WG-EMM-16/P03

30 May 2016

Original: English

WG-EMM

South Orkney Island 2016 Antarctic krill and ecosystem monitoring

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Introduction

Small scaled Russian exploratory fishing for krill in the Southern Ocean began in the late 1960s. During the 1970s the fisheries increased and annual catches of krill have exhibited a number of fluctuations since the beginning of commercial harvesting. Some of these changes have resulted from developments in technology and products whilst others have their origins in global economics and politics. The largest catches were reported in season 1981-1982 with more than 500 000 tonnes. Since 1989, the catches have been on a much lower level. The current krill fishery starts in December and ends usually in August-September. Although krill fishing is permitted in many parts of the Southern Ocean, the current fishery is concentrated around the South Shetland Islands and Bransfield Strait, the South Orkneys and South Georgia. These areas are located in CCAMLR (Commission on the Conservation of Antarctic Marine Living resources) statistical subareas 48.1 to 48.3. Norway participated with three vessels in the 2014/15 season and landed 146,968 tonnes, followed by China with 35,427 tonnes and South Korea with 23,342 tonnes. In total, 225,465 tonnes were fished this season. Products mainly produced from krill include meal and oil, which in turn goes to the feed, food supplements, cosmetics and medicine industries.

The understanding for how Antarctic krill stocks change temporarily, especially at larger spatial scales, is very limited. However, small spatial scaled krill monitoring programmes provide valuable year-to-year biomass and demography indices which can be used to answer some questions about change in the krill stock. During the last two decades monitoring of krill has been regularly performed by US AMLR in the Bransfield Strait and Elephant Island area (subarea 48.1) (e.g. Kinzey et al 2015) and the British Antarctic Survey off the South Georgia Islands (subarea 48.3) (e.g. Fielding et al. 2014). The Institute of Marine Research commenced in year 2011 an annual krill monitoring survey by utilizing fishing vessels, offered free of charge by the Norwegian krill fishery industry, as research platforms (Jensen et al. 2010).

During 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 areas with active fishing activity.

The Norwegian effort in the South Orkney region (48.2) was originally financed with a five year prospective. Due to the importance of the establishment and maintenance of krill abundance and demography time-series, the Norwegian fishery industry wishes to continue this cooperation as long as they stay active fishing krill in the Southern Ocean. To further contribute with information for understanding population dynamics, impact of environmental change, and potential effects on other components of this ecosystem the Norwegian Foreign Ministry provided financing of logistics and implementation of scientific personnel for a sixth season.

This report presents the outcome from the sixth of the annual survey seasons (2016) off the South Orkney Islands including the preliminary results from continuously recorded acoustic data, krill demography and other macro zooplankton from trawl station work, krill predator sightings data as well as krill-experimental work carried out on onboard.

Material and methods

Survey design, area and vessel

The supply vessel "La Manche" (Aker Biomarine AS) departed Montevideo, Uruguay on the 31 January. On the 07 January the vessel dropped anchor near Signy Island. Survey equipment and -personnel were transferred on the 08 January to the commercial trawler "Saga Sea" (also owned by Aker Biomarine ASA) while these two vessels were bound together. Immediate work on collecting and deploying moorings were made north of Coronation Island. Also commercial fishing were carried out before the ship headed for the north-westernmost position starting the work on the transect lines. The transect-survey commenced on the 10. February at 23:40 UTC and ended on the 15 February at 21:30 UTC. The vessel also went into Scotia Bay for calibration 15 February.

The survey design around the South Orkney Islands included five parallel transects extending from the northernmost waypoints at 59.67°S and southernmost waypoint at 62.00°S. Longitudes for transects 1 through 5 are at 44°W, 45°W, 45.75°W, 46.5°W and 47.5° W, respectively. This season the coverage of the survey area were not affected by sea-ice preventing vessel movements as experienced previous years. However, due to strong winds and high seas vessel speed had to be reduced and also 3 trawl stations were aborted (Figure

