Annex 6

Report of the Meeting of the Subgroup
on Acoustic Survey and Analysis Methods
(Bergen, Norway, 26 to 30 August 2019)

Contents

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Opening of the meeting

Introduction

1.1 The 2019 meeting of the Subgroup on Acoustic Survey and Analysis Methods (SG-ASAM) was held at the Institute of Marine Research (IMR), Bergen, Norway, from 26 to 30 August 2019. The Convener, Dr X. Zhao (China), welcomed the participants (Appendix A) and noted that at its previous meeting in Bergen in 2012 the Subgroup had initiated a proof of concept for the use of krill fishing vessels to collect acoustic data on krill and that it was a great pleasure to return to the same venue for a meeting that would be discussing the results of a large-scale, multi-national acoustic krill survey in which fishing vessels from several Members had successfully participated.

1.2 In welcoming participants to the meeting, Prof. Sissel Rogne (CEO IMR) highlighted that the successful completion of the 2019 Area 48 Survey was a great example of scientific and cultural collaboration that exemplified the work of CCAMLR. She wished the meeting every success and looked forward to seeing the results of the survey and the broader outcomes of the Subgroup as these would contribute greatly to the sustainable management of marine living resources, particularly in the Antarctic.

1.3 The meeting's provisional agenda was discussed, and the Subgroup adopted the proposed agenda without any changes (Appendix B).

1.4 Documents submitted to the meeting are listed in Appendix C. The Subgroup thanked the authors of papers and presentations for their valuable contributions to the work of the meeting.

1.5 This report was prepared by K. Abe (Japan), M. Cox (Australia), S. Fielding (UK), B. Krafft and G. Macaulay (Norway), K. Reid (Secretariat), G. Skaret (Norway) and X. Wang (China). Sections of the report dealing with advice to the Scientific Committee and other Working Groups are highlighted and collated in 'Recommendations to the Scientific Committee'.

Krill surveys conducted in 2019

Area 48

2.1 The Subgroup welcomed the extensive engagement in the collection of acoustic data, including from all Members that participate in the krill fishery, noting this had involved large-scale transects based on the design of the CCAMLR 2000 krill synoptic survey of Area 48 (CCAMLR-2000 Survey) as well as smaller-scale surveys that contribute to the ongoing time-series of krill density estimates from Subareas 48.1, 48.2 and 48.3.

2.2 Preliminary results from these surveys were presented (SG-ASAM-2019/03 Rev. 1, 2019/07, 2019/08 Rev. 1 and 2019/09), comprising acoustic, trawl and oceanographic data from the six vessels that participated. These data were allocated to the following surveys and survey strata (Figure 1):

(i) 2019 Area 48 Survey –

The CCAMLR-2000 Survey transects (with strata of Antarctic Peninsula (AP), Scotia Sea (SS), Eastern Scotia Sea (ESS), South Orkney Islands (SOI), South Shetland Islands (SSI), South Georgia (SG), and South Sandwich Islands (Sand)) conducted by Norway, Ukraine, UK and the Association of Responsible Krill harvesting companies (ARK).

(ii) Subarea 48.1 –

The AMLR transects around the South Shetland Islands conducted by China and Korea (with strata of West, Bransfield, Elephant and Joinville).

(iii) Subarea 48.2 –

Two overlapping survey areas routinely carried out by Norway around the South Orkney Islands (strata of South Orkney Concentrated (SOC) and South Orkney Fixed (SOF)).

(iv) Subarea 48.3 –

The Western Core Box (WCB) survey carried out by the UK.

2.3 Initial estimates of nautical area scattering coefficients (NASC) from krill were obtained using the swarm discrimination method at 120 kHz and processed to yield standing stock estimates based on the 2019 Area 48 Survey and the AMLR transects and were presented in SG-ASAM-2019/08 Rev. 1. This analysis made several processing decisions and assumptions that were discussed and revised during SG-ASAM-2019. Some processing errors were also discovered. Implementing these revisions and correcting errors changed the results (see Table 1). The main changes/corrections were:

(i) The method to allocate krill length frequency to NASC values. The revised procedure is described in paragraph 2.39. These new length frequency data were then used to generate the conversion factor between NASC and krill areal density. The results presented in SG-ASAM-2019/08 Rev. 1 used the aggregated survey vessel krill lengths from all trawls per survey strata (13 in total).

(ii) The location of the boundary between the Scotia Sea and Eastern Scotia Sea strata. The precise location of the boundary between these two strata could not be found in CCAMLR-2000 Survey reports and analyses. The analysis in SG-ASAM-2019/08 Rev.1 used a boundary that coincided with the easternmost transect in the Scotia Sea stratum and this caused processing awkwardness for automated spatially based allocation of krill length data into strata. To remedy this, the boundary was positioned 25 km to the east of the location shown in SG-ASAM-2019/08 (consistent with the spatial design in SC-CAMLR-XVIII, Annex 4, Appendix E, paragraph 18).

(iii) Choice of calibration coefficients. A typographical error in SG-ASAM-2019/08 Rev. 1, Table 11, led to the wrong choice of calibration coefficients for the *More Sodruzhestva* acoustic data. This resulted in NASC values being approximately 5% too high. The data were re-integrated using the correct choice of calibration coefficients, leading to a corresponding decrease in the backscatter.

2.4 The Subgroup advised the Scientific Committee that the krill biomass estimate from the 2019 Area 48 Survey was 62.6 million tonnes with a coefficient of variation (CV) of 13%.

2.5 The Subgroup noted that the *Fu Rong Hai*, in addition to its designated AMLR transects, also carried out its regular annual transects to the west of the South Shetland Islands. These transects were used in SG-ASAM-2019/07 to estimate mean krill areal density, but were not used to calculate the mean krill areal density reported in SG-ASAM-2019/08 Rev. 1.

