Studies of Antarctic krill, krill predators and trawl gear at South Orkney Islands, 2013

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Photo: Bjørn Krafft, IMR

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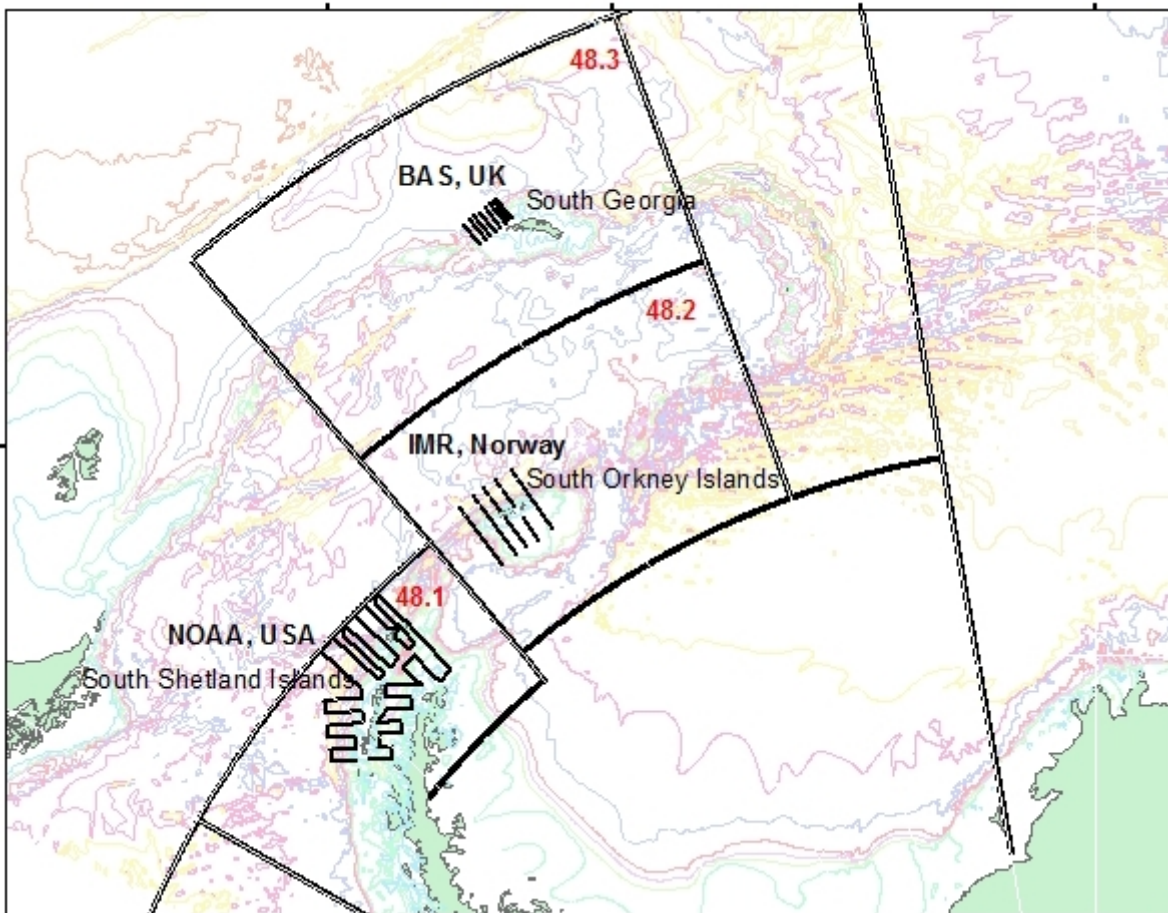
Content

Frontpage:
Humpback whale (*Megaptera novaengliae*) and Chinstrap penguins (*Pygoscelis antarcticus*) near South Orkney Islands. Foto: B.A. Krafft, IMR

Introduction and background

Exploratory fishery for Antarctic krill (*Euphausia superba*) commenced in the early 1960s by Soviet Union trawlers. During that decade, only a few tens of tonnes were landed annually. In 1972, a still modest, but more permanent fishery was established, and additional nations started operating in the areas spread around the whole Antarctic continent towards the end of the decade. The fisheries in the 1980s were dominated by Soviet Union followed by Japan, Poland and South Korea. The annual catches during this decade ranged between 119 000–528 000 tonnes. During the 1990s, Japan, Poland and Ukraine were fishing actively while the Soviet Union trawlers withdrew. During the 1990s, the annual catches ranged from 65 000–135 000 tonnes (see Budzinki et al. 1985, Nicol and Endo 1997, Everson 2000, Nicol and Foster 2003). From 2000–2010, Japan, South Korea, Norway, Poland, Ukraine, Russia, USA and Vanuatu has been involved in the *E. superba* fishery. The annual catch during that decade has ranged from 104 000 to 212 000 tonnes. During the seasons in 2010/11 and 2011/12, the reported catch was 181 000 tonnes and 147 000 tonnes, respectively. Since the 2006/07 season, the vessels sailing under the Norwegian flag has landed the largest annual catches of the nations currently involved in the *E. superba* industry.

In 1981, the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) came into force, as part of the Antarctic Treaty System. Its purpose is to regulate the fishery in the Southern Ocean to ensure long-term sustainable development and to prevent overfishing. At present, all commercial *E. superba* fishing occurs at three areas in the Southern Ocean: the statistical reporting areas 48.1 comprising the area around South Shetland Islands, 48.2 comprising the waters around South Orkney Islands, and 48.3, which include the area around South Georgia (see Figure 1). Other areas are open for fishing, but are little or not used. Precautionary catch limits on the *E. superba* fishery were first introduced by CCAMLR in 1991 (Nicol and Endo 1999). The precautionary catch limits for area 48 incorporate "trigger levels", which are levels of fishing that cannot be exceeded. Due to lack of knowledge about this marine ecosystem, the trigger levels are set with a high level of precaution to avoid potential conflict with land based predators dependant of *E. superba* as prey. The trigger levels set for the three areas exposed for active *E. superba* fishery are 155 000 tonnes for area 48.1, 279 000 tonnes for area 48.2 and 279 000 tonnes for area 48.3. During the season 2009/10, the fishery was stopped at 153 300 tonnes in area 48.1. This is the first season the trigger level has been reached in a sub area since this legislation was introduced (CCAMLR 2009, 2010). During the 2000 decade, a mere 26 % catch of the trigger level was landed in the 48.1 area, 19 % in average for the 48.2 area and only 13 % of the trigger level in area 48.3. During this decade, the highest proportional annual catches have been reported from area 48.2.

Based on data from a large scale acoustic survey organized by CCAMLR in year 2000 (see Hewitt et al. 2002), the *E. superba* biomass in the key fishing areas is estimated to be about 60.3 mill tonnes. Based on these results, a theoretic Total Allowable Catch Limit (TAC) has been set to 5.61 mill tonnes (SC-CAMLR 2010). The trigger level set for this area represents 11 % of the TAC limit and an annual catch around 200 000 tonnes constitute only 3.6 % of the TAC limit. However, future catch of *E. superba* is expected to catch up with the trigger levels due to increased marked demands and improved harvesting and processing technology. There is also an interest to catch more *E. superba* in the future than the trigger levels set today by CCAMLR member countries, and this will require a number of changes in the present management procedures.

Figure 1. CCAMLR Statistical Reporting Areas 48.1–48.3 with transect lines regularly surveyed for *E. superba* abundance and demography.

However, the dynamic physical and biological processes in the Southern Ocean are far from being well understood. The physical environment is changing *i.e.* with increased ocean acidification (Orr et al 2005), in the western Antarctic Peninsula the mean winter air temperature over the last 60 years has increased by 5–6°C (Gille 2002) and a decline in winter sea-ice around the Peninsula and Scotia Sea is observed (Stammerjohn et al. 2008). Changes have also been documented in the *E. superba*'s relationship to predators such as penguin densities, species composition and diet changes in certain areas (Trathan et al. 2011, 2012). The effects of the recovering in population of whales and fur seals are still little described (Christensen 2006, Nicol et al. 2008, IWC 2010). How ecosystem changes influence on the *E. superba* population dynamics needs increased research attention, as well as an urgent need for increased knowledge of intraspecific factors determining growth and viability.

