecosystem survey in the eastern Indian sector of the Antarctic (CCAMLR Division 58.4.1) with a focus on Antarctic krill during 2018/19 season by the Japanese survey vessel, *Kaiyo-maru*<br>H. Murase, K. Abe, R. Matsukura, H. Sasaki, R. Driscoll, S. Driscoll, F. Schaafsma, M. van Regteren, Q. Yang, H. Ohshima, K. Ohshima, R. Sugioka, J. Tong, N. Yamamoto, H. Doiguchi, E. Briggs, K. Doi, D. Hirano, K. Katsumata, M. Kiuchi, Y. Ko, D. Nomura, M. Orui, H. Sato, S. Toyoda, K. Yamazaki, T. Ishihara, K. Hamabe, S. Kumagai, T. Miyashita, N. Yamada, Y. Koyama and H. Sasaki |
| WG-EMM-2019/43 | Implementation and preliminary results from the synoptic krill survey in Area 48, 2019 conducted by the Chinese krill fishing vessel *Fu Rong Hai*<br>X. Wang, X. Zhao, B. Zou, G. Fan, X. Yu, J. Zhu, J. Zhang and Y. Ying |
| WG-EMM-2019/44 | Final report of the CEMP Special Fund project to develop an image processing software tool (SPPYCAMS) for analysis of camera network monitoring data<br>C. Southwell, A. Sikka, J. Cusick, H. Achurch, A. Lashko, K. Newbery, M. Salton, J. Kool, J. Hinke, G. Watters, M. Santos, G. Milinevsky, M. Korczak-Abshire, N. Ratcliffe, P. Trathan, A. Barbosa and L. Emmerson |
| WG-EMM-2019/45 | Revisiting krill ageing method using eyestalk cuticles<br>S. Kawaguchi, T. Barnes, N. Waller, B. Farmer, D. Hayes, R. Kilada, C. Reiss, G. Zhu, B. Krafft, A.-L. Agnalt, T. Ichii and T. Matsuda |
| WG-EMM-2019/46 | Summary of monitoring and research effort and preliminary results from the 2019 Scotia Sea krill monitoring survey with FV *Cabo de Hornos*<br>G. Skaret, M. Martinussen, G. McCallum, R. Pedersen, J. Rønning, A.L. Donoso, O.A. Bergstad and B.A. Krafft |
| WG-EMM-2019/47 | Preliminary results from the International Synoptic Krill Survey in Area 48, 2019<br>G. Macaulay, G. Skaret, T. Knutsen, O.A. Bergstad, B. Krafft, S. Fielding, S.G. Choi, S. Chung, K. Demianenko, V. Podhornyi, K. Vishnyakova, L. Pshenichnov, A. Chuklin, A. Shishman and M.J. Cox |

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| WG-EMM-2019/48 | Norwegian Cruise to Kong Håkons VII Hav 28 February – 10 April 2019<br>H. Steen |
| WG-EMM-2019/49 | Adult male Antarctic fur seals: tourists, trouble makers or marine ecosystem sentinels?<br>A. Lowther, C. Lydersen and K. Kovacs |
| WG-EMM-2019/50 | On the use of baited remote underwater video to study Antarctic toothfish distribution under the sea-ice: from data collection to processing<br>D. Di Blasi, S. Canese, E. Carlig, L. Ghigliotti, S.J. Parker and M. Vacchi |
| WG-EMM-2019/51 Rev. 1 | Mercury in the coastal Antarctic ecosystem: Initial findings<br>E. Kim, Z. Baumann, J.-H. Kim and J.-W. Jung |
| WG-EMM-2019/52 | VME detection thresholds: preliminary results of a study on the case of the sea pens (Pennatulacea) of the CCAMLR sector 58.4.4b<br>A. Martin and M. Eléaume |
| WG-EMM-2019/53 | The Bendiker project: barcoding of the benthos by-catch from the fisheries survey of the French EEZ of Kerguelen<br>A. Dettai, N. Ameziane, J. Blettery, G. Duhamel, M. Eléaume, M. Hautecœur, M. Norest, E. Sanson and A. Martin |
| WG-EMM-2019/54 | Barcoding and beyond: applications and developments for biodiversity evaluation in the Southern Ocean<br>A. Dettai, G. Duhamel, C. Gallut, M. Eléaume and A. Martin |
| WG-EMM-2019/55 | Methodical aspects of a large-scale international krill survey in 2019: comments and proposals<br>S. Kasatkina |
| WG-EMM-2019/56 | On spatial-temporal variability of krill length composition in Subarea 48.1. Comments and proposals<br>S. Kasatkina and A. Sytov |
| WG-EMM-2019/57 | Approach to the study of the ecosystem effect in the krill fishery<br>S. Kasatkina |
| WG-EMM-2019/58 | Indicators of krill flux at various spatial-temporal based on the data of multi-year research carried out in the Scotia Sea. Comments on krill fishery management<br>S. Kasatkina and V. Shnar |

