RAPPORT FRA HAVFORSKNINGEN

Nr. 9-2015

Antarctic krill and ecosystem monitoring survey at South Orkney Islands in 2015, and assessing escape mortality of krill in trawls

av Georg Skaret, Bjørn A. Krafft, Ludvig A. Krag, and Ronald Pedersen

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

Mai 2015

www.imr.no

Cruise participants:

Institute of Marine Research:
Georg Skaret, Bjørn A. Krafft and Ronald Pedersen

Technical University of Denmark:
Ludvig Ahm Krag

Project leader:
Olav Rune Godø

Contents

Introduction and background 6
Material and methods 7
 Survey design, area and vessel 7
 Acoustics 8
 Analyses of the acoustic data 10
 Estimation of biomass 11
 Biological sampling 11
 Hydrographical sampling 12
 Marine predator observations 12
Results 13
 Acoustics 13
 Biological sampling 15
 Hydrographical sampling 18
 Marine predator observations 18
 Assessment of escape mortality of krill 18
Acknowledgements 20
References 20

Introduction and background

The fishing operations for Antarctic krill (*Euphausia superba*) are concentrated within CCAMLR (Commission on the Conservation of Antarctic Marine Living resources) subareas 48.1, 48.2 and 48.3 in the Southern Ocean. The total krill catch for 2014 was slightly below 300000 tons. Regular monitoring of the krill during the last two decades has been carried out by US AMLR in the Bransfield Strait and Elephant Island (subarea 48.1), previously at austral summer time but presently at austral winter time, as well as the British Antarctic Survey off the South Georgia Islands (subarea 48.3) during austral summer time.

The two Norwegian fishing companies operating in the Antarctic krill fishery have in recent years contributed to more than half of the total catch, and as a contribution to the resource monitoring requested as part of the fisheries management, the Norwegian fishing company Aker Biomarine ASA, offered to carry out an annual 5-day krill monitoring survey during the years 2011-2015 (Jensen et al. 2010). Through discussions in CCAMLR WG-EMM (Working Group on Ecosystem Monitoring and Management) in 2010 it was agreed that the survey could be carried out in the CCAMLR statistical Subarea 48.2 according to similar standards as the annual scientific surveys undertaken in 48.1 and 48.3 (SC-CAMLR, 2010). Together the three surveys could form an integrated monitoring effort extending across the Scotia Sea and linking three of the areas with highest concentrations of krill and highest fishing activity. In 2012, the other Norwegian operating company, Olympic ASA, adhered to the agreement, and the Norwegian Fisheries Directorate recommended that each company's monitoring effort should reflect the number of vessels active in the fishery. At present 2 vessels from Aker and 1 from Olympic are active in the fisheries and the circulation is therefore two successive years of monitoring on board an Aker vessel, and one year on board the Olympic vessel.

The first annual survey was carried out in January/February 2011 using the F/V 'Saga Sea' (Aker Biomarine ASA) (Krafft et al. 2011). The results and study design from this survey was presented at the CCAMLR WG-EMM in 2011. The original survey design, which was suggested during the WG-EMM meeting in 2010 consisted of six parallel north-south bound transects extending 100 nmi. During this first survey season it was recognized a need to extend the monitoring effort covering the waters over the shelf edge, north of the South Orkney archipelago, where the majority of krill in this region traditionally aggregate. During the WG-EMM meeting in 2011 it was agreed to extend the survey transects 20 nmi northwards and to omit the westernmost transect line from the 2011 survey (SC-CAMLR, 2011). Before the survey in 2014, it was agreed to extend the transect lines further south in order to cover the Marine Protected Area south of the South Orkney Islands.

This report presents the results from the fifth of the annual survey seasons (2015) off the South Orkney Islands including results from continuously recorded acoustic data, krill predator sighting data collected during daylight hours along the transects and trawl station data. In addition, vessel time was disposed to on board experiments of the survival of krill which had escaped through the trawl meshes. These experiments were part of the ongoing project NEAT 2 (Net Escapement of Antarctic krill in Trawls), and we present the applied methods and preliminary results. Our scientific team consisted of scientists and engineers from the Institute of Marine Research (Norway) and Technical University of Denmark. As monitoring platform the krill fishing vessel 'Juvel' was used, owned by the Norwegian group of companies Olympic.

Material and methods

Survey design, area and vessel

The F/V "Juvel" (Olympic ASA) is a 99.5 m, 6000 KW krill fishing vessel which was used for the present survey. The vessel departed from Montevideo, Uruguay on the 27 January 2015. On the 6 February the vessel reached the South Orkney Islands, and immediately started to search for fishable krill aggregations on the northside of the Coronation Island (Figure 1). These krill were to be used in the survival experiments which are further described below. After two days of trawling, the vessel sailed to the position of the acoustic mooring which was deployed during the survey last year. After a few attempts, contact with the mooring was made, launching was triggered and it was successfully retrieved from the surface.