Additionally, knowledge of any potential influence caused by the commercial harvesting on this ecosystem needs to be well documented before the existing management system can be altered. Not only the indirect effects on the ecosystem by removing biomass from a particular trophic level, but also the direct effect of trawling on the harvested species. The pelagic trawlers involved in the *E. superba* industry apply different trawl systems and trawl designs. Very little information exists on the catch efficiency of the applied fishing technology. There are many unknown parameters on which to estimate the catch efficiency of different types of trawls, and increased knowledge on estimates of escapement and possible mortality rates will have great importance for a rational management of the *E. superba* fishery as well as for the industry's economic profit.
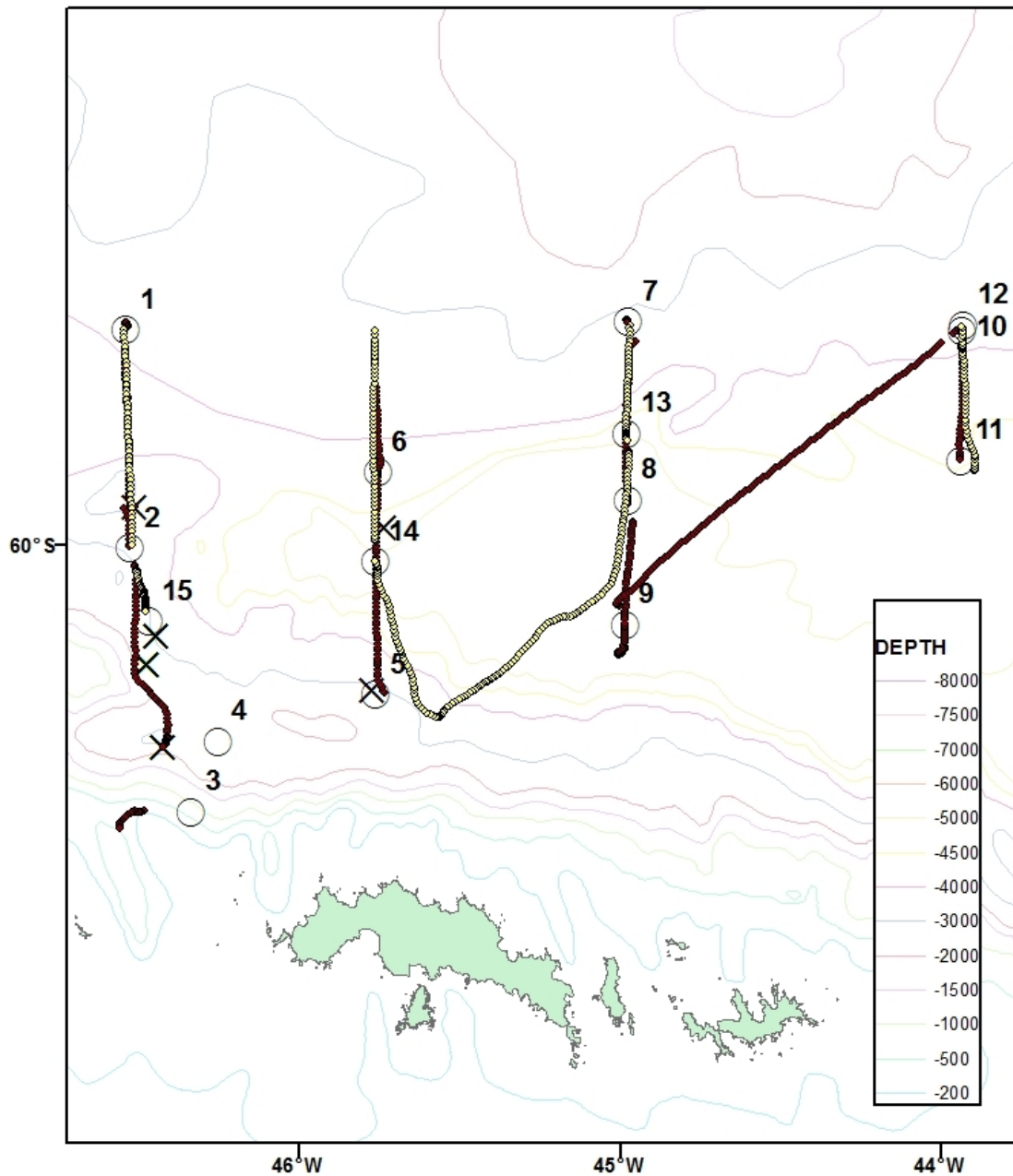
This project is intended to build time series of *E. superba* abundance and demography patterns related to hydrography and abundance and distribution patterns *of E. superba* predators, in the South Orkney Islands area. This report describes preliminary results from the third cruise conducted during this project by using a commercial fishing vessel as research platform (see also Krafft et al. 2011). The survey is conducted using similar standards (e.g. a set of parallel transects that are run every year) to other scientific surveys undertaken by the US AMLR Program and the British Antarctic Survey in subarea 48.1 and 48.3 (see Figure 1). Together these three surveys could form an integrated monitoring effort extending across the Scotia Sea and linking three areas containing major concentrations of *E. superba* that are the focus of the present commercial fishery.

Initial data collected in 2011 comparing the catch composition in the non-selective survey trawl with the 16 mm cod end in the commercial trawl, indicated that size selectivity of *E. superba* was occurring in the 16 mm cod end (Krafft et al. 2011). As an extension of an ongoing project "Net Escapement of Antarctic krill in Trawls" (NEAT) we also conducted practical field experiments for studying trawl selectivity of *E. superba* using collection bags on the commercial trawl and a specially designed multicompartment frame that could be towed independent of the commercial trawl as an autonomous unit.

Material and methods

Survey design, area and vessel

The supply vessel "La Manche" (Aker Biomarine ASA) departed Montevideo, Uruguay, on the 15 January 2013. On the 23 January, the vessel anchored in Discovery Bay, indenting the north side of Greenwich Island in the South Shetland Islands. Survey equipment and -personnel were transferred to the commercial trawler "Saga Sea" (also owned by Aker Biomarine ASA) while these two vessels were bound together. Calibration of the echo sounders 38 and 120 kHz frequencies were made (see below for further details) during the subsequent day in Admiralty Bay, King George Island. The original survey design around the South Orkney Islands includes five parallel transects extending from the northernmost waypoints at 59.67°S and southernmost waypoint at 61.75°S. Longitudes for transects 1 through 5 are at 44°W, 45°W, 45.75°W, 46.5°W and 47.5°W, respectively. During this season, parts of the survey area including the westernmost transect line and transect lines south of the islands could not be covered due to fast-ice and drifting pack-ice extending from the Weddell Sea to the north of the Antarctic Peninsula and eastwards north of the South Orkney Islands. For safety reasons it was also necessary to reduce the survey speed and deviate some from the original survey lines in order to get through pack-ice in certain areas. However, due to the available ship time devoted for this work, it was possible to run transects covering ice-free waters two times (see Figure 2). The study area was surveyed on the 25 to the 29 January. The survey personnel were then returned to "La Manche" on the 30 of January off the coast of King George Island, and the survey ended on the 2 February when the vessel reached Port Stanley, Falkland Islands.

Figure 2. Cruise lines (black circles=first leg (west-east), yellow circles=return leg (east-west)), positions for trawl stations (numbered circles) and positions for hauls made with the selection cage (cross) from the survey made off South Orkney Islands during January 2013.

Acoustic sampling procedure

For the collection of acoustic data, a Simrad echo sounder system logged data continuously at two frequencies, 38 and 120 kHz. From the original vessel set-up Simrad ES60 were replaced with Simrad EK60 General Purpose Transceivers connected to ES60 transducers mounted in the vessel hull. The system was calibrated using this echo sounder set-up in Admiralty Bay on King George Island prior to the survey using standard sphere calibration with a 38.1 mm tungsten carbide sphere (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.

6

Table 1. Specification of transceiver settings applied during the survey.

Echo sounder specification	38 kHz	120 kHz
Transducer type	ES38B	ES120-7
Transducer depth (m)	0	0
Transmitted power (W)	2000	250
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	10	38.4
Sound speed (ms^{-1})	1453	1453
Sample interval (m)	0.186	0.186
Two-way beam angle	-20.6	-21
S_v transducer gain (dB)	26.31	24.47
Angle sensitivity alongship	21.9	23
Angle sensitivity athwartship	21.9	23
3 dB beamwidth alongship	6.85	6.94
3 dB beamwidth athwartship	6.96	6.63

'Saga Sea' is also equipped with a high frequency (114 kHz) Simrad SH 90 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 in a vertical slice and a horizontal slice respectively. However, analyses of the sonar data could not be done within the time frame of the present survey analyses.

Analyses of the acoustic data

Diel vertical migration is known to sometimes influence acoustic biomass estimates of krill (Demer and Hewitt, 1995), and we therefore present separate estimates where night-time recordings have been removed.

Discrimination of targets

The method for target discrimination following the CCAMLR protocol with slight modifications was applied. This method takes advantage of the predictable frequency dependent volume backscattering strength (S_v; dB re m^{-1}) for *E. superba* within a specified range of body lengths. The range of ΔS_v-values ($S_{v,120} - S_{v,38}$) is used to discriminate *E. superba* from other targets. We used the *E. superba* length distribution found during the survey to calculate the values of ΔS_v (SC-CAMLR 2005; Reiss et al. 2008). The method was applied on sample bins of 50 pings horizontal*5 m vertical resolution, and if ΔS_v fell within the range estimated for *E. superba* targets it was included as *E. superba*.

The TS predictions of *E. superba* applied to calculate values of S_v at both frequencies were done using the simplified Stochastic Distorted Wave Born Approximation (SDWBA) package (Conti and Demer 2006). However, the parameters of the simplified SDWBA was derived from an updated version of the package (SG-ASAM 2010; Calise and Skaret 2011), parameterized with the imaginary parts of the complex numbers included. The ΔS_v finally applied was based on an *E. superba* length range calculated in 10 mm bins based on *E. superba* TS predictions from a 95 % PDF of *E. superba* length distribution based on the catches (SG-ASAM 2010). After the discrimination, the retained Nautical Area Scattering Coefficient (NASC)-values were averaged for each nautical mile.

7

Target strength prediction

The NASC were converted to biomass density (g m^{-2}) using the SDWBA package2010 (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 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 (coefficients are given in Table 2, see also Table 3).

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.

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).

Table 3. Coefficients of the Simplified SDWBA model derived from a full SDWBA model run parameterized according to Tab. 2.