1). After the completion of the standard survey the vessel started fishing commercially and this allowed for time to perform additional experiments as outlined in the coming text. All scientist personnel were returned to "La Manche" on the 22 February off Signy Island, and the survey ended on the 29 February when the vessel reached Montevideo, Uruguay.
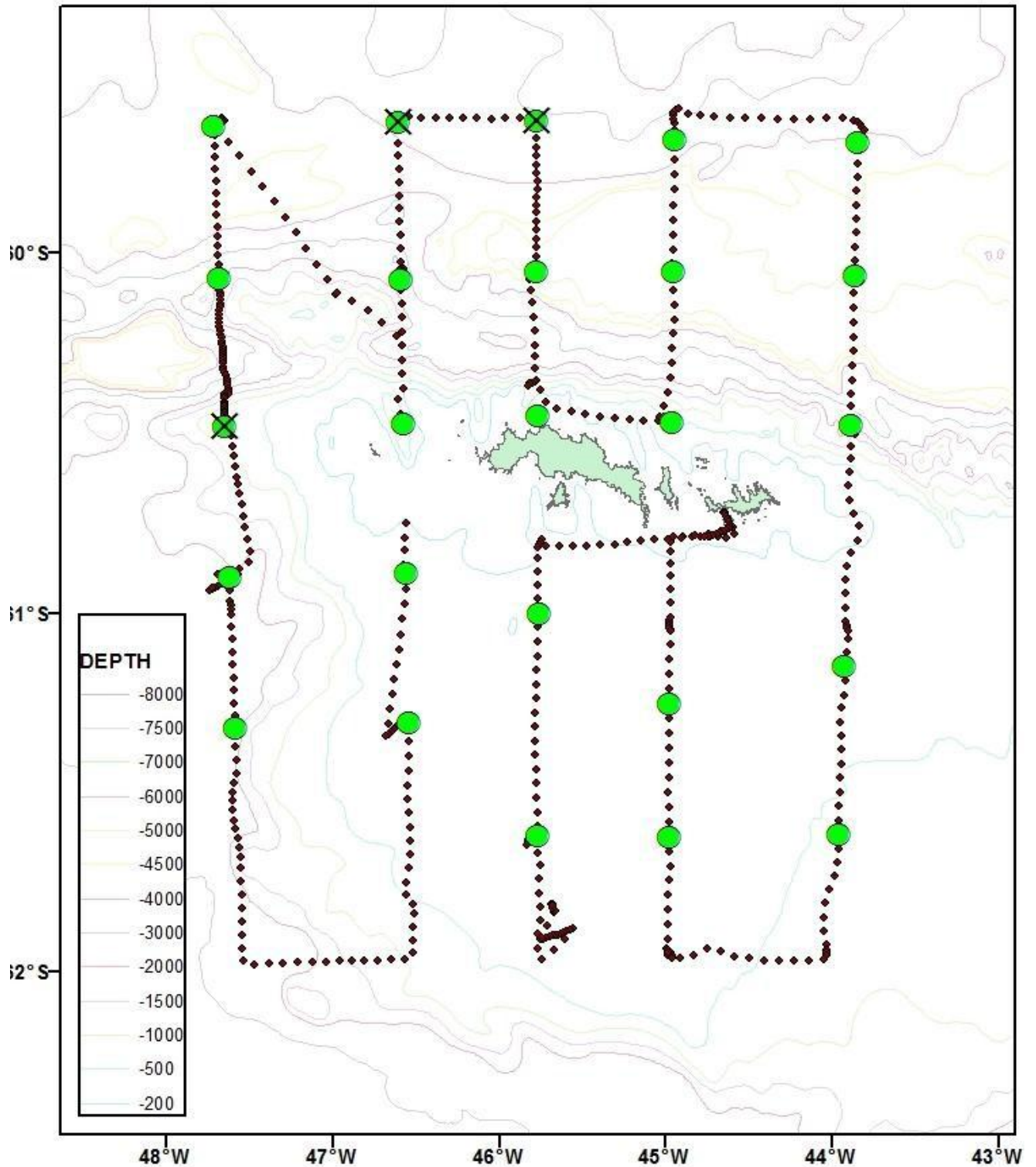
Figure 1. *Summary of the 2016 krill monitoring survey. The dashed lines denote the transect lines. The yellow circles indicate the trawl stations and cross marks*

denotes trawl stations not completed due to harsh weather conditions.