Cross-checking of the 2019 Area 48 Survey results

2.6 The scope of the cross-checking included the validation of the 2019 Area 48 Survey processing and analysis MATLAB code implemented by Dr Macaulay and the Echoview template (SG-ASAM-2017 report). The Subgroup agreed to check the following:

(i) the Echoview swarms-based template used

(ii) the MATLAB code developed by Dr Macaulay and used to produce the results in Tables 1 and 2 see (SG-ASAM-2019/08 Rev. 1 and 2019/10)

(iii) the transects were allocated to the correct stratum

(iv) the equations from SG-ASAM-2019/08 Rev. 1 were correctly implemented in MATLAB

(v) the equations and implementation for converting krill-attributed NASC to krill areal density (conversion factor)

(vi) the implementation of the random sampling theory estimator (Jolly and Hampton, 1990)

(vii) the applied Echoview calibration files (.ECS) against calibration values in SG-ASAM-2019/08 Rev. 1, Appendix B, Table 11).

Echoview swarms-based template

2.7 The Echoview template used in the 2019 Area 48 Survey was modified from the approved template https://github.com/ccamlr/CCAMLREchoviewR to use solely 120 kHz frequency data. Modifications were:

(i) corrected an export data error by the removal of the dB() operator from the formula operator virtual variable 'Krill NASC from mean S_v (export here for NASC values)'

(ii) corrected an echo integration error by revising the lower integration line from the virtual variable 'Krill NASC from mean S_v (export here for NASC values)'

(iii) corrected a calculation error by revising the layer thickness calculation workflow to change the method used to calculate the proportion of water column sampled. This was implemented by the inclusion of 'line bitmap' and 'mask' virtual variables.

2.8 Each vessel's echoview template implementation was checked to ensure that the swarms-based identification and resultant acoustic data were made on the 120 kHz frequency data. These implementations were uploaded to the 2019Area 48 Survey CCAMLR Secretariat public GitHub repository (https://github.com/ccamlr/2019Area48Survey) along with its associated calibration file (ECS file).

Check the MATLAB code used to produce the results in Tables 1 and 2

2.9 There were more than 1 000 lines of code in the GitHub repository provided by Dr Macaulay and the Subgroup agreed that line-by-line checking of the code was not viable within the meeting, nor would a line-by-line approach guarantee any code errors would be found. Consequently, R code provided by Dr Cox was used to check the output from a subset of the 2019 Area 48 Survey. The subset comprised acoustic data from three strata: AP; SS, and ESS. The krill length-frequency distributions from (SG-ASAM-2019/08 Rev. 1) for the three test strata were also used as validation data.

Transects were allocated to the correct stratum

2.10 Using custom R code, Dr Cox confirmed that the transects had been correctly allocated to the appropriate strata.

Equations in SG-ASAM-2019/08 Rev. 1 are correctly implemented in MATLAB

2.11 A comparison of the results generated by the MATLAB code was compared to the results of independently implemented R code and found to be in agreement.

Check the equations and implementation for converting krill-attributed NASC to krill areal density (conversion factor)

2.12 Using the by-stratum test length-frequency data, and krill target strength (TS) model results (WG-EMM-16/38), the conversion factors were checked using R code implemented by Dr Cox and found to be correct for the three test strata.

Check the implementation of the random sampling theory estimator

2.13 The equations and MATLAB implementation for krill biomass and associated variance estimates were correct. Identical biomass and variance estimates were obtained using the MATLAB and R-based code when using the test data. Specifically, checks were made using existing R functions jhF() and jhMultipleStrataF() available in the EchoviewR package.

Check the applied Echoview calibration files

2.14 The vessel calibration information (specifically TS gain and Sa correction), and environmental parameters of sound speed (c, m s^{-1}) and 120 kHz absorption coefficient (α, dB m^{-1}) were checked within the calibration files associated with each template. A discrepancy between SG-ASAM-2019/08 Rev. 1, Table 11 and the ECS files was identified. The original calibration files were checked and revised values were included in SG-ASAM-2019/08 Rev. 1. In addition, the updated ECS files were committed to the 2019 Area 48 Survey repository (https://github.com/ccamlr/2019Area48Survey).

Comparison of results using the dB window and the swarms-based methods

2.15 Four documents (SG-ASAM-2019/03 Rev. 1, 2019/06, 2019/09 and 2019/10) addressed the effect of krill identification techniques on krill biomass estimates using data from different survey areas collected by different vessels that participated in the 2019 Area 48 Survey.

2.16 SG-ASAM-2019/10 provided an analysis on the comparison between swarms-based and three-frequency (38, 120 and 200 kHz) dB-difference (as applied for the CCAMLR-2000 Survey analysis) krill identification methods from the *Kronprins Haakon* survey. The choice of krill identification method showed variable effect on krill biomass estimates, and in areas with well-defined krill schools, the estimated krill densities were least sensitive to the choice of identification method.

2.17 The Subgroup noted that the estimates of krill density per transect from the two methods were in good agreement.

2.18 SG-ASAM-2019/09 also compared the mean krill density between the swarms-based and three-frequency dB-difference identification techniques in the WCB region. The estimate of mean krill density was lower using the three-frequency method compared with the swarms-based method, but the CV of mean krill density is similar between the two methods.

2.19 The Subgroup noted that this difference, and the krill density estimates, were comparable to differences reported in SG-ASAM-2019/10 in strata containing few krill.

2.20 SG-ASAM-2019/03 Rev. 1 and 2019/06 also provided comparisons between the swarms-based method and two-frequency (38 and 120 kHz) dB-difference method with various identification windows using data collected from the South Shetland Islands.