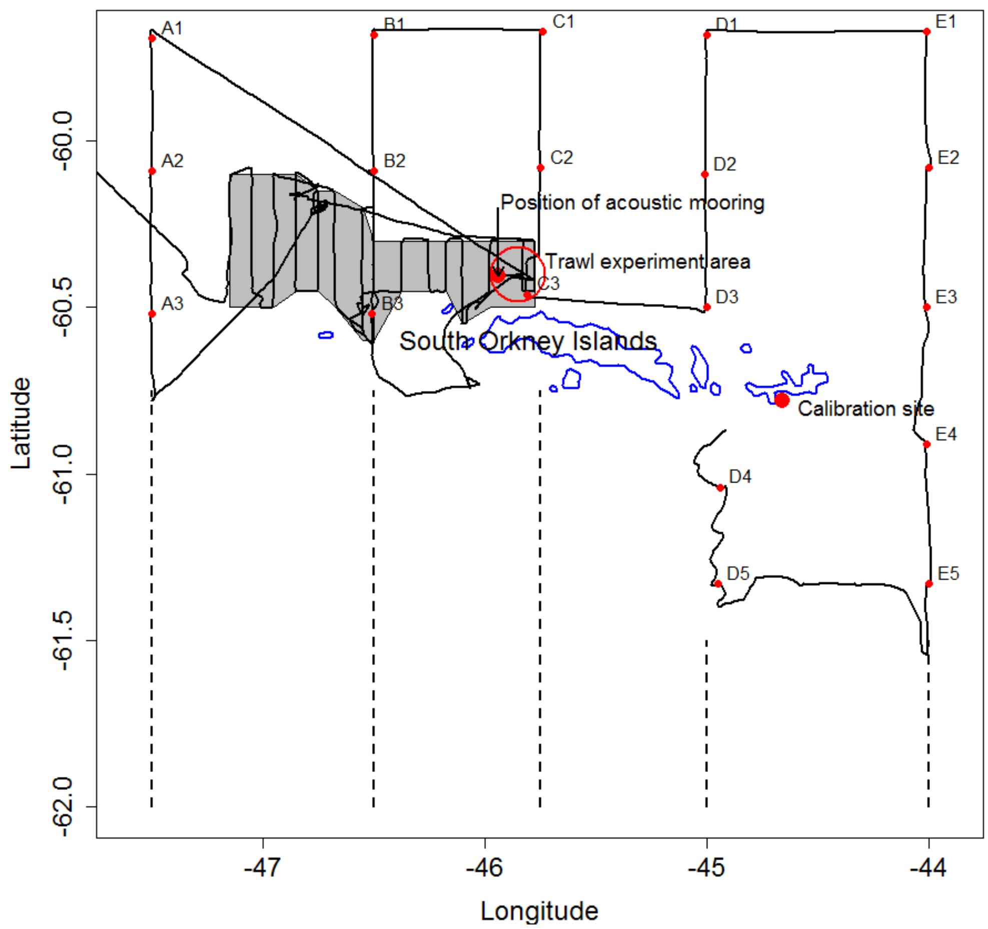

Figure 1. Summary map of the 2015 krill monitoring survey. The dashed lines denote the planned transect, while the fully drawn denote actual sailed tracks. Irregular tracks are due to ice coverage. The shaded grey area marks the stratum defined prior to this years' survey based on the historical fishery. Red dots with associated numbering indicate trawl stations.

The vessel went into Scotia Bay for calibration and started on the survey transect immediately after on the 9 February at approximately 0400 UTC and ended on the 12 February at 0700 UTC. The survey followed the design from previous years with a randomly chosen fixed starting point and five parallel transect lines extending from the northernmost waypoints at 59.67°S to the southernmost waypoints at 62.00°S, and positioned at longitudes 44°W, 45°W, 45.75°W, 46.5°W and 47.5° W, respectively (Figure 1). When passing the position of the mooring deployment from last year, it was deployed for a new year of data logging. Due to ice, much of the survey coverage south of the South Orkney Islands could not be done. After completing the standard survey, the vessel continued with the krill survival experiments, and the survey was completed with an extended small-scale coverage of the krill fishing area (Figure 1) which ended around 10:30 on the 14 February. All scientists were then transported to Port Stanley, Falkland Islands which was reached on the 17 February.

Acoustics

Acoustic mooring

An acoustic mooring (Acoustic Zooplankton Fish Profiler, ASL Environmental) was deployed last year on the 11 February at 60.24.291S and 45.56.306W at bottom depth 530 m with cable length from the anchor to the transducer at 200 m. The mooring was successfully retrieved on the 11 February. The housing was heavily corroded, but the parts inside the housing had not been attacked. The corrosion may have arisen as a result of an *ad hoc* frame which had to be constructed on board since the original frame never reached the vessel in time for the survey last year. After retrieval, data were transferred and the battery changed, and the mooring was mounted in the original frame (see figure 2). The mooring was deployed again in the vicinity of the previous location of deployment.

Figure. 2. Acoustic mooring mounted inside the company designed original frame. This frame was used when the mooring was redeployed for a new year of logging, but not during the 1-year period it had already been deployed.

Acoustic survey sampling procedure

For the collection of acoustic data, a Simrad echo sounder system logged data continuously at two frequencies, 38 and 70 kHz. From the original vessel set-up Simrad ES60 were replaced with Simrad EK60 General Purpose Transceivers connected to the ES60 transducers mounted in the vessel hull. Also a 120 kHz transducer was on board, but not mounted in the hull. Attempts were made to use it mounted in a paravane system, but the data quality was not good, and the data were not used.

The 38 and 70 kHz echosounders were calibrated in Scotia Bay, Laurie Island prior to the survey using standard sphere calibration (Foote et al.1987). The echo sounder was operating with a ping interval of 1 second. Nominal vessel speed during surveying was 10 knots. The transceiver settings are specified in Table 1. Acoustic data were sampled down to 500 m on both frequencies.

'Juvel' is also equipped with a high frequency (116 kHz in single CW/FM) Simrad SH 80 sonar and raw data on the .dat format were logged continuously with the sonar pointing 90 degrees to starboard side in the 'Bow up/180° vertical mode', tilt angle of -4 degrees and range of 600 m. In this mode data are acquired alternately in a vertical slice and a horizontal slice. Analyses of the sonar data could not be done within the time frame of the present survey analyses.

Table 1. Specification of transceiver settings on 'Juvel' applied during the 2015 survey.

Echosounder specification	38 kHz	70 kHz
Transducer type	ES38-B	ES70-7C
Transmitted power (W)	2000	700
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	10.1	23.4
Sound speed (ms^{-1})	1450	1450
Sample distance (m)	0.186	0.186
Two-way beam angle (dB)	-20.6	-21
S_v transducer gain (dB)	26.74	26.1
Angle sensitivity alongship	21.9	23
Angle sensitivity athwartship	21.9	23
3 dB beamwidth alongship (deg)	7.49	6.82
3 dB beamwidth athwartship (deg)	7.08	6.55

Analyses of the acoustic data

Discrimination of targets

The method for target discrimination as described in the CCAMLR protocol requires data from the frequencies 38, 120 and 200 kHz and our data were collected at 38 and 70 kHz. However, we used the idea that different targets have predictable frequency dependent volume backscattering strength (S_v; dB re m^{-1}) within a specified range of body lengths. Following this idea, targets which fall within a specific range of ΔS_v-values ($S_{v,70} - S_{v,38}$) will be identified as *E. superba*. The method was applied on sample bins of 50 pings horizontal*5 m vertical resolution. The minimum and maximum ΔS_v-values defining the krill identification 'window' were calculated using the simplified Stochastic Distorted Wave Born Approximation (SDWBA) package, SDWBApackage2010 (Conti and Demer 2006; SG-ASAM 2010; Calise and Skaret 2011), and was based on the krill length frequency distribution from the trawl samples where 95 % of the distribution was extracted from a cumulative probability density distribution (SG-ASAM 2010, SC-CAMLR 2005; Reiss et al. 2008). After the discrimination, the retained Nautical Area Scattering Coefficient (NASC)-values were averaged for each nautical mile.