	Coefficient
A	9.8651e+000 + 2.3868e+001i
B	1.3014e-001 + 2.5175e-002i
C	4.3695e-001 + 2.5007e-001i
D	-2.1381e-010
E	9.0861e-008
F	-1.4783e-005
G	1.1471e-003
H	-4.2574e-002
I	6.4795e-001
J	-8.7808e+001 - 7.2603e+000i

Biological sampling

Standard equipment for sampling macrozooplankton at trawl stations for this annual survey is a 3 mm meshed trawl having a 38 m^2 mouth-opening. This trawl was lost from the storehouse in Montevideo, instead a larger commercial trawl had to be used. A total of 15 trawl hauls were carried out along the transect lines (Figure 2) using a trawl having a 400 m^2 mouth-opening and a mesh size of 16 mm on the side panels from the mouth opening to the cod end. The mesh size of the cod end was of 11 mm.

To collect potential *E. superba* escaping from the 16 mm side panel, 4 collection bags were stitched to the panel. The collection bags were each of 3 mm mesh size, had a stainless steel framed 50 x 50 mouth opening, 3 m length and the rear end was tightened to a float.
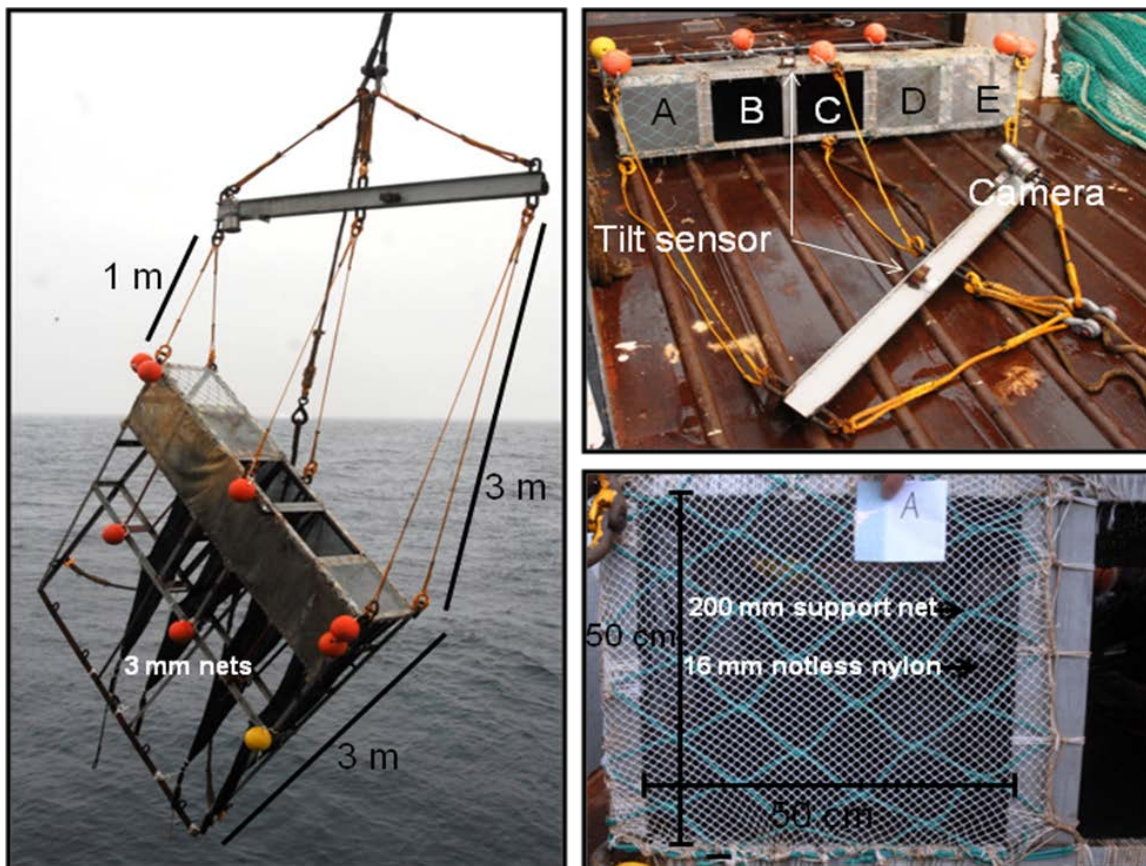
A Marport depth and temperature sensor and a Scanmar trawlspeed sensor (HC4-TSS) were attached to the trawl and logged continuously data during each haul. At each trawl station the trawl was lowered from surface to 200 m depth and then hauled at 2.5–3 knots.

The catch from each trawl station was weighed using a DeLaval spring scale (250 ± 1kg). A sub-sample was sorted, identified to the nearest taxonomic group and weighed using a Capere bench scale (5000 ± 1.0g). A sub-sample was also preserved from each trawl station, on borax-buffered formalin (4%) on a 100 ml plastic container. Body length was measured (± 1 mm) for *E. superba* 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).

Net Escapement of Antarctic krill in Trawls (NEAT): selection experiment

A multi compartment selectivity system was constructed to study selectivity of *E. superba* independently from the large commercial trawl. The system consists of five sequential compartments of 50 x 50 cm (A–E, see Figure 3). The mesh size on the panels in front of compartment A, D and E during this experiment was the 16 mm knotless nylon, used in the commercial trawls, supported by a 200 mm double 4 mm net stretched tightly underneath to avoid concavity. The 16 mm netting was mounted to the frame to give the meshes maximum opening. Compartment A–D each have a 3 m long collecting bag made in 3 mm non-selective netting to collect individuals entering each of these four

compartments. We expect that *E. superba* have a relative limited swimming capability and that the selectivity process of *E. superba*, compared to fish can be characterized as a more sedate process. We further expect that some *E. superba* get in contact with the netting before arriving in the cod end. Some of the smaller individuals that get in contact with the 16 mm netting will escape through it if they meet the mesh at a certain angle, where others of the same size will not as they meet the meshes differently. The system is towed in an angle having compartment E in the forward most position during fishing and compartment A in the aft most position (see Figure 3). When the system encounters a swarm of *E. superba* some individuals that meet compartment E will escape through the meshes and be lost where the rest will *roll* backwards over to compartment D. The catch in collecting bag D will therefore be made up of two fractions of *E. superba*; 1) the individuals that are *rolling* from E but are able to meet the meshes in D correct and therefore enters the collecting bag and 2) the individuals that only meets compartment D but meets the meshes correct and enters the collecting bag. The catch in compartment C collecting bag is made up of individuals rolling from D and the population meeting compartment C. Collecting bag B samples the population that is expected to meet each of the five compartments in average. Collecting bag A samples the selectivity occurring in compartment A without contributions of rolling individuals from other compartments. To treat the catches in the selectivity cage as a sequential process, the cage needs to be horizontal and stable during towing. Underwater camera (Sony mini DV Digital Handycam) mounted inside a custom made Titanium housing (Construction Services AS, Solheimsvik, Norway) and tilt sensors (DST Tilt, Star-Oddi, Iceland) were attached to the multi compartment system to monitor the performance of the system.

Figure 3. "Selection cage" constructed for studying catch efficiency in trawl nets.

Two different towing angles was initially planned, one low angle and one high angle to estimate the effect of different attach angles between *E. superba* and the netting on the size selectivity. Due to limited time were only the low angle tested during the 2013 cruise.

In total, 10 hauls were made, in selected areas with relatively high density of *E. superba* (see Figure 2). The catch from each net was sorted by taxa, weighed, and length measured as described in the section above.

Marine predator observations

Sightings for seabirds and marine mammals were carried out by 3 dedicated observers who rotated between observing and recording every 20 minutes. Observations were made during all daylight hours (0800–2400 UTC); in total 48 hours of observation were carried out. Observations were made along all transect lines and during transit between transect lines; no observations were made whilst trawling. Ship speed was 10 knots, with observations made from the bridge at 10 m above sea level. Observations were made forward and to one side covering targets out towards the horizon, usually from the Forward Starboard Quarter, but on one occasion with heavy rainfall from the Forward Port Quarter. 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. All sightings also included details of the meteorological conditions (i.e. wind, sea state, visibility, and glare). Records were entered directly into Excel using in-house software created in Labview. They were then processed for later analysis in Arc GIS. Observations were carried out using both the naked eye and through binoculars. A range of texts were used to identify unknown species.
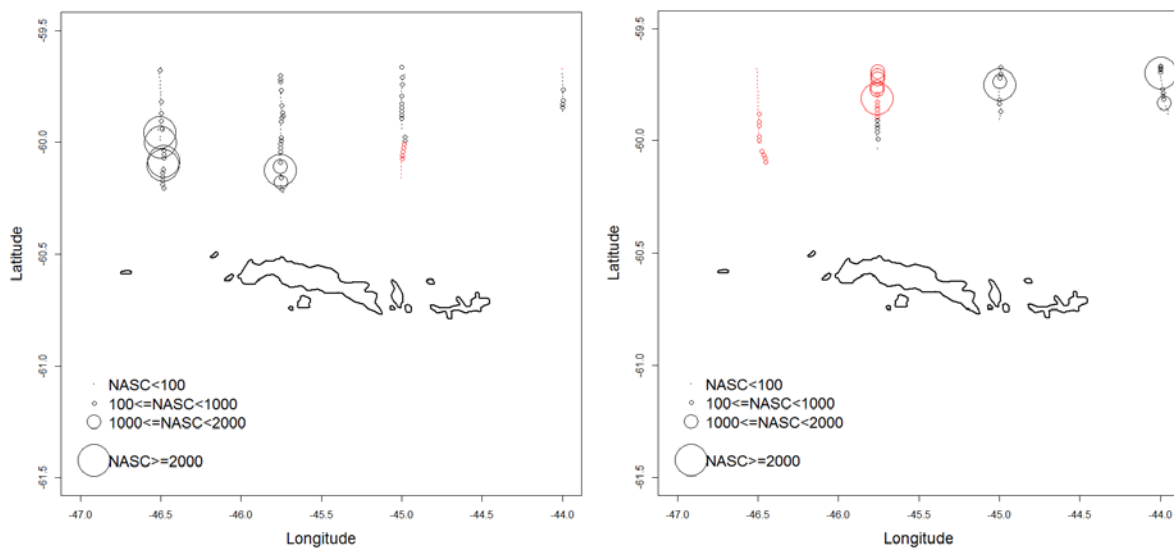
Hydrographical sampling

Hydrographical data were acquired using a SAIV handheld CTD sensor mounted with an interface unit and an additional sensor for measuring fluorescence. The CTD was mounted in an open metal frame for protection and tied on the headline of the trawl to obtain profiles of temperature, salinity and fluorescence during the trawl hauls. The CTD device was logging continuously in 10-second intervals throughout the whole cruise.