Echo sounder

'Saga Sea' is equipped with Simrad ES60 echo sounders operating at 38 and 120 kHz. These are the fishery versions of the scientific Simrad EK60 used for research purposes, and typically we have replaced the Simrad ES60 General Purpose Transceivers (GPTs) from the original vessel set-up with Simrad EK60 GPTs connected to the ES60 transducers mounted in the vessel hull. The scientific transceivers were not available this year but the ES60 GPTs can be calibrated and logged with only some limitations in software flexibility, and this was done for the present survey.

The echosounders were calibrated in Scotia Bay using standard sphere calibration (Foote et al.1987). The echo sounder was operating continuously during the survey with a ping interval of 1.5 seconds. Nominal vessel speed during surveying is 10 knots, but due to poor weather conditions, the speed had to be reduced in some parts of the survey. Acoustic data were sampled down to 500 m on both frequencies. Other transceiver settings are specified in Table 1.

Sonar

'Saga Sea' is equipped with a high frequency sonar: Simrad SH 90 (114 kHz) and a low frequency SP70. Since the original ES60 vessel echosounder transceiver was used, it was not possible to synchronize in an easy manner the echo sounder and sonar logging, so sonar data were not logged during the survey.

Table 1. *Specification of transceiver settings on 'Saga Sea' applied during the 2016 survey.*

Echosounder specification	38 kHz	120 kHz
Transducer type	ES38-B	ES120
Transmitted power (W)	2000	300
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	10.1	23.4
Sound speed (ms^{-1})	1456	1456
Sample distance (m)	0.186	0.186
Two-way beam angle (dB)	-20.5	-21
S_v transducer gain (dB)	26.24	24.2
Angle sensitivity alongship	22.0	17.0
Angle sensitivity athwartship	22.0	17.0
3 dB beamwidth alongship (deg)	7.23	8.90
3 dB beamwidth athwartship (deg)	7.47	8.95

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 120 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 ($S_{v,120} - S_{v,38}$) 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 NASC were converted to biomass density (g m^{-2}) using the SDWBApackage2010 (Conti and Demer, 2006; SG-ASAM 2010; Calise and Skaret, 2011) according to the CCAMLR protocol. The model was parameterized according to Table 1, or if nothing else specified according to Calise and Skaret (2011).

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 using the full SDWBA model.

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).

Biological sampling

Five trawl stations were attempted conducted on each of the 5 main transect lines using a "Macroplankton trawl" (see Krafft et al. 2010); a 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 and towed to surface at 2.5 knots speed. When a trawl was landed on deck, the total catch was weighed. A random subsample was preserved on borax-buffered formalin (4%). When the catch was large, a subsample was taken and sorted to the nearest taxonomic group and weighed. For *E. superba*, the length of individual krill 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; in contrast to all other stages the juveniles had no visible sexual characteristics, males were divided into three sub adult stages: MIIA1, MIIA2 and MIIA3 and two adult stages: MIIIA and MIIIB, females were divided into one sub adult stage: FIIA and five adult stages: FIIIA, FIIIB, FIIIC, FIIID and FIIIE (see Krafft et al.2015 for further details).

Hydrographical sampling

A SAIV CTD sensor 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. However this device, in addition to a Star Oddi Tilt sensor mounted in the same frame to monitor the performance of the trawl while towing, was lost after performing the two first stations in a storm with heavy seas as it was rubbed off the beam while hanging astern. The CTD was replaced with a Star Oddi mini CTD logging continuously in 1-minute intervals during the remaining survey period.

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 45 hours of observation were carried out, but due to technical problems with the recording system, ca. 20 hours of predator recordings were lost. 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 approximately 10m above sea level.

Observations were made forward and to one side covering targets out towards the horizon, usually from the Forward Starboard Quarter, but sometimes from the Forward Port 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, seals and penguins 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 laptop.

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.

Observations were carried out using the naked eye for spotting and through binoculars for identification. A range of texts were used to identify unknown species.

Verification of a method for ageing Antarctic krill

A newly developed method identifies growth zones in the Antarctic krill eye stalks (Krafft et al. 2016). However, to verify the method, the increment deposit rate requires verification. Initial calcein staining experiments were executed to identify the most suitable concentration. The animals were also held in tanks for monitoring growth over a 21 day period, using circulating seawater pumped directly from the surface and some groups also received daily doses of extra food. Molts of individual krill were also collected to describe the molting process and identify potential hard parts on the exoskeleton that remains through molts.