Target strength prediction

The retained NASC allocated to krill were converted to biomass density (g m^{-2}) using the SDWBApackage2010 (SG-ASAM 2010; Calise and Skaret, 2011) according to the CCAMLR protocol. The model was parameterized according to table 2, or if nothing else specified according to Calise and Skaret (2011).

Table 2. Parameter settings applied for the prediction of *E. superba* target strength using the full SDWBA model (Demer and Conti, 2006) as implemented in the SDWBApackage2010 (Calise and Skaret, 2011).

Parameter	Symbol	Value applied	Unit	Reference
Krill length	L	$38.35 \cdot 10^{-3}$	m	1
Density contrast	g	1.0357		2
Sound speed contrast	h	1.0279		3
Seawater sound speed	c	1453	m s^{-1}	
Fatness		1.2		4
Standard deviation of stochastic phase	$sd_{\phi 0}$	sqrt(2)/2	radians	5
Distribution of orientations	θ_0	N[-20,28]	degrees	6
Stochastic realisations		100		4

1 - McGehee et al. 1990; 2 - Foote et al. 1990; 3 - Foote, 1990; 4 - Calise and Skaret, 2011; 5 - Conti and Demer, 2005; 6 - SG-ASAM, 2010

The predicted target strengths were used to calculate weighted conversion factors (CF) from NASC-values to biomass density.

$$CF = \left[\sum f_i \cdot W(TL_i)\right] / \left[\sum f_i \cdot \sigma(TL_i)\right]$$

where f is the frequency of a specific length group (i) and W(TL) is weight at total length, which was calculated following Hewitt et al. (2004):

$$W(g) = 2.236 \cdot 10^{-3} \cdot TL^{3.314}$$

σ(TL) is the backscattering cross-section at a specific total length and was calculated based on the simplified SDWBA expressed as:

$$TS(kL) = A\left[\frac{\log_{10}(BkL)}{BkL}\right]^c + D(kL)^6 + E(kL)^5 + F(kL)^4 + G(kL)^3 + H(kL)^2 + I(kL) + J + 20\log_{10}\left(\frac{L}{L_0}\right)$$

where L_0 is the reference length 38.35 mm (McGehee et al. 1998), k is denoting acoustic wave numbers (k=2πf/c) used to transform the model to different frequencies (f) at a given sound speed (c). A to J are coefficients extracted from the full SDWBA model run parameterized according to the description in the beginning of this section.

Estimation of biomass

Based on the average biomass density for each nautical mile, a weighted biomass density for each transect line could be calculated and the sampling variance from the averages of each transect line according to Jolly and Hampton (1990). In cases of deviance from the original transect line due to ice coverage, the weighting was done according to original transect line.

Biological sampling

On each of the 5 main transect lines, trawl hauls were to be conducted every~25 nmi, which totals 30 trawl hauls according to the original design, but because of inaccessible areas, the number of stations was reduced to 19 (See fig. 1). Hauls were conducted using a "Macroplankton trawl"; a fine-meshed plankton trawl having a 6 x 6 m mouth opening and a mesh size of 7 mm from the mouth to the rear end. At each trawl station, the trawl was lowered from surface to 200 m depth (or~20 m above bottom if the water depth was shallower than 200 m). Towing speed was 2.0 knots and during hauling the wire speed was 5 min/100 m. When a trawl was landed on deck, the total catch was emptied into baskets and weighed. A random subsample was preserved on borax-buffered formalin (4%). An additional subsample was then taken and sorted, identified to the nearest taxonomic group and weighed. For *E. superba*, the length of individuals was measured (± 1 mm) from the anterior margin of the eye to the tip of telson excluding the setae, according to the "Discovery method" used in Marr (1962). Sex and maturity stages of *E. superba* were determined on fresh material using the classification methods outlined by Makorov and Denys (1981). In brief; the method divides males into three sub adult stages: MIIA1, MIIA2 and MIIA3 and two adult stages: MIIIA and MIIIB, and females into one sub adult stage: FIIA and five adult stages: FIIIA, FIIIB, FIIIC, FIIID and FIIIE. In contrast to all other stages, juveniles have no visible sexual characteristics.

Hydrographical sampling

Hydrographical data were acquired using a SAIV handheld CTD sensor. The CTD was mounted in an open metal frame for protection and welded on the trawl beam to obtain profiles of temperature and salinity during the trawl hauls. The CTD device was logging continuously in 10-second intervals during the first part of the survey.

Marine predator observations

Sightings for seabirds and marine mammals were carried out by a dedicated observer. Observations were made during daylight hours (0600-2000 local time); in total approximately 42 hours of observation were carried out. Observations were made along all survey transects and during transit between transects; no observations were made whilst trawling. Ship speed was 10 knots, with observations made from the bridge at 10m above sea level.

Observations were made forward and to one side covering targets out towards the horizon, usually from the Forward Port Quarter, but sometimes from the Forward Starboard Quarter, depending upon weather conditions. Each recorded observation included the species and the number of individuals observed, the time (in UTC), the ship's position, the distance to the target at first sighting, and the relative angle from the vessel. For whales, the swim direction relative to the vessel was also recorded. Records were made using an in-house voice recording system which contains a microphone and a GPS connected to a pc. The system records vessel position and time continuously at regular intervals, and a .wav sound-file is generated each time a sighting is read into an activated microphone. In addition, records were entered into an in-house software and exported for later analysis.

Observations were carried out using both the naked eye and through binoculars. A range of texts were used to identify unknown species and documentations were made with film and photo.

Assessment of escape mortality of krill

A pilot study (NEAT) using both mathematical modeling techniques and practical experiments on size selection of krill shows that escape occurs even from some of the smallest commercial meshes used in the fishery. In a new project (NEAT2), we aim to assess the rate of escape mortality to establish selectivity predictions of krill for any trawl design, including trawlbody and codend. The indirect fishing mortalities include organisms that die after either escaping or being discarded from fishing gear due to inflicted injuries.

The initial field experiments were performed using a trawl with a fine mesh cover bag; covered codend method (Wileman et al., 1996) to capture the krill that escape through the codend. Large aquariums with continuous water exchange were used as holding facilities for krill. Krill was monitored over several days for measuring mortality and stress levels after being exposed to this type of strain.

Results

Acoustics

Acoustic mooring

The mooring echosounder had been logging data for the entire period it had been deployed (approximately 1 year). A total of ca. 28 GB of data had been logged at a frequency of 1 ping each 4. second and within a range of ca. 300 m. An example echogram is shown in Figure 3. All data were stored with a server at IMR and data access given to those involved in processing and analyses.