Preliminary results

Acoustics

The abundance and distribution of krill based on acoustic recordings are shown for both coverages in Figure 4 as well as Tables 6 and 7. Although the overlap is not complete between coverages and the timing differs, the local variability in distribution between the coverages is notable underlining the patchy distribution of the target and how abundance varies over short time spans. It did not make a big difference to exclude the night-time recordings.

Figure 4. Distribution of Nautical Area Scattering Coefficients (NASC (m^2/nmi^2) allocated to krill. Left: first coverage and right: second coverage. Black circles denote daytime hours, and red circles night-time hours. The data were collected during 25–28 January 2013 in the South Orkney Island waters.

Biological sampling

Of the total number of 15 trawl stations, one haul (station 11, Figure 2) failed to catch any macro-zooplankton, and most likely this was due to net failure. Euphauciids dominated in the total catch with *E. superba* as the dominating species. *Thysanoessa macrura* only occurred during one haul (station 1, Figure 2) in the catch from the cod end of the in the main trawl. However, this species was found in the collection bags during two hauls (stations 3 and 4, Figure 2) and during 9 out of 10 hauls using the selection cage (see Figure 5 as example). *Salpa thompsoni* was found at 5 stations (stations 1, 5, 7, 9 and 13, Figure 2 and 6) and dominated in the catch at station 7. Station 1 was dominated by jellyfish, and was also present in the catch at station 2. Amphipods were only caught at station 1, represented by *Vibilia antarctica*. A squid was found in the catch at station 9. Fish occurred in the catch at 4 trawl stations (1, 2, 9 and 15) and 5 species were determined: *Paradiplospinus gracilis*, *Gymnoscopelus nicholsi*, *G. braueri*, *Electona paucirastra* and *Notolepis coatsi*.

Krill at 30 m depth.

12

Table 4. Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctic krill caught in the South Orkney Islands area, during 25–28 January 2013.
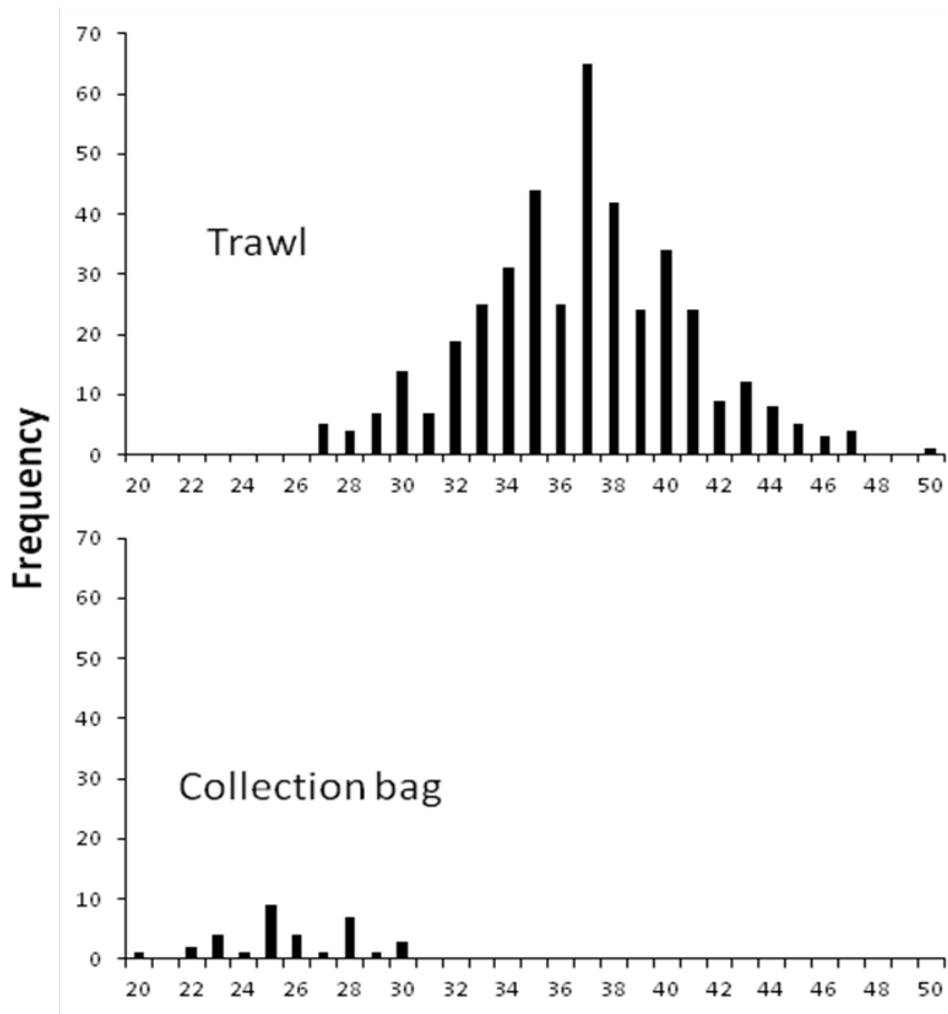
Krill	No.	Proportion	Total length
Juvenile stage 1	5	0.4	27.6 ± 1.5
Male subadult MIIA1	26	2.0	30.9 ± 5.1
Male subadult MIIA2	91	7.2	37.2 ± 4.6
Male subadult MIIA3	51	4.0	41.1 ± 3.7
Male adult MIIIA	82	6.5	44.3 ± 3.9
Male adult MIIIB	476	37.5	44.5 ± 4.5
Female subadult FIIB	32	2.5	32.7 ± 6.8
Female adult FIIIA	28	2.2	36.2 ± 5.2
Female adult FIIIB	235	18.5	41.4 ± 4.8
Female adult FIIIC	147	11.6	43.8 ± 4.8
Female adult FIIID	64	5.0	43.6 ± 4.6
Female adult FIIIE	33	2.6	46.4 ± 3.7
Total	1270		

Table 5. Selectivity parameters and fit-statistics based on one successful haul with a collecting bag (3 mm) on the commercial trawl (16 mm). The collecting bags measured 50*50 cm in the front and were mounted to a steel frame. The values in the table are based on a probit model which resulted in the lowest AIC-value.
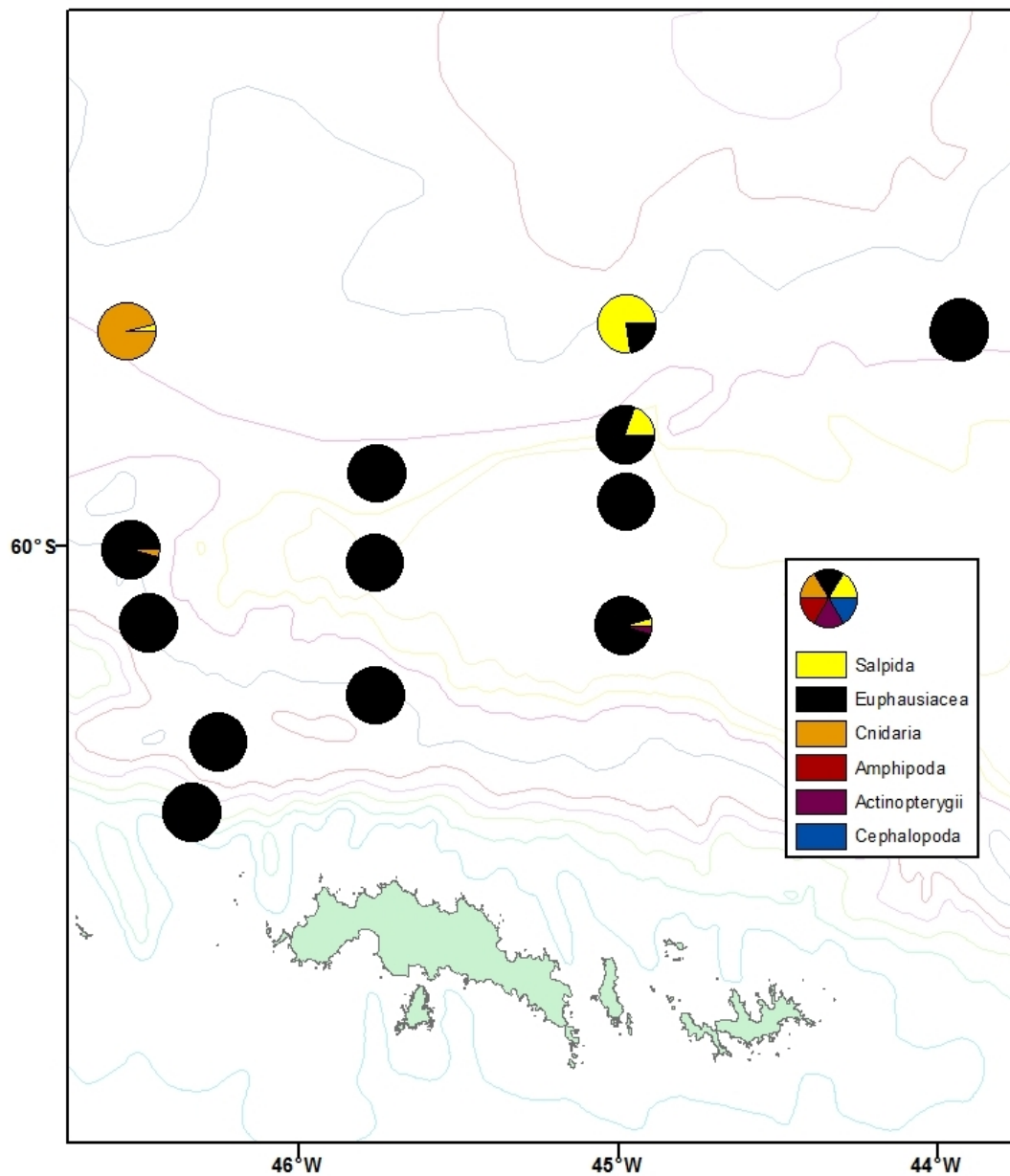
L50	27.88
SR	2.28
AIC	58.59
p-Value	0.98
DEV	12.89
DOF	26
R-Square	0.93