2.21 SG-ASAM-2019/06 showed that the estimates of krill density from default (–20 20) dB window and without dB window (using 120 kHz data only) were in good agreement for the swarms-based method, whilst the mean areal krill biomass density estimates were lower when the (2 16) and (0.4 12) dB window were applied. SG-ASAM-2019/03 Rev. 1 also observed a lower estimate in the krill density when applying the dB-window in the swarms-based method.

2.22 The Subgroup noted that a dB window, for which the default setting was –20 to 20 dB in the Echoview template agreed at SG-ASAM-2017, has been applied to the swarms-based method in the above two analyses, and recalled that the intention to retain the dB window in the template was to enable research to be carried out on the sensitivity of swarms-based approaches to krill length-frequency data (SG-ASAM-2018 report, paragraph 3.4).

2.23 The Subgroup noted that most of the vessels participated in the 2019 Area 48 Survey did not have all the frequency channels required for applying the three-frequency dB-differencing method, whilst all the vessels collected 120 kHz data that enabled the data from all vessels to be used with the swarms-based method.

2.24 The Subgroup noted that the above analyses suggested that the estimates of krill biomass density from the swarms-based method and dB-difference method are generally in agreement and comparable.

2.25 The Subgroup also noted that the two methods have variable effects on krill density estimates under different survey conditions and encouraged efforts to investigate the factors that cause such effects.

Revised/refined analysis, including taking into account any issues raised during WG-EMM

2.26 SG-ASAM-2019/10 described methodological aspects of the 2019 Area 48 Survey, including the effects of:

(i) acoustic surveying being conducted during day and night

(ii) using non-standardised krill sampling gear with the potential for different krill selectivity between the vessels participating in the survey

(iii) using the swarms-based and the dB-window method for krill identification (see paragraphs 2.15 to 2.25).

Collection of acoustic data during day and night

2.27 The Subgroup recalled that during the 2019 Area 48 Survey acoustic data collection was carried out during both day and night whereas during the CCAMLR-2000 Survey acoustic data were only collected during the day (between civil dawn and dusk) (WG-EMM-16/38). WG-EMM had requested that the implication of this data collection approach in the 2019 survey be evaluated (WG-EMM-2019 report, paragraph 2.53).

2.28 The analysis presented in SG-ASAM-2019/10 indicated that removing the data collected at night resulted in a reduction in the number of NASC values included in the biomass estimation of 21% but only a 6% increase in the overall biomass estimate across the entire survey area. The direction of the effect was not consistent as in some strata the biomass estimate was lower when the data collected at night had been removed.

2.29 SG-ASAM-2019/05 investigated the potential effect of day/night surveying on the survey estimates from the *Fu Rong Hai* around the South Shetlands in February. Both during day (sunrise to sunset) and night (sunset to sunrise), krill were distributed closer to the surface than the 15 m surface exclusion layer which was applied, but the effect was stronger during night-time, with 5.7% and 16.6 % respectively of daytime and night-time backscatter was distributed closer than 15 m to the surface.

2.30 The Subgroup reviewed WG-EMM-2019/32 which contained an analysis based on data from two deployments of upward looking moorings off the South Orkney Islands. The moorings had been deployed for 1 year and 6 months respectively in two different years. The results from both deployments indicated that krill were distributed within 20 m of the surface in the period February and March. During the first deployment, 7% of krill backscatter was recorded closer than 20 m to the surface during daytime and 22% during night-time. During the second deployment the proportions were 13% and 24% for day and night respectively.

2.31 The Subgroup noted that differences in the acoustic estimates typically arise from the effects of diel vertical migration that increases the relative amount of krill shallower than transducer depth and/or the surface detection which was set to 20 m for the 2019 Area 48 Survey). The scale of the differences in biomass of krill from day and night survey data (SG-ASAM-2019/05 and 2019/10) are consistent with the observed changes in the relative amount of krill occurring shallower than 20 m that has been observed from mooring data (WG-EMM-2019/32). This indicates that any changes in swarming behaviour between day and night do not introduce a significant bias when using the swarms method.

2.32 The Subgroup agreed that while there are differences in the biomass estimates using all of the data and when restricting the data to that collected between civil dawn and dusk (i.e. during the day), these differences were not significant and the inclusion of all data in the estimation process results in a reduction in the CV of the resulting biomass. The Subgroup agreed that using data from day and night does not bias the results and agreed that all of the data should be used to estimate the biomass.

2.33 The Subgroup noted that changes in krill behaviour may introduce changes in the frequency response and TS of krill and encouraged Members to investigate these effects using broadband acoustics.

Biological data

2.34 The analysis presented in SG-ASAM-2019/08 Rev. 1 demonstrated that the choice of krill length distributions used to convert acoustic backscatter into krill density has a significant effect on the estimates of krill density.

2.35 Biological sampling was conducted once at midday and midnight by the vessels conducting the 2019 Area 48 Survey transects (following the timings used in the CCAMLR-2000 Survey). The Subgroup noted the WG-EMM discussion on the potential to use all krill length data available from a variety of sources to provide information on the wider krill population length-frequency distribution during the period of the survey (WG-EMM-2019 report, paragraph 2.52).

2.36 The potential effect of selectivity in the trawl meshes of the different gear used for the large-scale survey (RMT 8, a scientific trawl and a commercial trawl and gear used during the AMLR transects) was provided in SG-ASAM-2019/10 based on a comparison of the length distribution obtained by the different vessels and the theoretical length at which 50% of the krill were retained in the net (L_{50}, using the optimal body orientation during mesh penetration (Krag et al., 2014)). This indicated no overlap between L_{50} and the krill length distribution except for a single vessel (that contributed two trawl hauls used in the analyses).

2.37 The Subgroup agreed that, based on the analysis in SG-ASAM-2019/10, the nets were able to catch all size classes of krill representatively but noted that there might be a difference in catch efficiency for nets with different mouth size and volume of water filtered while towing.