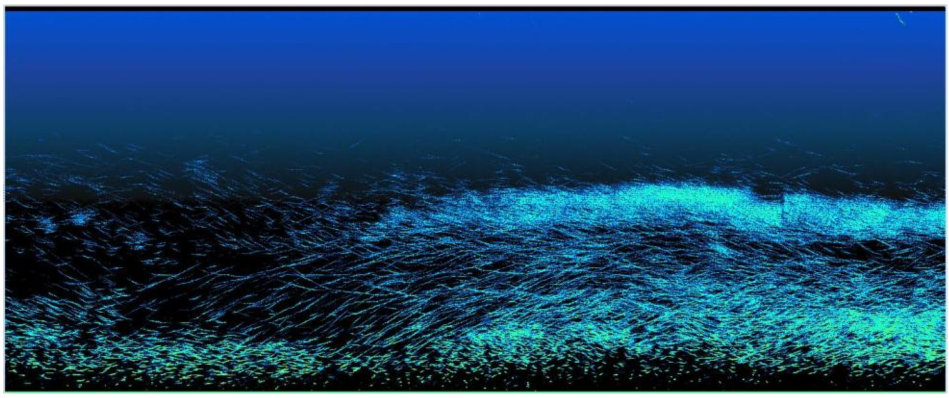

Figure 3. Example echogram from 1 hour of acoustic recordings from the mooring at a ping rate interval of 4 seconds. The vertical range is 300 m, and the upper limit of the echogram is at 30 m ca. depth.

Acoustic survey estimates

The distribution of acoustic backscatter allocated to krill is shown if Figure 4. The highest NASC-values allocated to krill were observed in the northern part of the covered area, further north than the typical distribution from previous surveys. However, it should be noted that on several occasions very high NASC-values were recorded but not allocated to krill, also in areas where high krill abundances were expected. These unexpected results most likely point to a methodological issue since identification of krill was based on the differences in backscattering between the frequencies 70 and 38 kHz, instead of 120 and 38 which has been validated through several studies. This is even more apparent in Figure 5 which shows the recorded NASC-values from the small-scale transect. This transect was conducted within the area where krill was observed, but only very little of the recorded NASC was actually allocated to krill. The biomass estimates shown in table 3 are therefore likely biased. These estimates together with all the others in the survey time series will be revised and presented for the 2015 CCAMLR EMM working group.

Table 3. Summary table of krill biomass estimation from the 2015 survey. As mentioned in the text there were likely issues with the krill identification biasing the results low.

	Freq (kHz)	BM density (g/m^2)	Var	Biomass (mill. tons)	CV (%)
	70	19	9	0.760	15
Ordinary survey	38	12	6	0.460	22
	70	11	9	0.015	26
Small scale survey	38	6	2	0.009	24

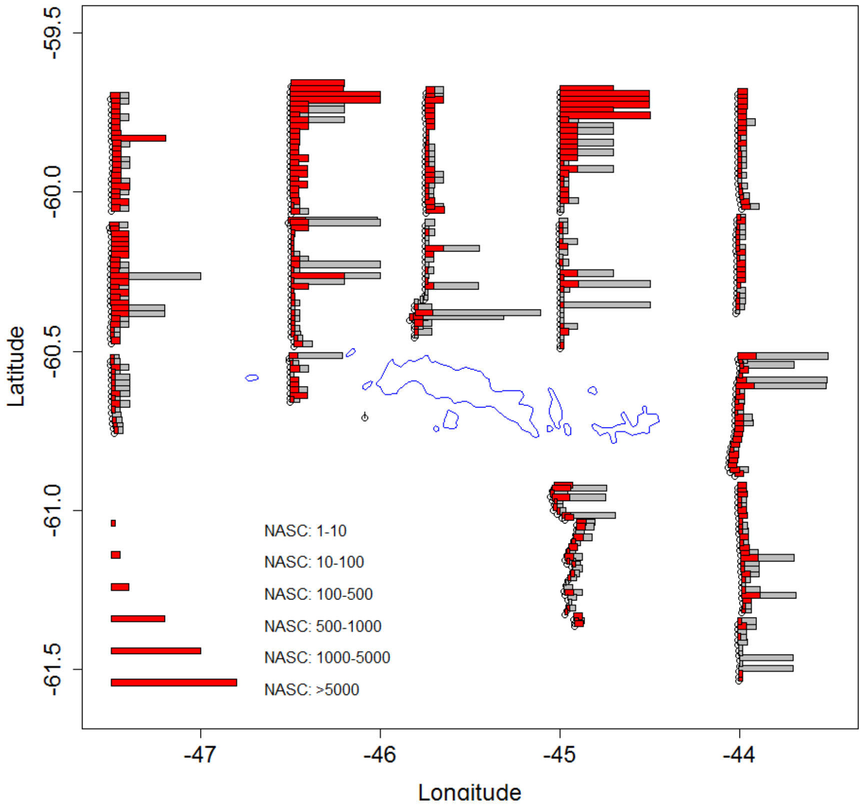

Figure 4. Distribution of Nautical Area Scattering Coefficients (NASC) allocated to *E. superba* from the 70 kHz recordings. Red colour marks NASC allocated to krill, and grey colour marks total NASC.