Table 6. Biomass table with night-time recordings excluded. Line 1, Line 2 etc. denote transect lines and L denotes length of the included part of the line in nautical miles.

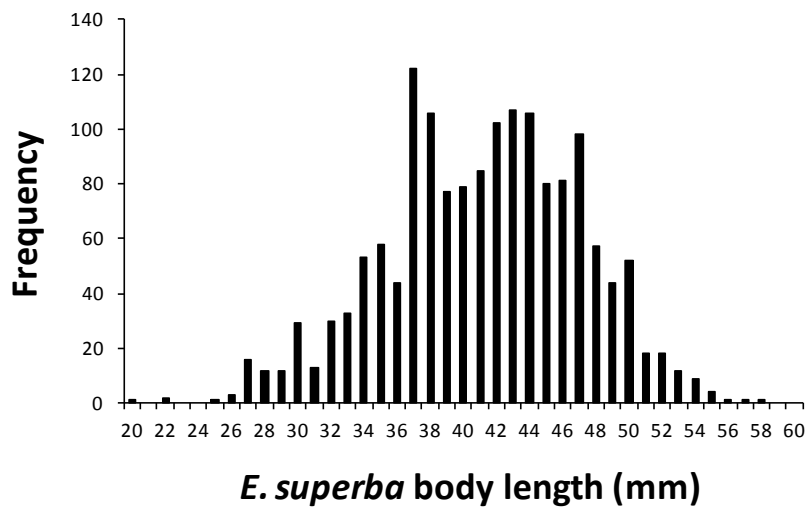| Frequency	Line1		Line 2		Line 3		Line 4		Total BM dens (g/m^2)	Var	CV (%)
	BM dens (g/m^2)	L (nmi)	BM dens (g/m^2)	L (nmi)	BM dens (g/m^2)	L (nmi)	BM dens (g/m^2)	L (nmi)			
120 kHz	250	35	213	32	75	19	52	11	181	1838	24
			81	7	243	15	230	17	208	1177	16
38 kHz	82	35	113	32	52	19	27	11	80	249	20
			38	7	141	15	257	17	173	3134	32

Figure 5. Station 4 with *E. superba* body length measured from the catch in the main trawl (top) and from collection bags attached to the 16 mm side trawl panel.
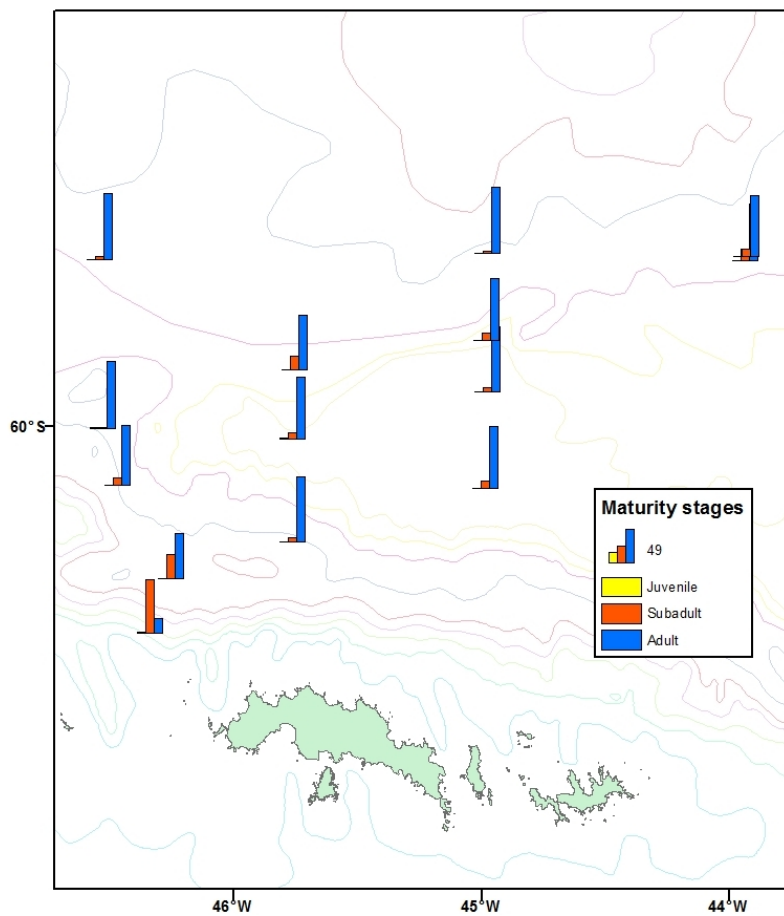
Figure 6. Proportional presence of macrozooplankton in trawl catches made in the South Orkney Islands waters in January 2013. Presence of taxa <1 % is not visible in the pie chart due to restrictions of the resolution in the software ArcView, where the figure was generated.