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| WG-EMM-2019/59 | CEMP cameras data validation experiment at the Galindez Island gentoo penguin (*Pygoscelis papua*) colonies<br>P. Khoetsky, A. Dzhulai, V. Smagol, G. Milinevsky, I. Dykyy, A. Simon, M. Telipska, E. Dykyi, I. Parnikoza and L.Pshenichnov |
| WG-EMM-2019/60 | Galindez Island gentoo penguin (*Pygoscelis papua*) colonies at GAI CEMP site population behaviour/dynamics in the 2018/19 season<br>P. Khoetsky, A. Dzhulai, G. Milinevsky, I. Dykyy, E. Dykyi, I. Parnikoza and L. Pshenichnov |
| WG-EMM-2019/61 | Informational report on cruise of Ukrainian krill fishing vessel *More Sodruzhestva* within international synoptic survey in the Statistical Area 48<br>V. Podhornyi, K. Vishnyakova, L. Pshenichnov, K. Demianenko, A. Chuklin and A. Shishman |
| WG-EMM-2019/62 | Ukrainian complex marine expeditions in the Southern Ocean<br>E. Dykyi, V. Komorin and A. Fedchuk |
| WG-EMM-2019/63 | Progress on development of small-scale marine protected areas in the Argentine Islands Archipelago<br>A. Fedchuk and G. Milinevsky |
| WG-EMM-2019/64 | Zooplankton studies during international krill synoptic survey in CCAMLR Subarea 48.1 in 2019 onboard Ukrainian fishing vessel *More Sodruzhestva*<br>L. Samchyshyna, E. Dykyi and G. Milinevsky |
| WG-EMM-2019/65 | A drone-based Antarctic fur seal (*Arctocephalus gazella*) census of the St. Telmo Islands, South Shetland Archipelago<br>D.J. Krause and M.E. Goebel |
| WG-EMM-2019/66 | Long-term change in zooplankton communities of the Southern Ocean between 1997 and 2018: implications for fisheries and ecosystems<br>M.H. Pinkerton, M. Decima, J. Kitchener, K. Takahashi, K. Robinson, R. Stewart and G.W. Hosie |
| WG-EMM-2019/67 | Distribution and possible areas of spatial mixing of two stocks of humpback whales, a krill predator, in the Indo-Pacific region of the Antarctic revealed by genetic analyses<br>L.A. Pastene, M. Goto, M. Taguchi and K. Matsuoka |