Krill mesh escapement

High speed cameras were shooting images of krill escaping from nets by employing a experimental simulation technique. The net escapement process of krill through trawl netting was studied in detail to model post release mortality inflicted by different escape behaviour.
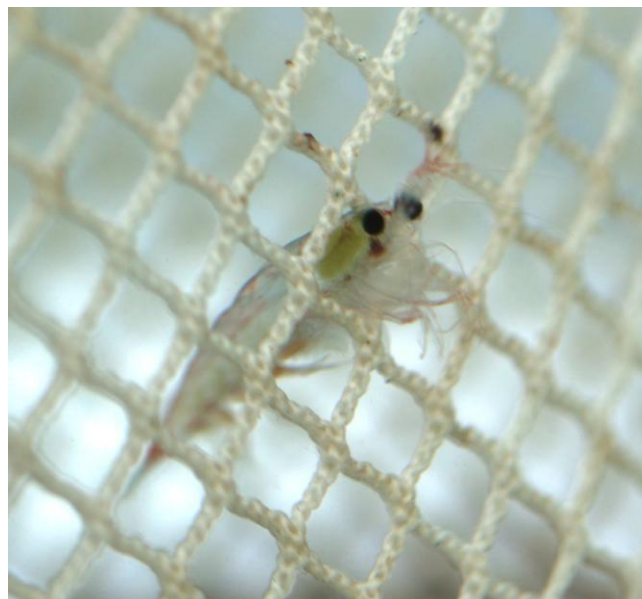
Figure 2. *Example of image of krill penetrating a trawl mesh.*

Results

Acoustics

Acoustic survey estimates

The distribution of acoustic backscatter allocated to krill is shown if Figure 3. The highest NASC-values allocated to krill were observed in the westernmost transect line, further west and south than previous years. There were lower values in the northern part of the covered area than previously observed. The biomass estimates are shown in Table 2.
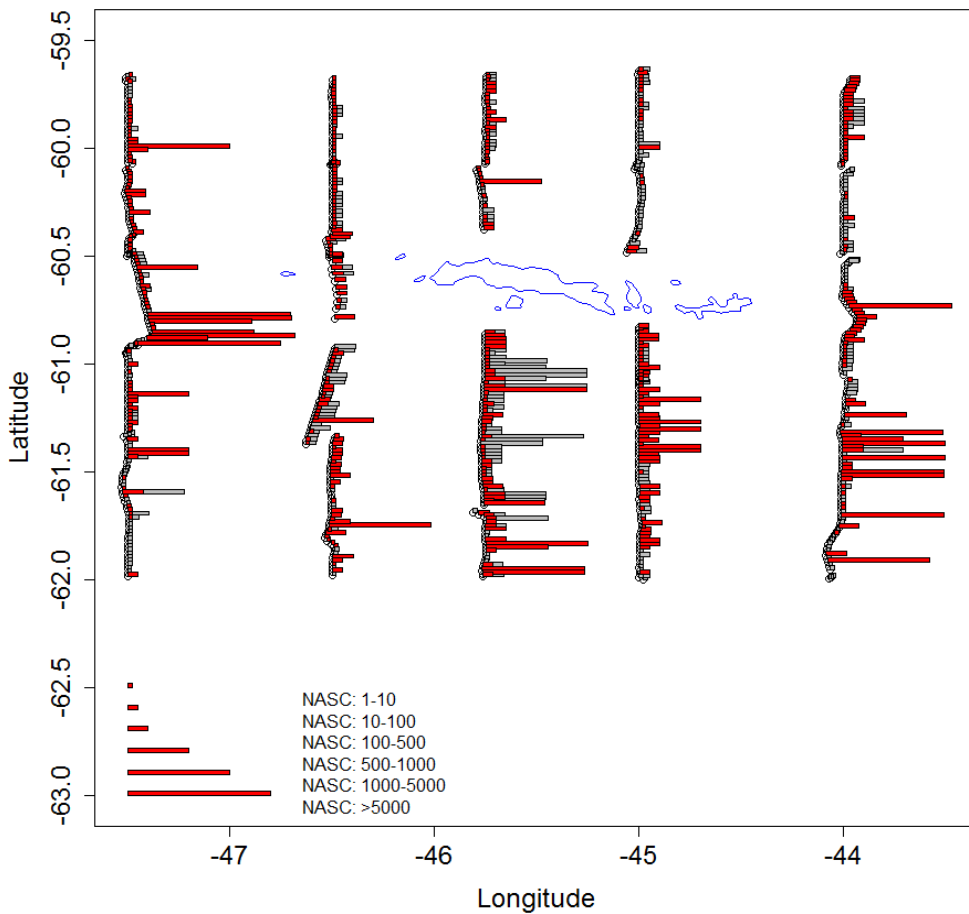