All stations contained specimens of *E. superba*. The average body size of *E. superba* was 42.3 ± 5.7 mm, ranging between 20–58 mm (Table 4, Figure 7). The sample comprised 0.4 % juveniles, 15.7% subadults and 83.9% adults, with a male versus female sex ratio close to 1:1 (53 % males and 47 % females) (Figure 8 and 9). Adult males with spermatophores or open spermatophore ducts (37.5 %, MIIIB), and adult females with spermathophores attached to their thelycum (18.5 %, FIIIB) dominated in the trawl catches (Table 4).
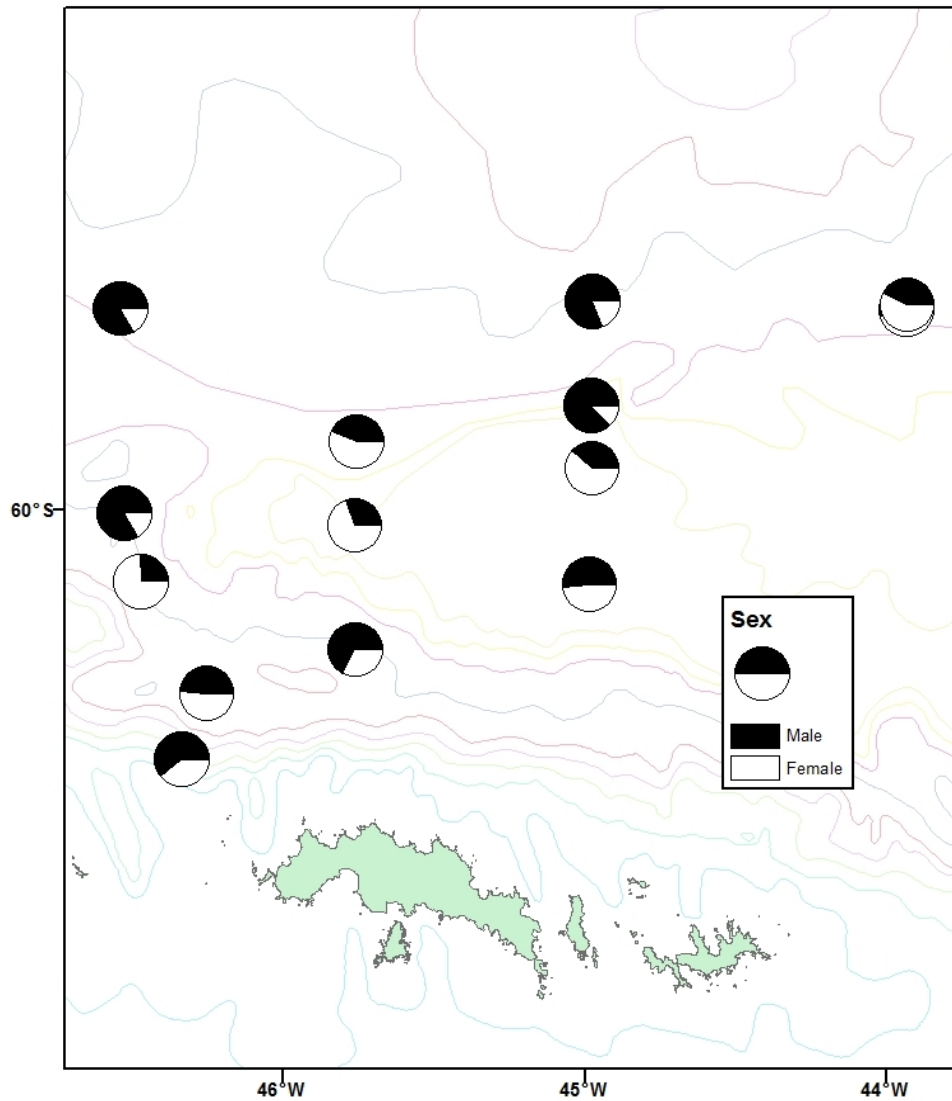
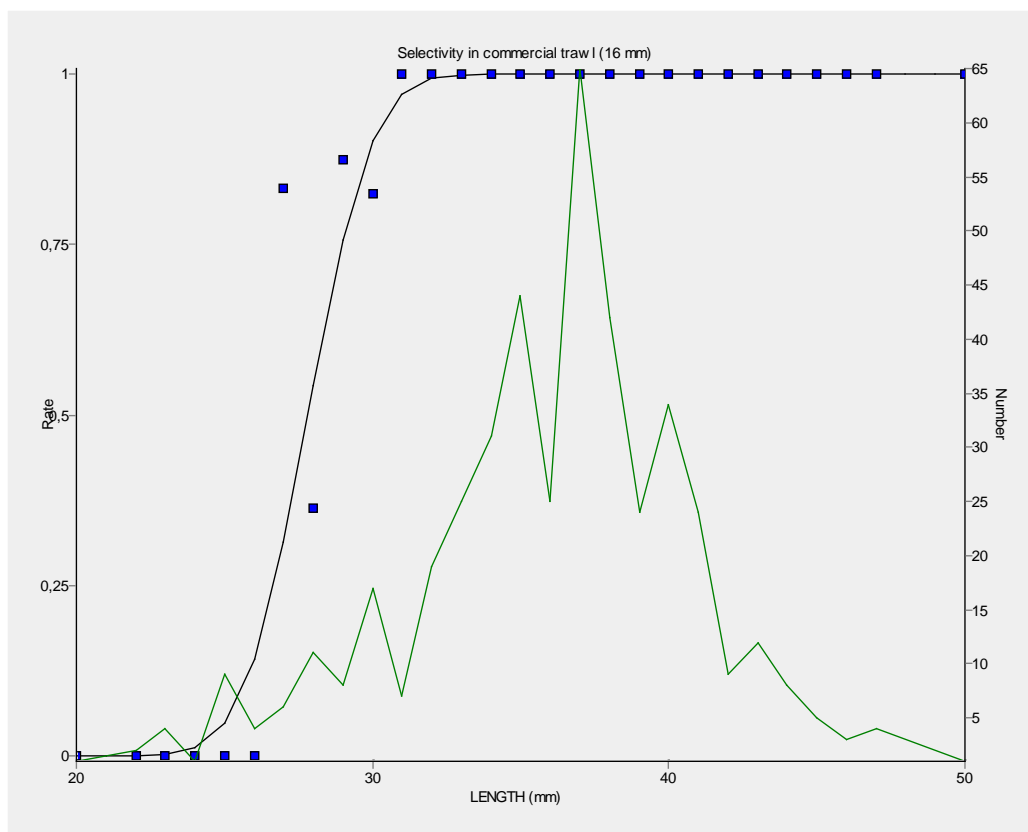**Figure 7.** Krill length histograms based on all samples combined.

Figure 8. Distribution of the maturity stages of *E. superba* captured during January 2013 in the South Orkney Island waters.

Figure 9. Distribution and proportion of *E. superba* males and females from the trawlstations made during January 2013 in the South Orkney Island waters.

The *E. superba* body length measured from the catch in the collection bags represented smaller body length range compared with the length rage and demographic composition found from the catch in the main trawl (see Figure 4). A probability plot based on selectivity parameters described in Table 5 with data from station 4 on body length measurements made from the main trawl and collection bags, the plot shows a very high probability to penetrate a 16 mm meshed trawl at body length > 27 mm (Figure 10).

Figure 10. Selectivity curve (probit) based on collecting bag attached to commercial krill trawl during fishing. The collecting bag (3 mm) was attached to the topside of forward part of the trawl which is made of 16 mm. The results in the figure are based on one successful tow with the collecting bag. The krill population (un-raised data) is indicated with the solid line.
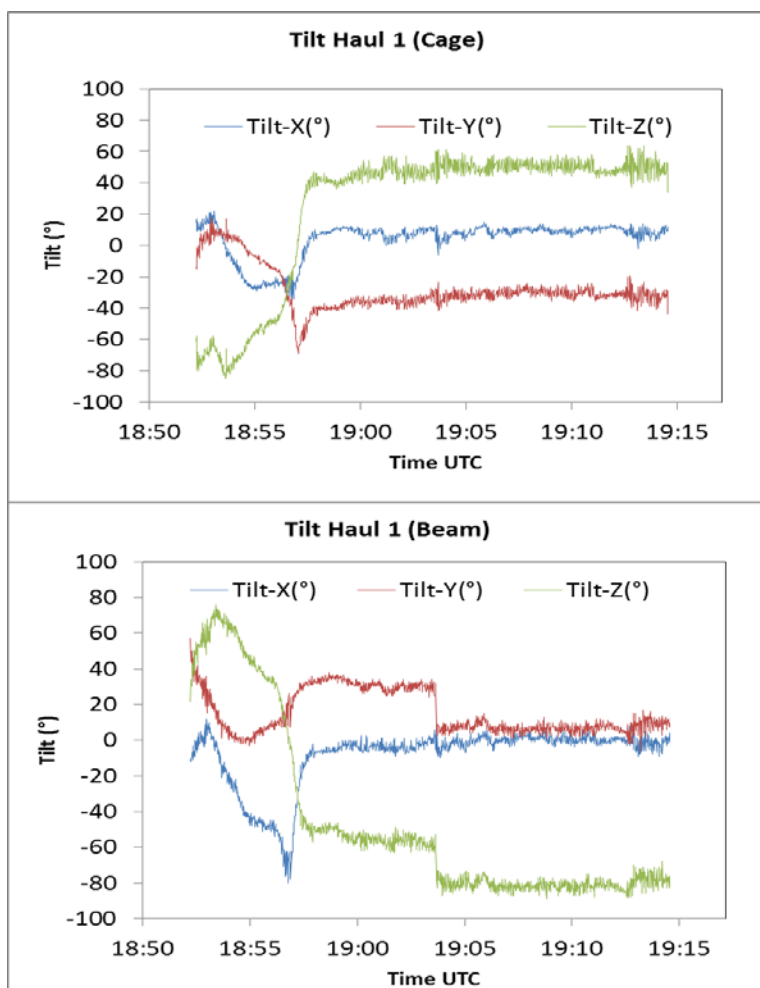
Table 7. Biomass table with night-time recordings included. Line 1, Line 2 etc. denote transect lines and L denotes length of the included part of the line in nautical miles.

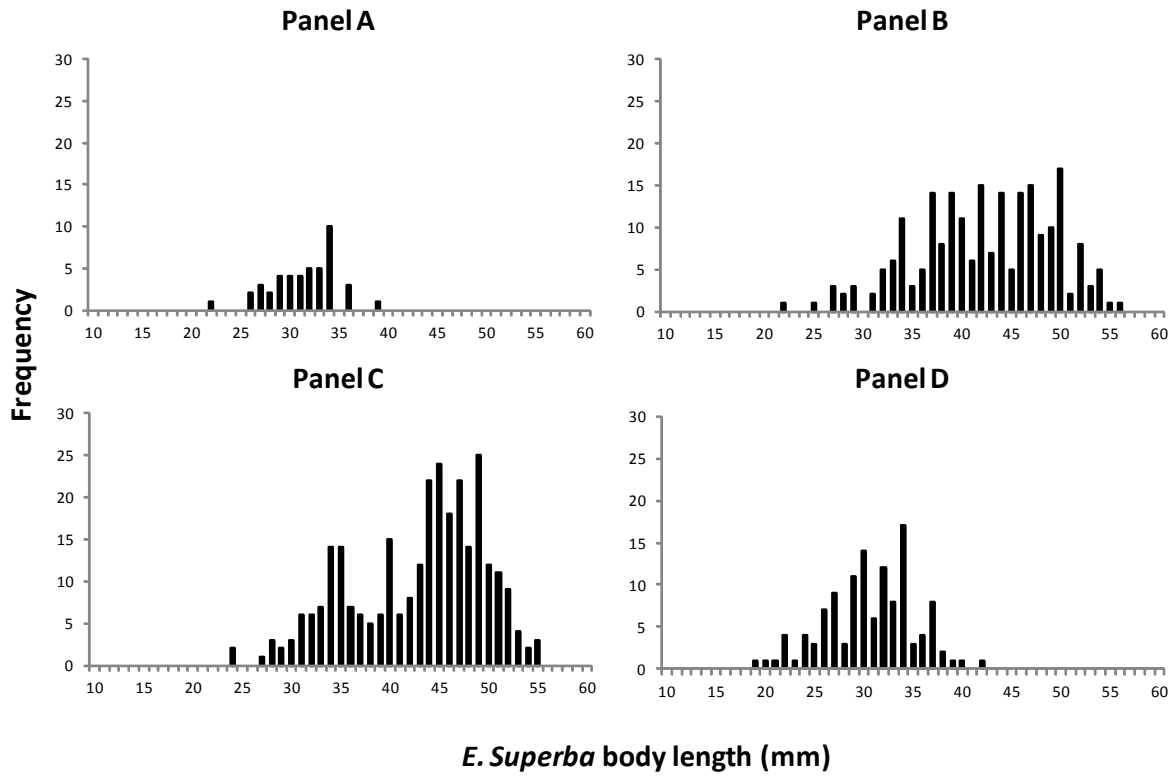| Frequency	Line1		Line 2		Line 3		Line 4		Total BM dens (g/m²)	Var	CV (%)
	BM dens (g/m²)	L (nmi)	BM dens (g/m²)	L (nmi)	BM dens (g/m²)	L (nmi)	BM dens (g/m²)	L (nmi)			
120 kHz	250	35	213	32	79	29	51	12	171	2128	27
	56	25	383	20	243	15	230	17	216	6143	36
38 kHz	82	35	113	32	48	29	32	12	76	274	22
	29	25	374	20	141	15	257	17	191	7129	44