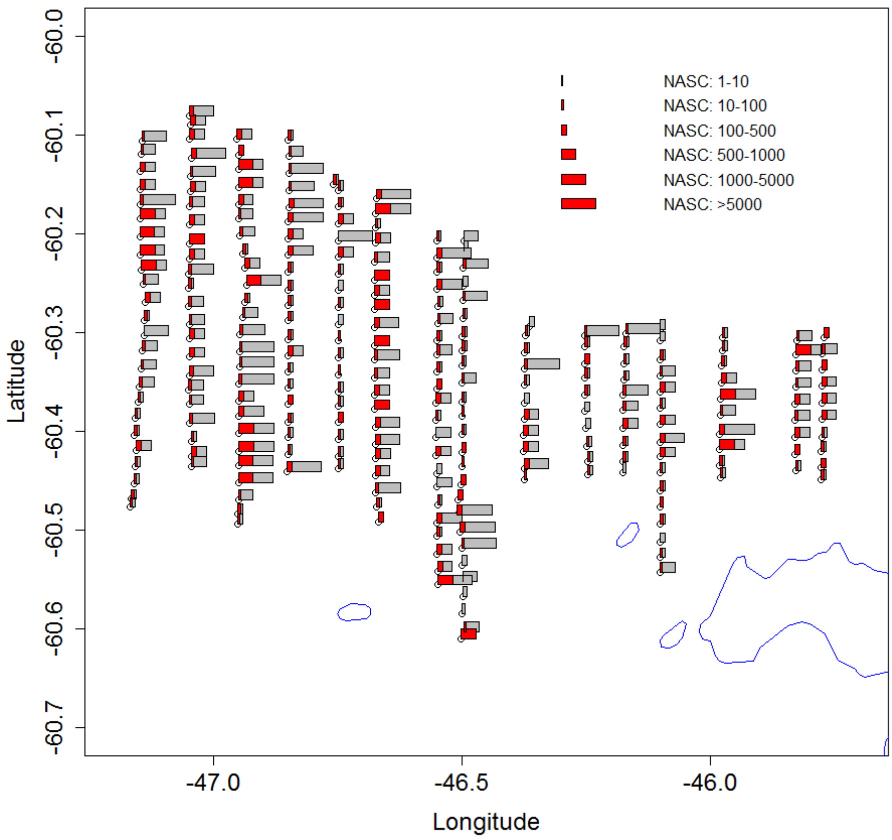

Figure 5. Distribution of Nautical Area Scattering Coefficients (NASC) allocated to *E. superba* from the 70 kHz recordings from the small scale survey. Red colour marks NASC allocated to krill, and grey colour marks total NASC.

Biological sampling

Of a total of 19 trawl stations, three hauls were empty. Euphausiids dominated in the total catch with *E. superba* as the dominating species (Figure 6). Two other species of krill were found, the *Thysanoessa macrura* and *Euphausia triacantha*. *Salpa thompsoni* occurred in 9 stations and were particularly frequent in the north. Fish of various species and *Themisto gaudichaudi* were also frequently present, in 8 and 7 stations, respectively.

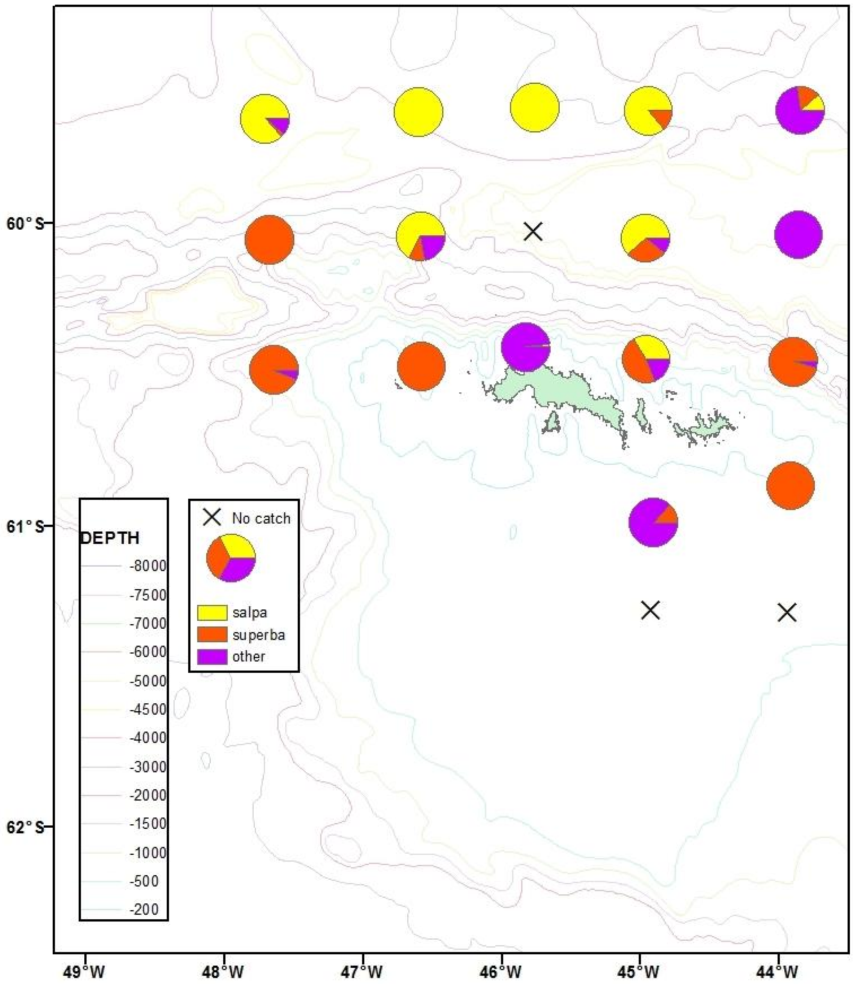

Figure 6. Proportional presence of macrozoo-plankton in trawl catches made in the South Orkney Islands waters during the 2015 season.

Krill length distribution was unimodal with an overall average of 43.4 mm (Figure 7). Less than 1 % of the sampled animals were juveniles (table 4). Males were dominant in the samples with subadults and adults about equally represented, while adults were dominant among the females.

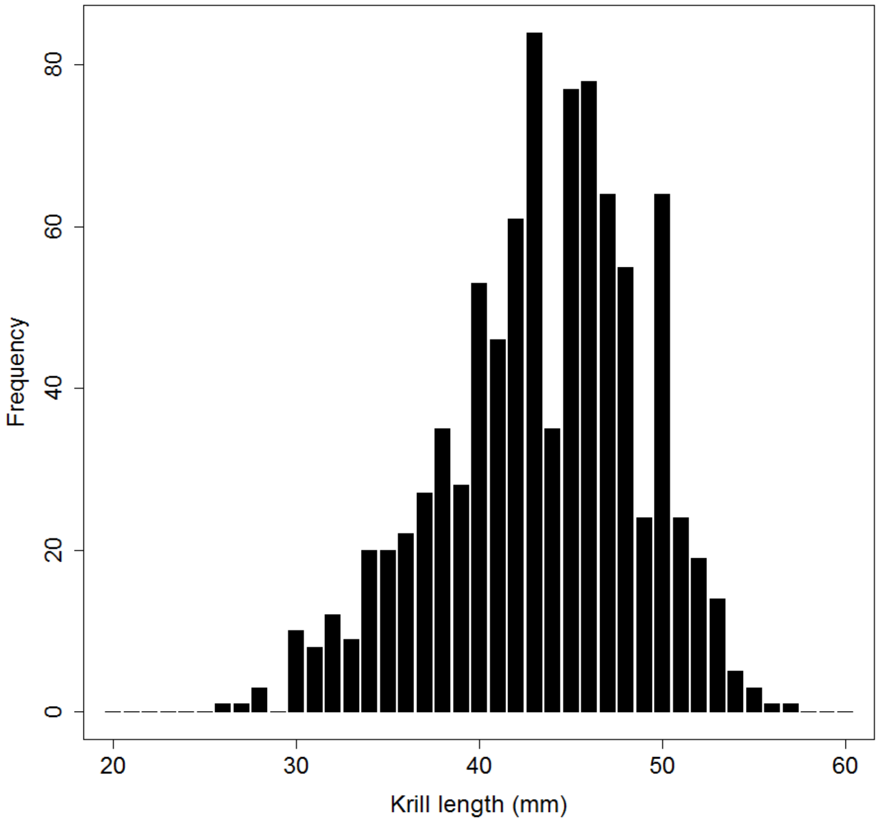

Figure 7. Krill length distribution based on all samples combined.