Figure 3. *Distribution of Nautical Area Scattering Coefficients (NASC; m^2/nmi^2) allocated to*
E. superba (red) and other targets (grey) from the 120 kHz recordings.

**Table 2.** *Summary table of krill biomass estimation from the 2016 survey.*

Freq (kHz)	BM density (g/m^2)	Var	Biomass (mill. tonnes)	CV (%)
120	59	695	2.33	0.45
38	61	1032	2.41	0.52

Biological sampling

A total of 22 trawl stations was successfully completed during the survey, 3 stations were incomplete due to harsh weather conditions (Figure 1). The largest catches were localized on the northern shelf and north of the shelf edge (Figure 4). *Salpa thompsoni, Periphylla pheriphylla*, *Euphausia superba* and fish dominated in the total catch weight, respectively (Figure 5). The most frequent taxa occurring were the *Salpa thompsoni* (present at 18 stations), *Themisto gaudichaudi* (present at 18 stations), *Thysanoessa macrura* (present at 14 stations), *Diphyes sp*. (present at 12 stations), *Chamsocephauls gunnari* (present at 11 stations), *Calycopsis sp*. (present at 11 stations), *Euphausia superba* (present at 11 stations), *Vibilia sp* (present at 10 stations) and *Electrona antarctica* (present at 7 stations). Three species of krill were present in the area: *E. superba*, *E. Tricantha* and *Thysanoessa macrura*.
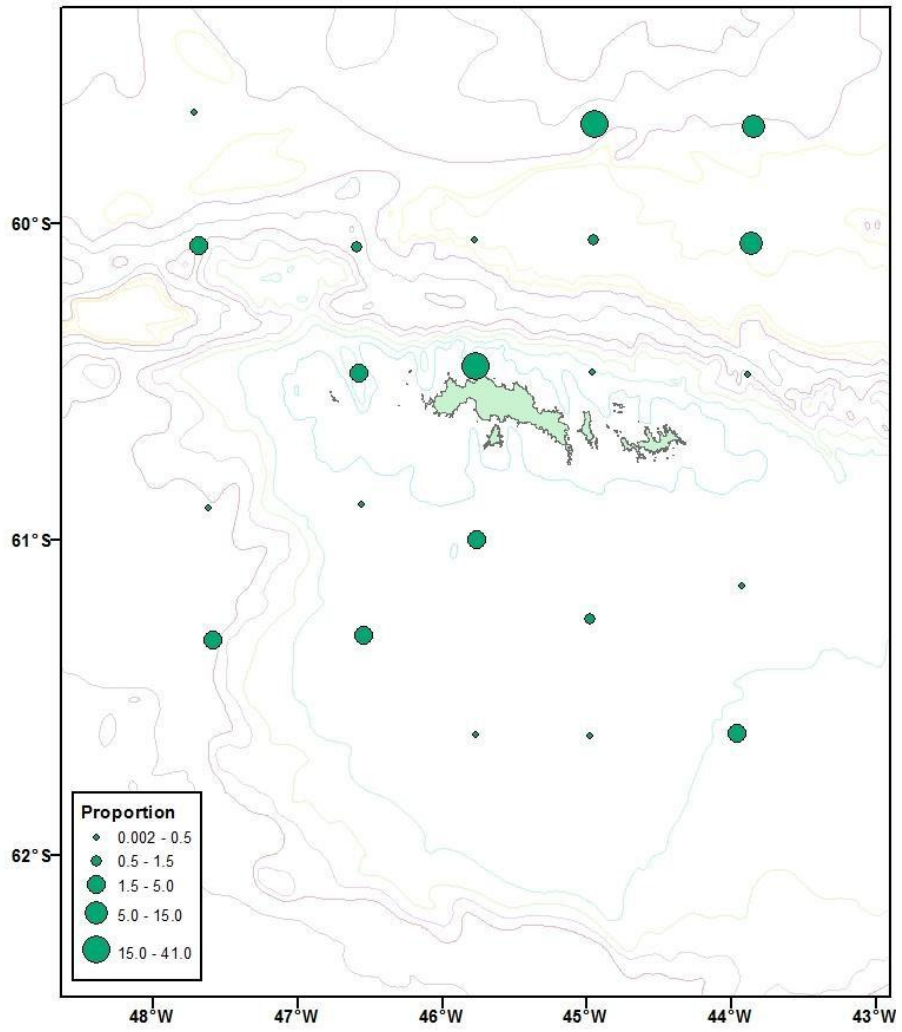
**Figure 4**. *Proportional size of trawl catches.*
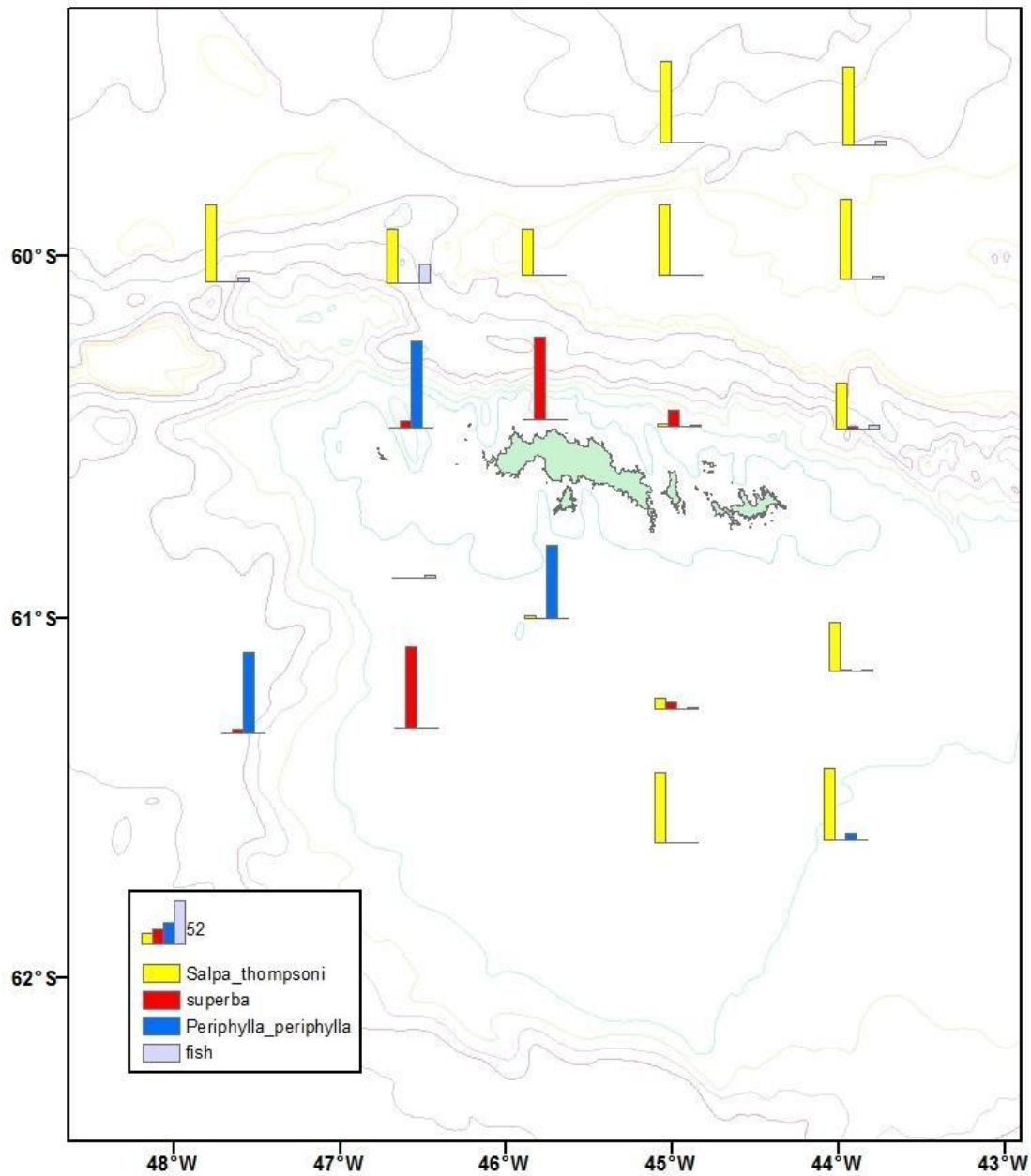
Figure 5. *The four most common taxa in terms of proportional catch weight.*