2.38 The Subgroup agreed that the objective of using all available krill length data was to have the best representation of the krill length frequency in the survey area. The Subgroup further agreed that this was best achieved by aggregating the krill length data from within the external boundaries of the ESS, SS and AP strata of the 2019 Area 48 Survey.

2.39 The Subgroup noted that krill length data were collected during the period of the acoustic survey on the vessels conducting the survey, from scientific observers on krill fishing vessels and from krill-dependent predators as part the CCAMLR Ecosystem Monitoring Program (CEMP). For each strata all of the krill length data collected during the period that the acoustic survey was conducted in that strata were used to produce a strata-specific krill length-frequency distribution. Krill length frequencies from individual sampling platforms (survey vessels, fishing vessels and predators) were equally weighted, by using the proportion of krill in each length class for each sampling platform, and summing the proportions for each length class across all sampling platforms.

Area 58 Japanese survey

Review of preliminary survey results, including the use of broadband acoustic data

2.40 SG-ASAM-2019/02 was presented by Dr Abe and included the preliminarily estimate of the biomass of krill (*Euphausia superba*) in Division 58.4.1 in 2018/19 of 4.349 million tonnes based on the swarms-based method using data obtained by the *Kaiyo-maru*. The point estimate was comparable with the estimate from 1996 BROKE survey (4.83 million tonnes with CV = 17%). However, he cautioned that these estimates cannot be compared directly because the:

(i) biomass estimation methods were different

(ii) timing of the surveys was different (the *Kaiyo-maru* survey commenced about 40 days earlier than the BROKE survey)

(iii) areal coverages were different, primarily because of differences in the positions of the sea ice edge, especially in the western part of the division.

2.41 The CV reported in SG-ASAM-2019/02 was calculated using the formulas described in WG-EMM-16/28. However, some typographical errors were found in the formulas, as pointed out in SG-ASAM-2019/08 Rev. 1, consequently an updated biomass with CV will be estimated following formulas in SG-ASAM-2019/08 Rev. 1 and the results will be presented to the next SG-ASAM.

2.42 The Subgroup noted that the ice conditions in Division 58.4.1 during the survey meant that the vessels were unable to get close to the shelf, therefore, the occurrence of ice krill (*E. crystallorophias*) was minimal and the influence on the integration result is thought to be small. On the other hand, since the survey line was extended to the north, it should be noted that bigeye krill (*Thysanoessa macrura*) appeared, especially in the western area at the beginning of the survey.

2.43 Dr K. Amakasu (Japan) provided a preliminary report on broadband acoustic measurements conducted during the Japanese survey by the *Kaiyo-maru*. The broadband measurements were successfully performed with echo sampling using EK80 in FM mode conducted during rectangular midwater trawls (RMT) tows. The data collected indicated that the frequency response of Antarctic krill primarily depend on length distribution of targets but other factors, including orientation, should be investigated further.

2.44 The Subgroup very much appreciated and welcomed this first reported achievement in applying a broadband acoustic technique to krill.

2.45 The Subgroup noted that while the range resolution is increased by the pulse compression processing, the across-beam resolution due to the beam width has not improved, so it is actually difficult to detect a single target in the swarm. For this reason the broadband data for krill are proceeding using S_v spectra.

2.46 The Subgroup noted that acoustic data from around swarms may be of interest in understanding the broadband acoustic characteristics of salp. Dr Amakasu clarified that, at present, the analysis is being conducted mainly on krill, so analysis of the other organisms around swarms has not progressed, however, this will be analysed in the future.

2.47 Dr Abe provided a preliminary report on mass density contrast g and sound-speed contrast h measurements of *E. superba* and *T. macrura* that indicated that both material properties were related to species and maturity. The mass density contrasts, in case of *E. superba*, were affected by whether animals were gravid or non-gravid, and the mass density of *E. superba* was different from *T. macrura*. In case of *E. superba*, sound-speed contrasts were affected by the body size and maturity. Comparing the two species, the sound-speed of *E. superba* was higher than that of *T. macrura*. The estimates of both material properties were higher than the existing knowledge. Furthermore, as both material properties are likely to be influenced by lipid content (the results of lipid analyses are awaited), it will be important to investigate the relationship between lipid contents and material properties.

2.48 The Subgroup agreed that as growth stage, seasonal changes and regional characteristics are thought to be the cause of differences in g and h, it would be useful to consider this matter in a focused meeting on factors affecting g and h, including measurement methods.

Review of collection and analysis of krill acoustic data from fishing vessels

3.1 SG-ASAM-2019/01 provided an update on the nominated acoustic transects undertaken by fishing vessels in 2018 and 2019 and identified three areas for greater clarification from SG-ASAM:

(i) the timing and frequency of nominated acoustic transects undertaken by fishing vessels

(ii) the method for data transmission of the acoustic data and its exploration

(iii) whether the Secretariat should hold raw or processed data.

3.2 The Subgroup agreed that data from the nominated acoustic transects undertaken by fishing vessels was intended to provide intra-annual-scale biomass estimates during the period of the fishery that provide additional context to the subarea surveys. SG-ASAM recommended a minimum sampling frequency would require fishing vessels entering a subarea to undertake the nearest nominated acoustic transect (either prior to or within the first few days of fishing) and to complete the same transect immediately prior to leaving the subarea. The Subgroup noted that the completion of additional transects opportunistically in the intervening period would also be beneficial.

3.3 The Subgroup noted that communication between fishing vessels to coordinate the undertaking of nominated transects over a wider time period could be beneficial to interpreting intra-annual variability and requested that the Secretariat liaise with ARK to explore the best way for this communication to occur.

3.4 The Subgroup commended the collection of acoustic data by Chilean and Norwegian fishing vessels along the nominated transects that had been transferred to the Secretariat successfully through cloud-based electronic transfer and recommended the Secretariat work with ARK to provide instructions for using this transfer method to accompany the acoustic collection procedures.