Table 4. Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctic krill caught in the South Orkney Islands area in the 2015 season.

Krill maturity stages	No.in sample	Proportion(%)	Total length(Mean±SD)
Juvenile stage 1	8	0.9	29.1 ± 1.6
Male subadult MIIA1	91	10	35.5 ± 3.8
Male subadult MIIA2	106	11.6	39.6 ± 3.3
Male subadult MIIA3	101	11.1	45.0 ± 3.3
Male adult MIIIA	111	12.2	47.4 ± 2.7
Male adult MIIIB	138	15.1	47.6 ± 3.3
Female subadult FIIB	51	5.6	38.1 ± 2.9
Female adult FIIIA	34	3.7	39.8 ± 3.9
Female adult FIIIB	127	13.9	43.5 ± 3.5
Female adult FIIIC	34	3.7	45.1 ± 3.1
Female adult FIIID	70	7.7	47.1 ± 4.5
Female adult FIIIE	42	4.6	45.3 ± 3.7
Total	913		

Hydrographical sampling

The temperature recorded down to maximum 200 m ranged from -1°C and 2°C in the survey area, but generally warmer in the northernmost stations (Figure 8). Minimum temperature was typically measured at the thermocline around 50 m, below which temperature typically increased. Salinity ranged from 33.5 to 35 with the lowest values measured close to the surface and salinity typically increasing below the halocline towards the maximum depth.

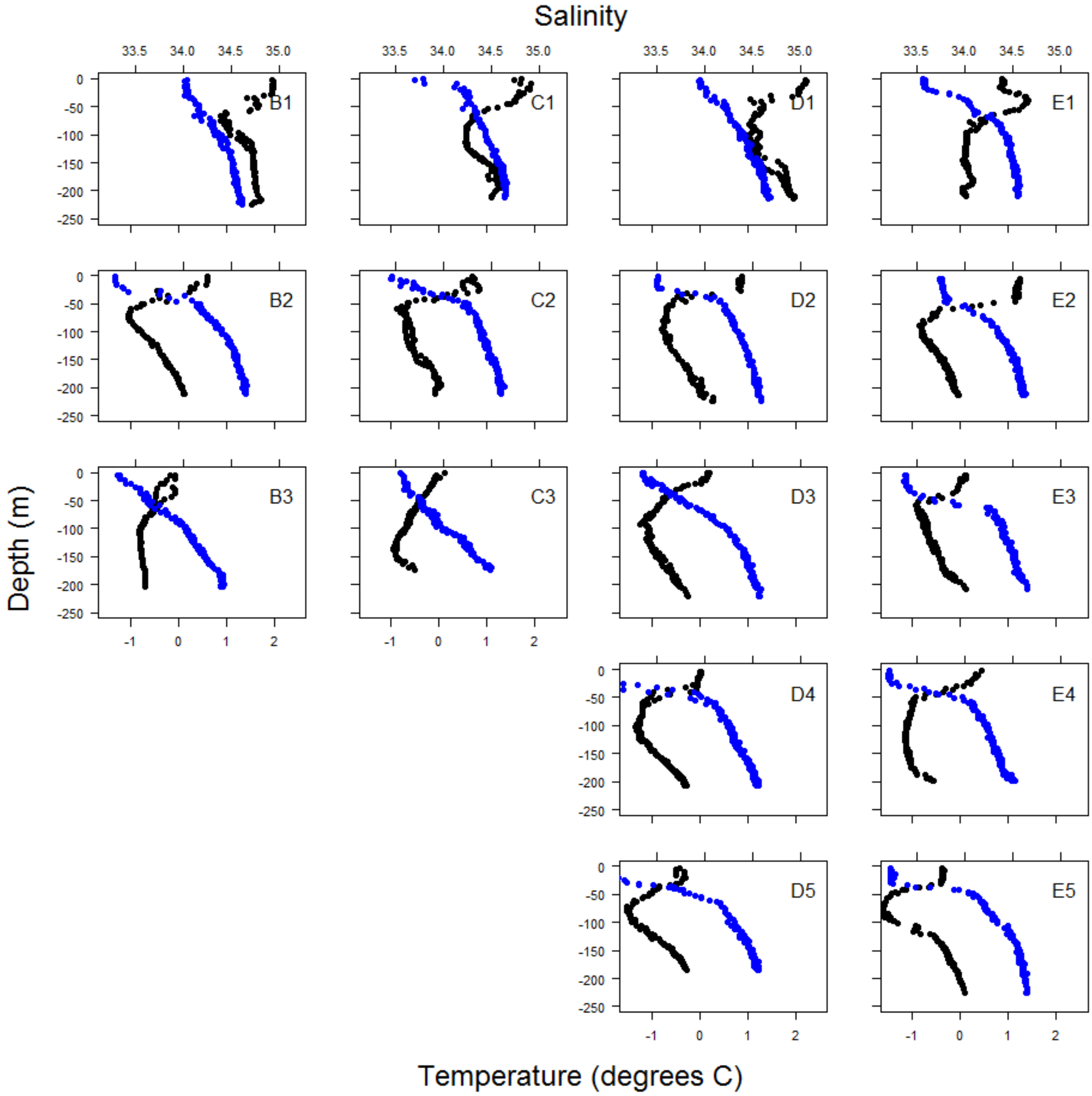

Figure 8. Temperature and salinity profiles.

Marine predator observations

A total of 2971 observations were made covering 25 species of marine predators. Notable observations were 258 whales, of which 144 were fin whales (*Balaenoptera physalus*) and 43 humpback whales (*Megaptera novaeangliae*), 2762 chinstrap penguins (*Pygoscelis antarcticus*) and 177 Antarctic fur seals (*Arctocephalus gazella*) (Figure 9).