Net Escapement of Antarctic krill in Trawls (NEAT): selection experiment

The selectivity cage proved stable during towing (see Figure 11). Visual inspections made of the underwater camera recordings further supported this. The catch data from the selectivity cage, given in Figure 12 and 13 clearly show an occurrence of size selectivity in the 16 mm netting and Figure 10 also shows selectivity in the trawls 16 mm netting. The data collected in the four collecting bags (A–
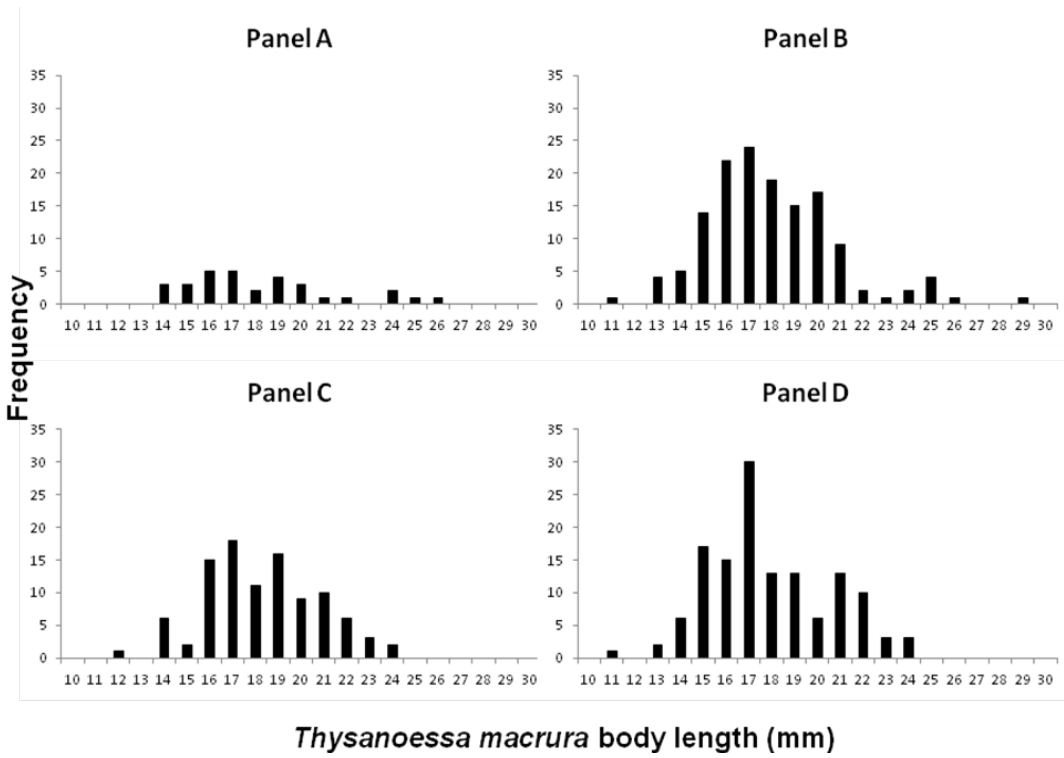
18

D, see Figure 12, 13 and 14) will be modelled as a four compartment system to describe size selectivity in 16 mm commercial netting and the possible attack modes of *E. superba* encountering the meshes indicating the average contact that is necessary for successful mesh penetration for the individuals in the selective length range. Underwater observations were collected during all tows with the selectivity cage and the observed contact orientations of *E. superba* meeting the netting, in both the commercial trawl and in the selectivity cage, will be used to verify the penetration models for of *E. superba* to predict selectivity in different trawl designs based on the morphological modeling established in the NEAT project. Underwater observations made available from the commercial trawl can be used to establish realistic mesh openings during fishing and the variation in the mesh openings. The data from the selectivity cage will be compared with data obtained in the collecting bags mounted on the commercial trawl.
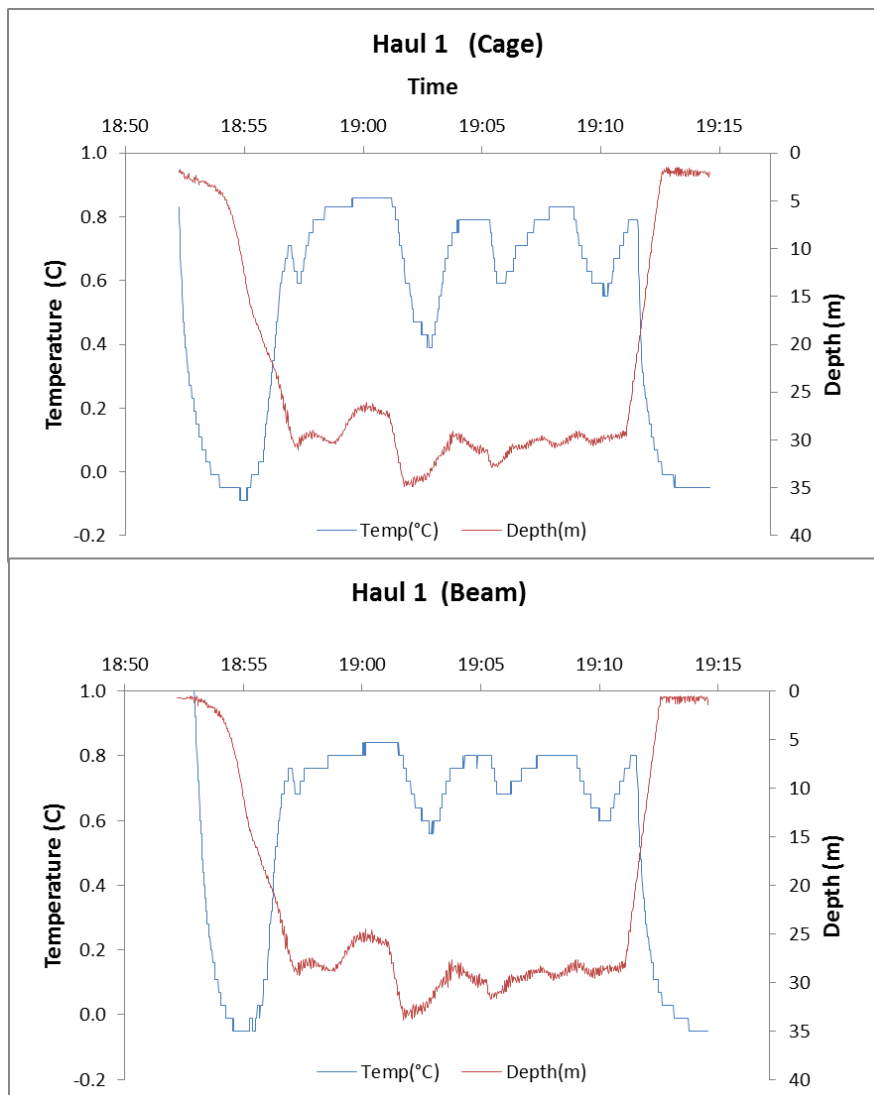

Figure 11. Tilt data in three directions (x, y, z) in relation to the gravity field during haul 1. Both the towing beam and the selectivity cage showed little variation during the tow at fishing depth. The precise angle between the towing beam and the selectivity cage during each tow can be calculated based on the above data.

19

Figure 12. *E. Superba* body length measured from the catch from the selection cage departments (A-D).

Figure 13. *Thysanoessa macrura* body length measured from the catch collected by the selection cage.

20

Figure 14. Depth and temperature profile during haul 1. Two tilt sensors were used during each haul, one sensor on the selectivity cage (top plot) and one sensor on the towing beam (bottom).