3.5 SG-ASAM acknowledged the benefit of having a single repository of raw acoustic data enabling rapid analysis or changes to method resulting in re-interpretation. It recommended that raw data and requested metadata is submitted to the Secretariat. Submission of processed data in addition was also welcomed and the group noted that version control of the templates used to create processed data was essential and endorsed the use of the CCAMLR Secretariat GitHub repository to manage this process.

3.6 The Subgroup requested that all existing data that had been collected by krill fishing vessels along nominated transects be sent to the Secretariat in order to provide a complete catalogue of the transect data that has been collected. The Subgroup encouraged the annual submission of nominated transect data in the future.

3.7 The Subgroup noted the example of the interactive map-based exploration of data that Echoexplore™ provided in SG-ASAM-2019/01 and suggested that the Secretariat used this software to manage the acoustic data files and also add data layers of the location of acoustic data from nominated acoustic transects undertaken by fishing vessels to the CCAMLR GIS server.

3.8 The Subgroup recommended that processing of the nominated transects become a task of SG-ASAM, undertaken at the annual meeting. This would facilitate maintenance of version control of the processing template and provide up-to-date analysis of annual data.

3.9 Dr Wang presented an example of acoustic data collected from the Chinese *Long Teng* using a three-frequency EK60 echosounder during periods of transit from fishing grounds to transhipment locations. SG-ASAM noted the high quality of the collected data and agreed that it demonstrated the value of acoustic data from fishing vessels. The Subgroup agreed that the value of such data would be considerably enhanced when collected along the nominated transects.

Other technical aspects relevant to the krill acoustic surveys and data analysis

Supervised and unsupervised processing of acoustic data

4.1 Dr Fielding presented SG-ASAM-2019/09 which compared krill density estimates calculated using supervised processing of acoustic data applying Echoview with unsupervised processing using a custom-made python processing routine named RapidKrill. The development of RapidKrill has been financed by the Antarctic Wildlife Research Fund (AWR) and the routine is developed to enable fast and robust unsupervised processing of acoustic data from different platforms, including low power platforms and also transfer of results on condensed form requiring only low bandwidth.

4.2 The comparison between processing routines were done on 15 survey transects comprising the WCB survey and the South Sandwich area on EK60 data from the UK 2019 cruise on RRS *Discovery* (DY098), and the agreed Echoview template for data processing had been implemented in RapidKrill.

4.3 Overall there was good consistency between the outcome of the unsupervised RapidKrill and supervised Echoview approach, and results from the WCB showed that the difference in results due to choice of discrimination method (dB-difference or swarm-based) was much larger than the difference due to processing routines.

4.4 The Subgroup noted that the python-based toolbox (Echopy) to process acoustic data using the swarms-based approach is open source and available to CCAMLR and the wider community for download from the BAS-acoustics GitHub account (https://github.com/bas-acoustics) along with example datasets. The python-based toolbox (Rapidkrill) to summarise acoustic data in real-time and transmit over email should be available within the next month.

4.5 The Subgroup agreed that RapidKrill was a potentially very useful tool enabling processing of acoustic data in a consistent way. The group encouraged more testing of the software on already processed data, and noted that it had the potential to become a standard tool for the processing of acoustic data in CCAMLR and requested the Scientific Committee consider how further development of the software might be supported in the future.

Chinese acoustic krill biomass time series

4.6 Dr X. Yu (China) presented SG-ASAM-2019/04 Rev. 1 where krill biomass from 2013 to 2019 had been estimated from fishing vessel surveys in the previous US-AMLR survey area. Data were from echosounders most often calibrated and running 38, 70 and 120 kHz, and the swarms-based method was used for krill discrimination. The results showed a strong increasing trend in biomass over the period, but the authors remarked that the calibration of 38 kHz had not been of good quality during 2013 and 2015, and also that the survey had not been conducted during the same period every year.

4.7 The Subgroup strongly encouraged this survey effort to be continued. The Subgroup also encouraged further work to investigate whether other sources of information, for example from CEMP sites, supported the findings of an increasing biomass trend during this period.

4.8 The Subgroup further noted that due to the difficulties in repeating such surveys at the same time every year, the nominated transects visited over the fishing season (see paragraph 3.2) as well as moorings would be important to shed light on intra-annual variability in krill density. Ultimately, a nested approach combining krill density data on different temporal and spatial scales should be aimed at.

Technical aspects relevant to krill acoustic survey

4.9 The Subgroup noted that the TS estimates in the SG-ASAM-2010 report, Table 5, were produced by an SDWBA model package which was used for biomass estimation during that meeting, but which had later been updated (Calise and Skaret, 2011). The most recent model package uses a different, and assumed to be a more correct, krill shape representation at frequencies above 120 kHz, and the TS estimates at 200 kHz hence differ from those presented in the report of SG-ASAM-2010.

4.10 The Subgroup noted that the comparison of the swarms-based and dB-window identification method presented in both SG-ASAM-2019/09 and 2019/10 were undertaken using the TS estimates calculated during the SG-ASAM-2010 meeting (WG-EMM-11/20). The Subgroup recognised that this analysis was the closest comparison of methods between the 2010 and 2019 identification techniques. However, it recommended that the updated values calculated by Dr Macaulay are uploaded to the CCAMLR Secretariat GitHub repository. The Subgroup identified that any krill estimate made using 200 kHz acoustic data should use these 2019 TS estimates.

4.11 The Subgroup noted that the process prior to the SG-ASAM-2019 meeting with several Members producing krill biomass estimates had shown that there was a need for software that implements the standardised procedures to go from acoustic raw data through processing to a krill biomass estimate.