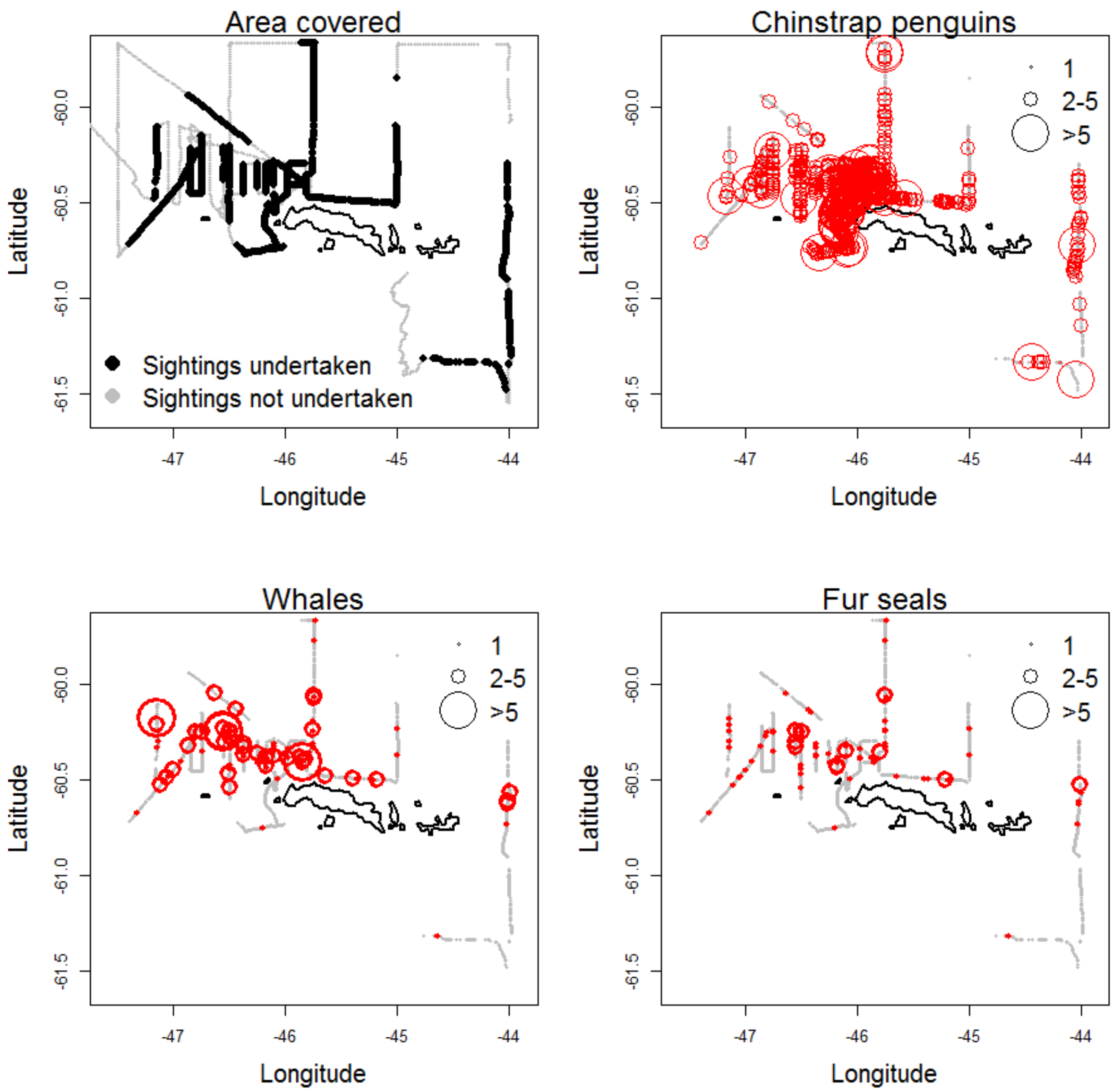

Figure 9. Overview of recorded sightings of chinstrap penguins (*Pygoscelis antarcticus*), whales (fin whales; *Balaenoptera physalus* and humpback whales; *Megaptera novaeangliae*) and fur seals (*Arctocephalus gazella*) during the survey.

Assessment of escape mortality of krill

The control groups that were first established in the aquarium environment (Figure 10) before the experiment began, showed very low mortality during the entire experimental period. Krill escapement through the trawl meshes is shown in Figure 11. The first experiment results also indicate that the proportion of krill that die as a result of the escaping masks is also low. Such mortality is found to be much higher in many of the pelagic fish species such as herring and mackerel. One possible explanation for the observed robustness of the krill, in contrast to pelagic fish, is that they have a relatively powerful exoskeleton that protects against mechanical wear and that they are also far more mobile than previously assumed. Further analyzes of samples taken to measure physiological changes that indicate stress levels will give us more information about the extent of the effect of being exposed to this kind of influence.

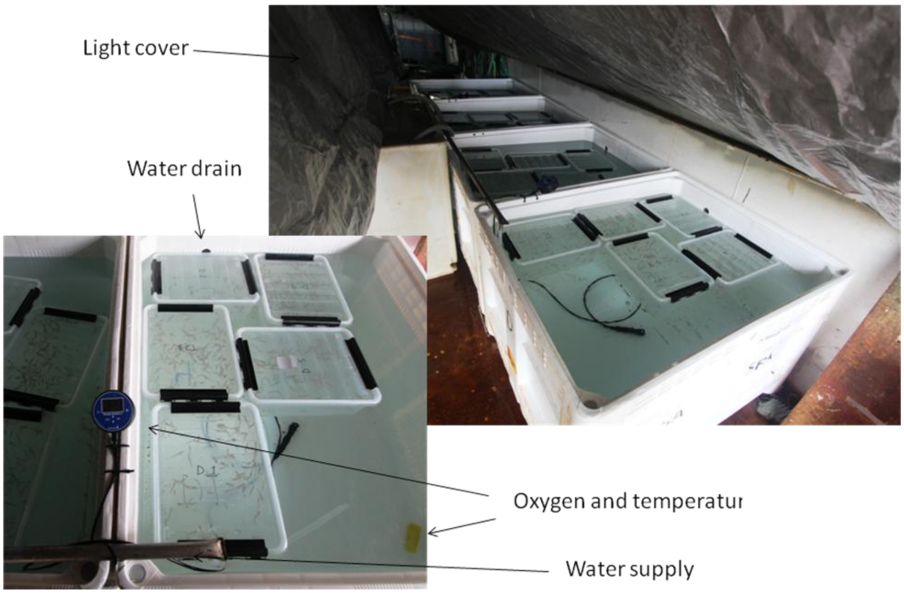

Figure 10. Experimental set-up with krill in aquariums.