Potential for selectivity studies onboard the commercial Norwegian vessels

Initial selectivity studies were conducted this year for the first time onboard a Norwegian commercial trawler in the Southern ocean. The preliminary results, based on collecting bags on the commercial trawl clearly indicated the occurrence of size selectivity in the commercially used gears. The strength of the data is however limited by the relative low number of individuals caught. The results obtained with the selectivity cage will not reflect the selectivity occurring in the commercial trawl due to differences in the attack angle, mesh opening and other design issues. The selectivity cage however proved useful to obtain data that can be used to understand and describe the selection process in commercial trawls in detail and investigating effect like e.g. different attack angles (cutting rates in trawls), mesh openings and *E. superba* orientation during mesh contact.
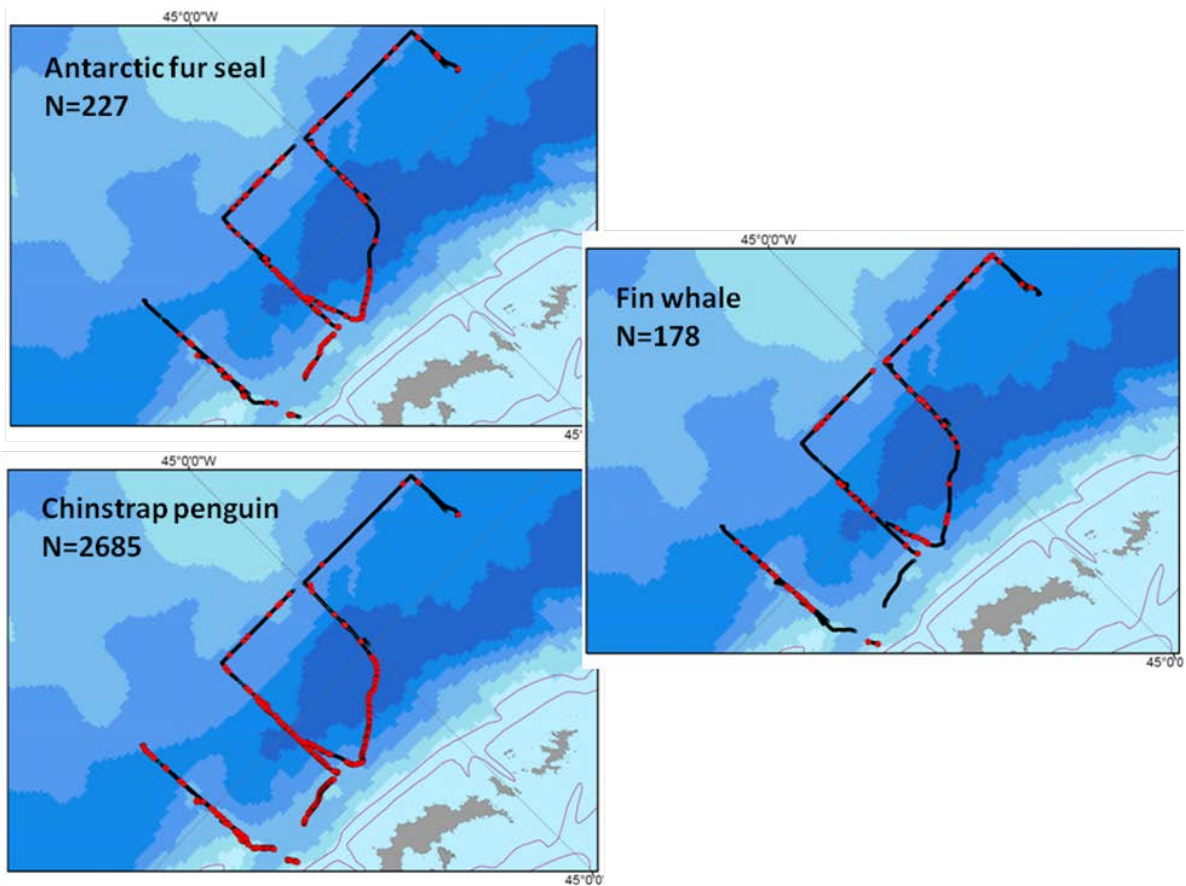
The practical experience obtained from the selectivity studies conducted during 2013 cruise on Saga Sea have identified limitations and possibilities for conducting future selectivity studies onboard the Norwegian commercial trawlers in the Southern Ocean. It is concluded that selectivity studies, including traditional techniques e.g. covered cod end studies can be performed with success in this fishery.

21

Marine predator observations

A total of 2818 observations of marine predators were made and 24 species were recognized. Notable species included 178 fin whales (*Balaenoptera physalus*) observed along the cruise tracks, 2685 chinstrap penguins (*Pygoscelis antarcticus*) and 227 Antarctic fur seals (*Arctocephalus gazella*) (Table 8, Figure 15).

Table 8. Numbers of observations and sightings of marine mammals and seabirds during 25–28 January 2013 at South Orkney Islands.
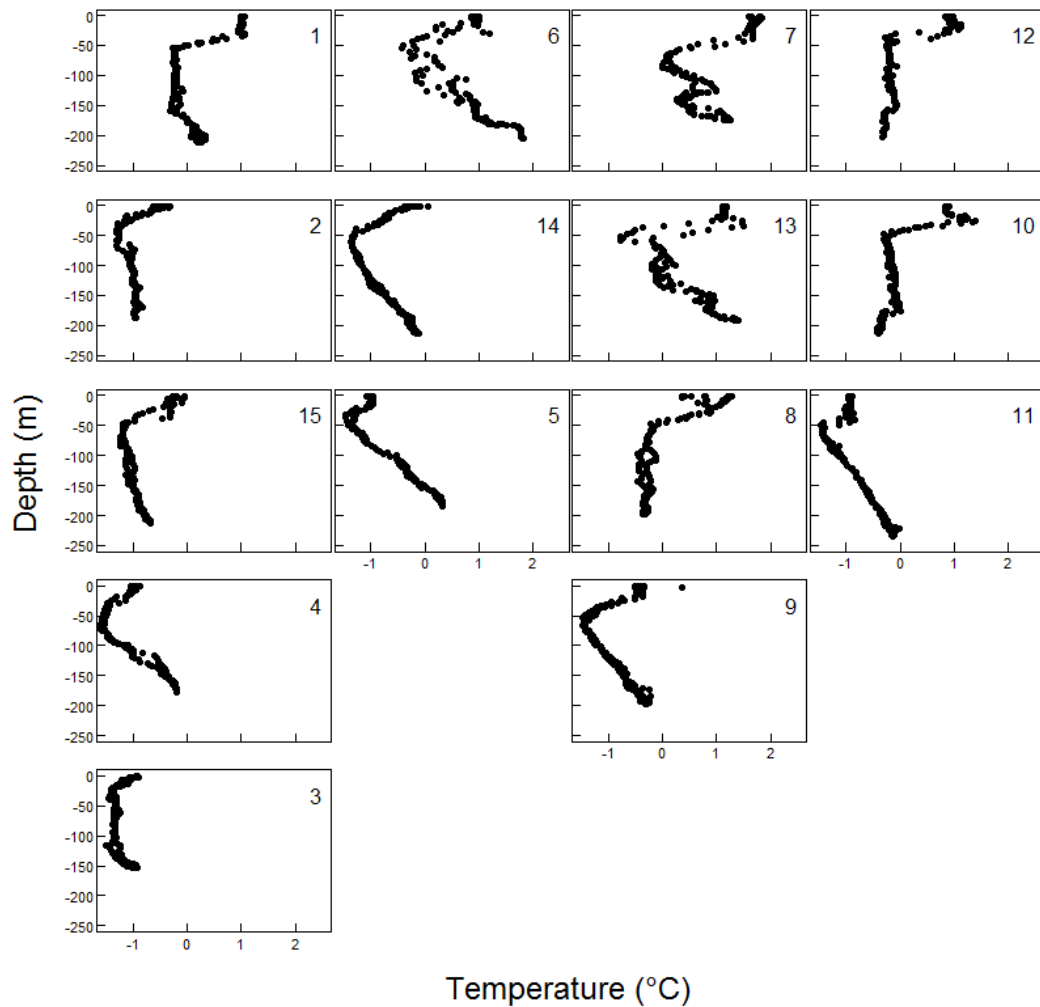
Species	Count of Observations	Count of animals
Antarctic fur seal	160	227
Fin whale	95	178
Humpback whale	4	6
Southen bottlenose whale	3	9
Southern right whale	1	2
Antarctic fulmar	295	850
Antarctic petrel	7	9
Antarctic prion	502	1041
Antarctic tern	9	11
Black-browed albatross	203	228
Black-bellied storm petrel	90	110
Cape petrel	430	1289
Grey-headed albatross	2	2
Light-mantled sooty albatross	9	9
Chinstrap penguin	448	2685
Gentoo penguin	1	3
Southern giant petrel	218	238
Sheathbill	5	8
Skua	4	4
Snow pretrel	2	2
Wandering albatross	3	3
White-chinned petrel	14	14
Wilson's storm petrel	265	298
Unidentified albatross	1	1
Unidentified penguin	5	119
Unidentified storm petrel	10	17
Unidentified seal	3	3
Unidentified whale	29	42

Figure 15. Observations of Antarctic fur seals (*Arctocephalus gazella*), chinstrap penguins (*Pygoscelis antarcticus*) and fin whales (*Balaenoptera physalus*).

Hydrographical sampling

During service immediately after the cruise due to suspicious salinity values, it was discovered that both the salinity and the fluorescence sensors though appearing in good state, were defect and the output values not usable. Temperature profiles are plotted in Figure 16.

Figure 16. Temperature profiles at the survey stations.

Acknowledgements

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