4.12 The Subgroup identified that there was not a current version-controlled Echoview template for undertaking the dB-difference identification method on acoustic data. SG-ASAM agreed that a version-controlled template, similar to that available for the swarms-identification method, would be useful and encouraged its development for the next SG-ASAM meeting. The Subgroup further agreed that revision control of the Echoview templates was required and recommended that agreed templates uploaded to the CCAMLR Secretariat GitHub repository are reviewed at each SG-ASAM meeting to register any further agreed developments.

4.13 The Subgroup noted that the open source software StoX (Johnsen et al., 2019) had been developed for this purpose for fish stock estimation in the north Atlantic and could potentially be applied for krill. The leader of the StoX project (Dr Johnsen, IMR) kindly presented the software during the meeting. It is built on java and R designed with a user-friendly interface. The software uses acoustic and biotic input data on standard .xml-format, and all processing steps and user choices are logged in a separate process file. An adjacent R-package called Rstox has been developed to enable processing independent of the GUI interface.

4.14 The Subgroup welcomed Norway's offer to evaluate the use of StoX for krill biomass estimation, and further to test it on krill datasets if possible.

Other business

Subarea acoustic surveys metadata

5.1 SG-ASAM-2019/04 Rev. 1 described a five-year time series of krill estimates around the South Shetland Islands (2013–2019) made on the Chinese fishing vessel *Fu Rong Hai*. The Subgroup welcomed the continuation of existing time series along these well-defined transects and encouraged China and other Members to continue survey estimates in this region, thereby contributing to the time-series of regional biomass estimates in this subarea.

5.2 The Subgroup welcomed the submission of the metadata associated with the surveys described in SG-ASAM-2019/04 Rev. 1 as a contribution to the request by WG-EMM (WG-EMM-2019 report, paragraph 2.21) for compiling all estimates of regional biomass. The Subgroup also welcomed the provision of example metadata from the USA that had been provided to the Secretariat for surveys in Subarea 48.1.

5.3 The Subgroup recalled the metadata request for these regional estimates (WG-EMM-2019 report, Tables 5 and 6) and clarified that the request for survey area and strata name were optional metadata variables only recommended where an areal biomass had been previously calculated.

5.4 The Subgroup noted that there was a short period of time between the WG-EMM-2019 request and the SG-ASAM-2019 meeting, and recommended that Members submit additional metadata to the Secretariat prior to the next SG-ASAM meeting, in order to facilitate consistent formatting of the information.

CCAMLR Science

5.5 The Science Manager raised the possibility for a *CCAMLR Science* special issue on CCAMLR's management of the krill fishery including the 2019 approach to krill biomass assessment. The Subgroup endorsed the concept, identifying it as an opportunity to collate and publish some of the methodological achievements in providing a new large-scale krill density estimate, new information from subarea time series and a place to describe the progress in fishing-vessel based science. The Secretariat's Science Manager offered to prepare a paper proposing the *CCAMLR Science* special issue to the Scientific Committee.

Convener of SG-ASAM

5.8 Dr Zhao identified his intention to step down as Convener of SG-ASAM and encouraged Members to consider potential candidates that could be proposed to the Scientific Committee to convene the SG-ASAM meeting next year.

Advice to the Scientific Committee and future work

6.1 The Subgroup identified the following items relevant to providing advice to the Scientific Committee and to its future work:

(i) krill biomass estimate from the 2019 Area 48 Survey (paragraph 2.4) including independent cross-checking of this result (paragraphs 2.4 to 2.14) and examination of survey methods (paragraphs 2.15 to 2.39).

(ii) preliminary krill biomass estimate in Division 58.4.1 (paragraph 2.40)

(iii) request for all existing data collected by krill fishing vessels along nominated transects be sent to the Secretariat to create a single repository of raw acoustic data (paragraphs 3.5 and 3.6)

(iv) development and support for tools for the processing of acoustic data in CCAMLR (paragraph 4.5)

(v) the Convener of SG-ASAM for its meeting next year (paragraph 5.8).

Adoption of the report and close of the meeting

7.1 At the close of the meeting Dr Zhao thanked all participants for their hard work and collaborative data analysis that had contributed greatly to the successful outcomes from SG-ASAM this year. In particular he thanked Dr Macaulay for his engagement with all Members that had made a substantial contribution to the meeting. Dr Zhao also thanked IMR for hosting the meeting in a very relaxed atmosphere and the Secretariat for its efficient support to the meeting.

7.2 On behalf of the Subgroup Dr O.R. Godø (Norway) thanked Dr Zhao for his focussed and inclusive convening of the meeting that had emphasised the engagement of all participants in providing clear outcomes from the meeting. Reflecting on Dr Zhao's retirement as Convener of SG-ASAM, Dr Godø applauded the developments made in the work of the Subgroup that have redefined the role of acoustic data in the toolbox of ecosystem understanding in CCAMLR.

7.3 Dr Zhao thanked Dr Godø and all of those that contributed to the collaborative work of SG-ASAM, noting that this included many contributors engaging in a wide range of activities from data collection to analysis and participation in subgroup meetings.

References

Calise, L. and G. Skaret. 2011. Sensitivity investigation of the SDWBA Antarctic krill target strength model to fatness, material contrasts and orientation. *CCAMLR Science*, 18: 97–122.

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Table 1: Krill biomass estimates for survey strata conducted in Area 48 in 2019 (updating Table 5 of SG-ASAM-2019/08.) The nominal areas for each the strata are taken from SC-CAMLR-XIX, Annex 4, Appendix G, paragraph 2.3 and WG-EMM-11/26). * these survey strata do not have defined areas and hence only a density estimate. Biomass estimates are rounded to the nearest 1 000 tonnes.