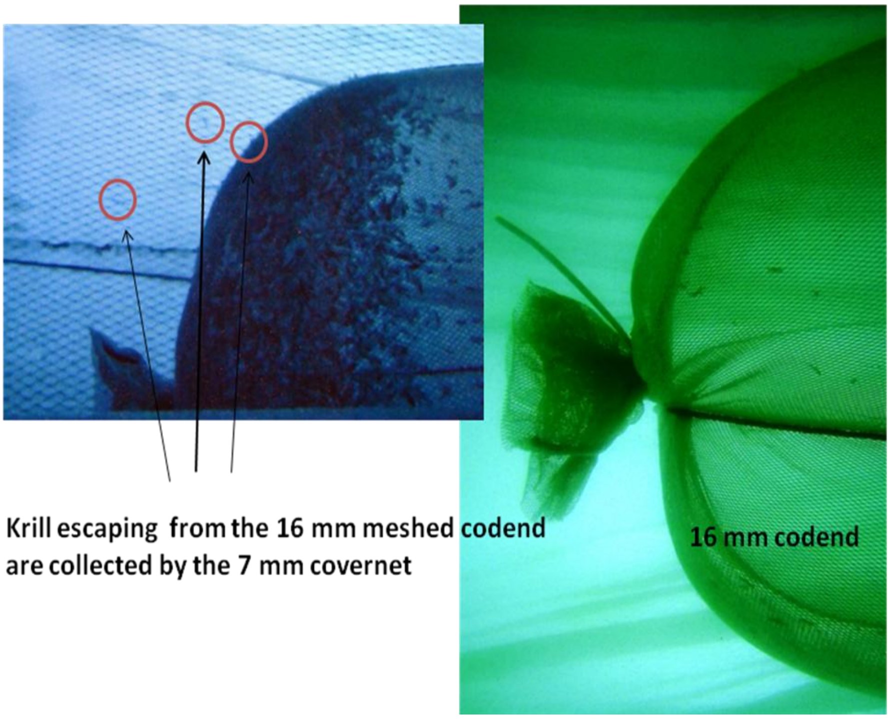

Figure 11. Krill escaping through a codend with 16mm masks during trawling into a fine meshed cover (7 mm). This krill was examined in holding facilities onboard to monitor mortality rates and stress levels.

Acknowledgements

We extend our gratitude to the Olympic ASA for providing 'Juvel' and its crew to disposal for this research survey free of charge. We are most grateful to the captain, officers and crew on board 'Juvel' for all the help provided during the cruise. We are also grateful to Kjell Arne Fagerheim for providing us with a voice recording system for the predator observations.

References

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

Conti, S.G. and D.A. Demer. 2006. Improved parameterization of the SDWBA for estimating krill target strength. ICES Journal of Marine Science, 63 (5): 928-935.

Demer, D.A. and S.G. Conti. 2005. New target-strength model indicates more krill in the Southern Ocean. *ICES Journal of Marine Science*, 62 (1):25–32.

Foote, K.G., H.P. Vestnes, D.N. MacLennan and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report, 144, 69 pp.

Foote, K.G. 1990. Speed of sound in *Euphausia superba*. *Journal of the Acoustic Society of America*, 87 (4):1405–1408.

Foote, K.G., I. Everson, J.L. Watkins and D.G. Bone. 1990. Target strengths of Antarctic krill (*Euphausia superba*) at 38 and 120 kHz. *Journal of the Acoustic Society of America*, 87 (1): 16–24.

Hewitt, R. P., Watkins, J., Naganobu, M., Sushin, V., Brierley, A. S., Demer, D., Kasatkina, S., Takao, Y., Goss, C., Malyshko, A., Brandon, M., Kawaguchi, S., Siegel, V., Trathan, P., Emery, J., Everson, I., and Miller, D. 2004. Biomass of Antarctic krill in the Scotia Sea in January/February 2000 and its use in revising an estimate of precautionary yield. Deep-Sea Research Part Ii-Topical Studies in Oceanography, 51: 1215-1236.

Jensen N, Nicoll R, Iversen SA (2010) The importance of obtaining annual biomass information in CCAMLR Sub-area 48.2 to inform management of the krill fishery. WG-EMM-10/9. 5 pp.

Jolly GM, Hampton I (1990) A stratified, random-transect design for acoustic surveys of fish stocks. Canadian Journal of Fisheries and Aquatic Sciences 47: 1282–1291.

Krafft BA, Skaret G, Calise L (2011) Antarctic krill and apex predators in the South Orkney Islands area 2011, surveyed with the commercial fishing vessel Saga Sea. Rapport fra Havforskningen No. 6, 21 pp.

Makorov RR, Denys CJI (1981) Stages of sexual maturity of (*Euphausia superba*). BIOMASS Handbook No. 11, pp 1-13.

Marr J (1962) The natural history and geography of the Antarctic krill (*Euphausia superba* Dana). In: Discovery reports vol 32. National Institute of Oceanography, Cambridge University Press, Cambridge pp 33-464

McGehee, D.E., R.L. O'Driscoll and L.V. Martin Traykovski. 1998. Effects of orientation on acoustic scattering from Antarctic krill at 120 kHz. *Deep-Sea Research Part II*, 45 (7): 1273–1294.

Reiss C.S., A.M. Cossio, V. Loeb and D.A. Demer 2008. Variations in the biomass of Antarctic krill (Euphausia superba) around the South Shetland Islands, 1996-2006. ICES Journal of Marine Science. 65: 497-508.

SG-ASAM. 2010. Report of the fifth meeting of the subgroup on acoustic survey and analysis method. Cambridge, UK, 1 to 4 June 2010. Submitted for: *Report of the Twenty-ninth Meeting of the Scientific Committee (SC-CAMLR-XXIX/6).* CCAMLR, Hobart, Australia: 23 pp.

SC-CAMLR. 2005. Report of the First Meeting of the Subgroup on Acoustic Survey and Analysis Method (SG-ASAM). In: *Report of the Twenty-fourth Meeting of the Scientific Committee (SC-CAMLR-XXIV/BG/3)*, Annex 6. CCAMLR, Hobart, Australia: 564–585.

SC-CAMLR, 2010. Report of the Working Group on Ecosystem Monitoring and Management. In: *Report of the Twenty-ninth Meeting of the Scientific Committee (SC-CAMLR-XXIX),* Annex 6. 173-244.

SC-CAMLR, 2011. Report of the Working Group on Ecosystem Monitoring and Management. In: *Report of the Thirtieth Meeting of the Scientific Committee (SC-CAMLR-XXIX),* Annex 4. 119-210.

Wileman, D., Ferro, R.S.T., Fonteyne, R., Millar, R.B. (Eds.), 1996. Manual of Methods of Measuring the Selectivity of Towed Fishing Gears. , ICES Coop. Res. Rep., No. 215, 126 pp.