The demographic composition of the *E. superba* caught in the trawl indicate that the proportional occurrence of male subadults in stage MIIA1 was highest (24%), followed by adult females FIIIA (19%), male adults at MIIIA (16%) and female adults in stage FIIIB (12%) (Table 3). This indicates that the timing of the survey was on the left side of a rising reproductive curve.

Table 3. *Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctic krill caught in the South Orkney Islands area in the 2016 season.*

Krill maturity stages	No. in sample	Proportion (%)	Total length (Mean±SD)
Juvenile stage 1	10	2	25.0 ± 3.9
Male subadult MIIA1	149	24	34.9 ± 2.6
Male subadult MIIA2	36	6	39 ± 3.7
Male subadult MIIA3	18	3	44.3 ± 3.0
Male adult MIIIA	100	16	50.3 ± 3.4
Male adult MIIIB	64	10	51.4 ± 3.1
Female subadult FIIB	21	3	37.7 ± 2.4
Female adult FIIIA	118	19	46.1 ± 3.1
Female adult FIIIB	76	12	47.8 ± 3.1
Female adult FIIIC	14	2	49.8 ± 4.2
Female adult FIIID	0	0	
Female adult FIIIE	4	1	47.5 ± 4.2
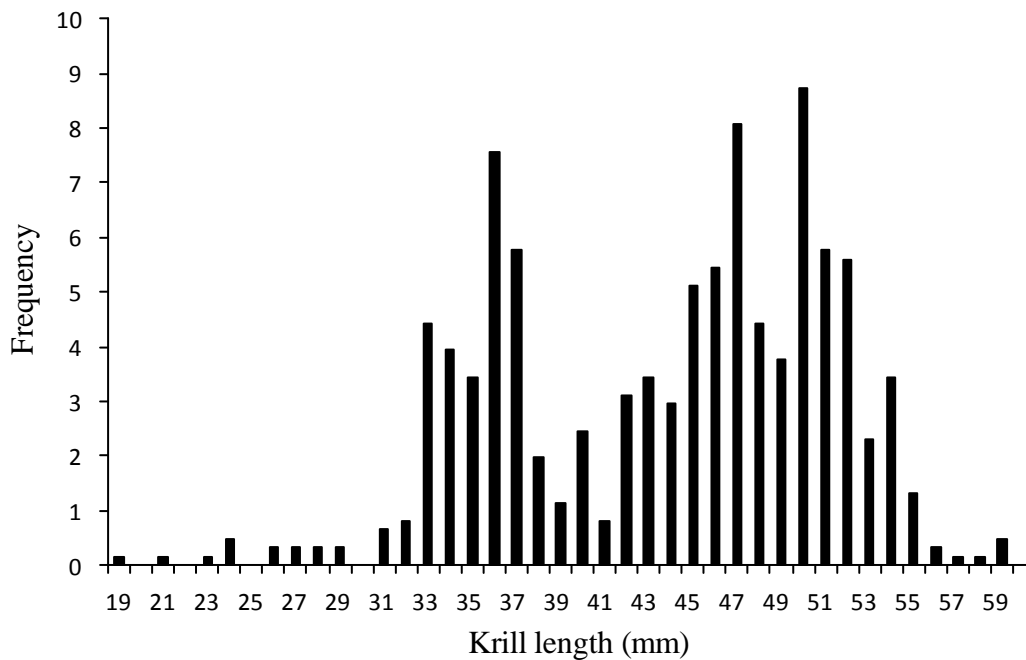
Figure 6. *Antarctic krill length histogram based on all samples combined.*