Survey	Stratum	Nominal area (km^2)	Mean krill density ($g\ m^{-2}$)	Krill biomass (tonnes)	Variance component ($10^6\ t^2$)
2019 Area 48 Survey	Antarctic Peninsula	473 318	40.5	19 158 000	4 432 000
2019 Area 48 Survey	Scotia Sea	1 109 789	25.9	28 742 000	56 678 000
2019 Area 48 Survey	Eastern Scotia Sea	321 800	23.9	7 677 000	1 555 000
2019 Area 48 Survey	South Shetland Islands	48 654	67.7	3 295 000	621 000
2019 Area 48 Survey	South Orkney Islands	24 409	77.8	1 900 000	337 000
2019 Area 48 Survey	South Georgia	25 000	9.1	227 000	3 000
2019 Area 48 Survey	South Sandwich Islands	62 274	25.9	1 616 000	68 000
Subarea 48.1	Elephant Island	43 865	56.0	2 458 000	822 000
Subarea 48.1	West	38 524	9.9	381 000	5 000
Subarea 48.1	Bransfield Strait	24 479	102.4	2 507 000	210 000
Subarea 48.1	Joinville Island	18 151	83.9	1 507 000	238 000
Subarea 48.2	South Orkney Concentrated	*	170.6		
Subarea 48.2	South Orkney Fixed	*	59.0		
Subarea 48.3	Western Core Box	*	22.3		

Table 2: Krill biomass estimates for the 2019 Area 48 Survey.

Mean density ($g\ m^{-2}$)	Density variance ($g^2\ m^{-4}$)	Density CV (%)	Standing stock (tonnes)	Standing stock variance ($10^6\ t^2$)	Standing stock CV (%)
30.3	14.9	13	62 615 000	63 694 000	13

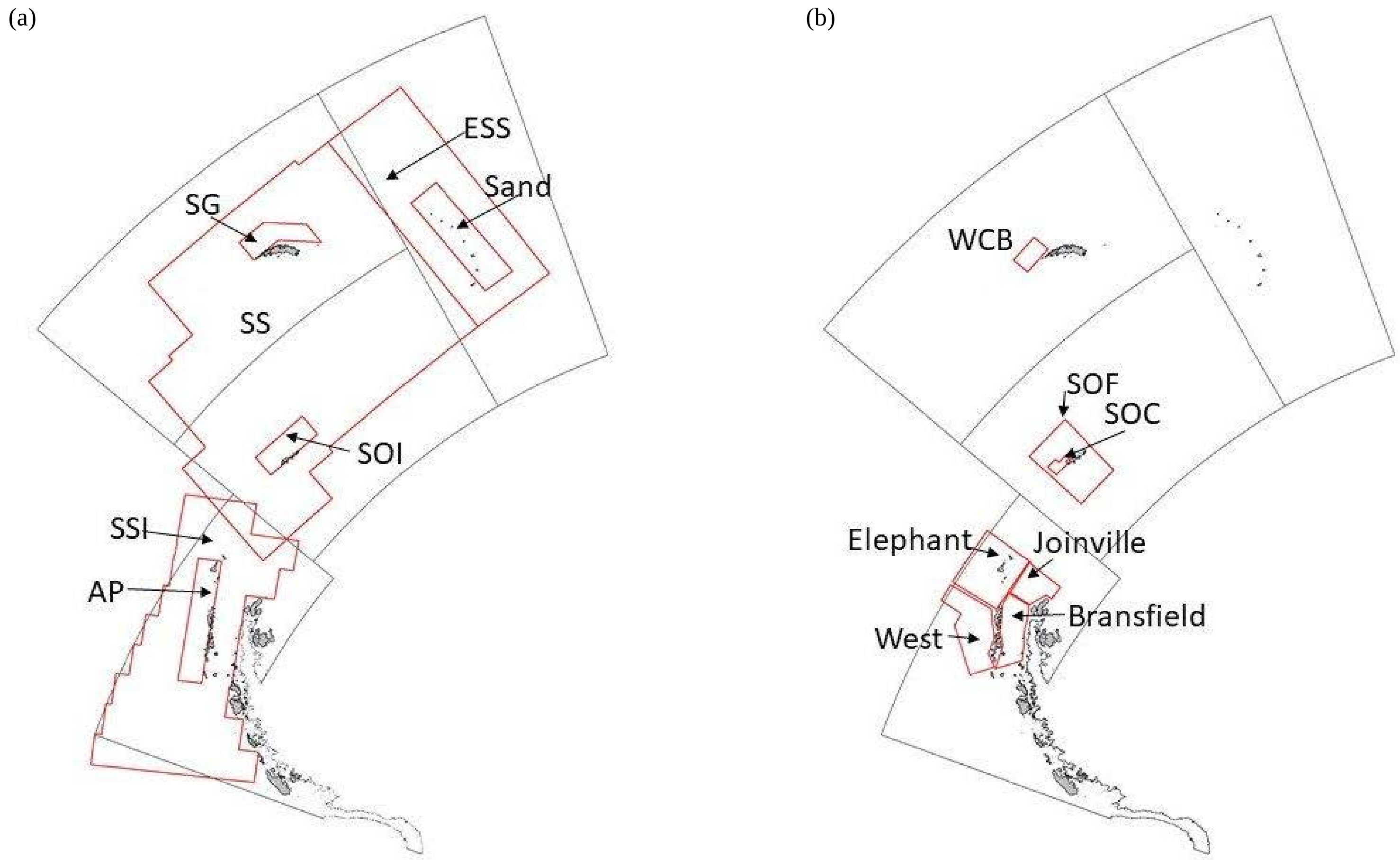

Figure 1: Strata referred to in paragraph 2.1.1 in: (a) 2019 Area 48 Survey and (b) subarea surveys. Data for strata boundaries from https://raw.github.com/ccamlr/2019Area48Survey/master/map_data/survey%20strata.geojson.