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| WG-EMM-2019/68 | Outline of a research program to investigate the abundance, abundance trends and stock structure of large whales in the Indo-Pacific region of the Antarctic, including a survey plan for the 2019/20 austral summer season<br>Delegation of Japan |
| WG-EMM-2019/69 | Results from the 2019 annual acoustic krill monitoring off the South Orkney Islands<br>G. Skaret, B.A. Krafft, G. Macaulay, T. Knutsen and O.A. Bergstad |
| WG-EMM-2019/70 | Krill physiology and impact of temperature variations: a comparative approach<br>J.-Y. Toullec and C.-Y. Lee |
| WG-EMM-2019/71 | Unfolding connectivity patterns along the Antarctic Circumpolar Current in the sub-Antarctic region<br>S. Sergi, G. Grizaud, C. Cotté and F. d'Ovidio |
| WG-EMM-2019/72 | Population variability of biological parameters of penguins along the Antarctic Peninsula<br>A. Barbosa |
| WG-EMM-2019/73 Rev. 1 | Habitat suitability for the VME *Ptilocrinus amezianeae* over the Kerguelen Plateau<br>M. Eléaume, A. Martin, L.G. Hemery, C. Chazeau, J. Blettery and N. Améziane |
| WG-EMM-2019/74 | Extinction risk of Antarctic and sub-Antarctic colonies of Pygoscelid penguins under climate change context<br>M. Huerta and S.A. Estay |
| WG-EMM-2019/75 | New CCAMLR SISO Observer Manuals and updated longline logbook<br>Secretariat |
| WG-EMM-2019/76 | Using krill length data from fishery-dependent and fishery-independent data sources to measure changes in the Antarctic krill population structure in the Bransfield Strait<br>Secretariat |
| WG-EMM-2019/77 | Update to the proposed data structure and implementation of the Marine Protected Area (MPA) Research and Monitoring Plan (RMP) Project List database<br>Secretariat |

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| WG-EMM-2019/78 | Preliminary report on the South Sandwich Island research cruise by RRS *Discovery* (DY098) in January–February 2019<br>S. Fielding, C. Manno, G. Stowasser, B. Apeland, D. Ashurst, A. Ariza, M. Baines, L. Cornwell, A.B. Hulbert, K.R. Jones-Williams, C. Lacey, E.G. Langan, E.D. McRae, F.A. Perry, S. Pinder, E.J. Rowlands, F. Saccomandi, C. Silverstri, M.E.S. Sørensen, A. Slomska, J. Jackson, E.J Murphy, M. Reichelt, S. Thorpe, P. Trathan and G. Tarling |
| WG-EMM-2019/79 | Krill associated ecosystem studies in the western Indian Ocean sector of the Southern Ocean during austral summer<br>B.R. Smitha, H. Manjebrayakath, C.R. Asha Devi, N. Saravanane and M. Sudhakar |
| WG-EMM-2019/80 | Important marine mammal areas (IMMAs) – scientific protocol<br>S. Gallon, P. Marras-Aït Razouk and Y. Ropert-Coudert |

Other Documents

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| WG-EMM-2019/P01 | Krill faecal pellets drive hidden pulses of particulate organic carbon in the marginal ice zone<br>A. Belcher, S.A. Henson, C. Manno, S.L. Hill, A. Atkinson, S.E. Thorpe, P. Fretwell, L. Ireland and G.A. Tarling<br>*Nature Communications*, 10 (2019): 889, doi: 10.1038/s41467-019-08847-1 |
| WG-EMM-2019/P02 | Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming<br>A. Atkinson, S.L. Hill, E.A. Pakhomov, V. Siegel, C.S. Reiss, V.J. Loeb, D.K. Steinberg, K. Schmidt, G.A. Tarling, L. Gerrish and S.F. Sailley<br>*Nature Climate Change*, 9 (2019):142–147, doi: 10.1038/s41558-018-0370-z |
| WG-EMM-2019/P03 | Stable isotope analysis reveals trophic variation in adult Antarctic krill (*Euphausia superba*) around the Antarctic Peninsula from austral fall to early winter<br>H.T. Zhang, G.P. Zhu, Q. Song, S.Q. Wang, Y. Yang and Q.Y. Yang<br>*Acta Oceanol. Sin*., 37 (6) (2018): 90–95, doi: 10.1007/s13131-018-1176-6 |
| WG-EMM-2019/P04 | How trophic dynamics of adult Antarctic krill *Euphausia superba* responses to the condition of no ice in the water during the winter: a case study at South Georgia?<br>G.P. Zhu, H.T. Zhang, B. Deng and Q.Y. Yang<br>*Fish. Res*., 215 (2019): 1–8, doi: 10.1016/j.fishres.2019.02.011 |