Marine predator observations

The conditions for predator observing were not ideal during the survey. High waves and strong wind during parts of the survey made long range detections challenging. A total of 815 sightings of 1549 individuals covering 21 species of marine predators were done. Notable observations were 47 whales, 499 chinstrap penguins (*Pygoscelis antarcticus*) and 51 Antarctic fur seals (*Arctocephalus gazella*) (Figure 7).
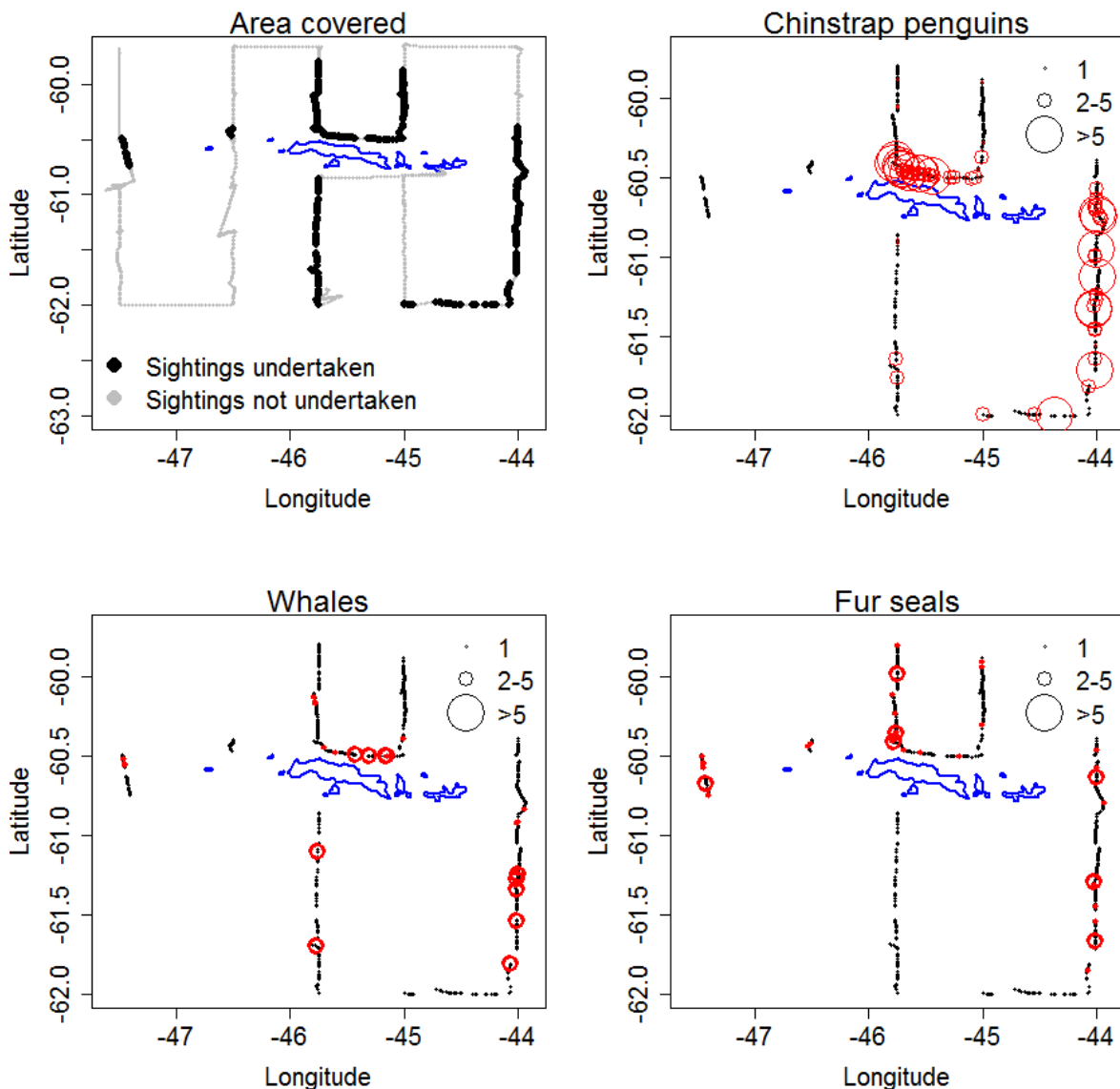
Figure 7. *Overview of recorded sightings of chinstrap penguins (Pygoscelis antarcticus), whales (fin whales; Balaenoptera physalus and humpback whales; Megaptera novaeangliae) and fur seals (Arctocephalus gazella) during the survey.*

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Acknowledgements

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