Appendix A

List of Participants

Subgroup on Acoustic Survey and Analysis Methods
(Bergen, Norway, 26 to 30 August 2019)

Convener	Dr Xianyong Zhao Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Science zhaoxy@ysfri.ac.cn
Australia	Dr Martin Cox Australian Antarctic Division, Department of the Environment martin.cox@aad.gov.au
Chile	Professor Patricio M. Arana Pontificia Universidad Catolica de Valparaíso patricio.arana@pucv.cl
China, People's Republic of	Mr Xinliang Wang Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Science wangxl@ysfri.ac.cn
	Dr Xiaotao Yu Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences yuxt@ysfri.ac.cn
Japan	Dr Koki Abe National Research Institute of Fisheries Engineering, Fisheries Research Agency abec@fra.affrc.go.jp
	Dr Kazuo Amakasu Tokyo University of Marine Science and Technology amakasu@kaiyodai.ac.jp
	Dr Hiroto Murase Tokyo University of Marine Science and Technology hmuras0@kaiyodai.ac.jp
Korea, Republic of	Dr Seok-Gwan Choi National Institute of Fisheries Science (NIFS) sgchoi@korea.kr

	Dr Sangdeok Chung National Institute of Fisheries Science sdchung@korea.kr
	Professor Kyounghoon Lee Chonnam National University ricky1106@naver.com
	Mr Wooseok Oh Chonnam National University owsnice@gmail.com
	Mr Sang Gyu Shin National Institute of Fisheries Science (NIFS) gyuyades82@gmail.com
Norway	Dr Olav Godø Christian Michelsen Research olgo@norceresearch.no
	Dr Tor Knutsen Institute of Marine Research tor.knutsen@imr.no
	Dr Bjørn Krafft Institute of Marine Research bjorn.krafft@imr.no
	Dr Gavin Macaulay Institute of Marine Research gavin.macaulay@hi.no
	Dr Georg Skaret Institute of Marine Research georg.skaret@imr.no
Ukraine	Mr Viktor Podhornyi Institute of Fisheries and Marine Ecology (IFME) pvv04111970@i.ua
United Kingdom	Dr Sophie Fielding British Antarctic Survey sof@bas.ac.uk
CCAMLR Secretariat	Dr Keith Reid Science Manager keith.reid@ccamlr.org

Appendix B

Agenda

Subgroup on Acoustic Survey and Analysis Methods
(Bergen, Norway, 26 to 30 August 2019)

1. Opening of the meeting

2. Large-scale krill surveys conducted in 2019

   2.1 Area 48 multinational survey
      2.1.1 Cross-checking of survey results among different participants
      2.1.2 Comparison of results using the dB window and the swarm-based methods
      2.1.3 Revised/refined analysis, including taking into account any issues raised during WG-EMM

   2.2 Area 58 Japanese survey
      2.2.1 Review of preliminary survey results, including the use of broadband acoustic data

3. Review of collection and analysis of krill acoustic data from fishing vessels

   3.1 Progress in data collection and delivery of acoustic data from fishing vessels
   3.2 Procedures for the collection and analysis of krill acoustic data collected on designated transects

4. Other technical aspects relevant to the krill acoustic surveys and data analysis

5. Other business

6. Advice to the Scientific Committee

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

Appendix C

List of Documents

Subgroup on Acoustic Survey and Analysis Methods
(Bergen, Norway, 26 to 30 August 2019)

SG-ASAM-2019/01	Acoustic data collection by the krill fishing industry to improve the monitoring of krill abundance K. Reid and J. Arata
SG-ASAM-2019/02	Preliminary biomass estimation of Antarctic krill based on the swarm-based method for CCAMLR Division 58.4.1 in 2018/19 using data obtained by Japanese survey vessel *Kaiyo-maru* K. Abe, R. Matsukura, N. Yamamoto, K. Amakasu and H. Murase
SG-ASAM-2019/03 Rev. 1	Density estimation of Antarctic krill (*Euphausia superba*) around South Shetland Island and Elephant Island (Subarea 48.1) using two frequencies with 38 and 120 kHz S. Choi, S. Chung, I. Han, W. Oh, D. An and K. Lee
SG-ASAM-2019/04 Rev. 1	Time series of Antarctic krill estimates around the South Shetland Islands from 2013 to 2019 X. Yu, X. Wang, X. Zhao, J. Zhang, G. Fan, Y. Ying and J. Zhu
SG-ASAM-2019/05	Diel vertical distribution of Antarctic krill around the South Shetland Islands in February 2019 and its potential effect on biomass estimation X. Wang, X. Yu, J. Zhang and X. Zhao
SG-ASAM-2019/06	Comparison of krill density estimated with swarm-based and dB-difference method using acoustic data collected by Chinese fishing vessel participating in the 2019 Area 48 survey X. Yu, X. Wang, J. Zhang and X. Zhao
SG-ASAM-2019/07	Biomass estimates of Antarctic krill based on survey conducted by the Chinese fishing vessel FV *Fu Rong Hai* during the 2019 Area 48 survey X. Wang, X. Yu, X. Zhao, J. Zhang, G. Fan, J. Zhu and Y. Ying

SG-ASAM-2019/08 Rev. 1	Biomass results from the International Synoptic Krill Survey in Area 48, 2019 G. Macaulay, G. Skaret, T. Knutsen, O.A. Bergstad, B. Krafft, S. Fielding, S. Choi, S. Chung, K. Demianenko, V. Podhornyi, K. Vishnyakova, L. Pshenichnov, A. Chuklin, A. Shishman, X. Wang, X. Zhao and M. Cox
SG-ASAM-2019/09	Supervised and unsupervised (RapidKrill) estimates of krill density from DY098 A. Ariza, S. Fielding and R. Blackwell
SG-ASAM-2019/10	Methodological aspects of the International Synoptic Krill Survey in Area 48, 2019 G. Macaulay, G. Skaret, T. Knutsen and B. Krafft