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Antarctic krill and apex predators in the South Orkney Islands area 2011, surveyed with the commercial fishing vessel Saga Sea

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Antarctic krill and apex predators in the South Orkney Islands area 2011, surveyed with the commercial fishing vessel *Saga Sea*

By Bjørn A. Krafft, Georg Skaret, Lucio Calise

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Bergen, 6. mai 2011

Content

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Introduction and background

Norway has recently become the nation with the largest landings of Antarctic krill (*Euphausia superba*) from the Southern Ocean, with catches representing more than half of the total fishery. The Norwegian catch in 2010 was 120 000 tons and the total catch was 211 000 tons of krill. Similar to other Antarctic krill fishing nations, Norwegian fishing operations are currently concentrated within CCAMLR (Convention on the Conservation of Antarctic Marine Living resources) subareas 48.1, 48.2 and 48.3. Krill is abundant in this region, but biomass assessments are few and out-dated.

During the CCAMLR WG-EMM (Working Group on Ecosystem Monitoring and Management) in July 2010, Aker Biomarine ASA offered to carry out a 5 day survey each year for the next five years in the CCAMLR statistical Subarea 48.2 using the Norwegian krill fishing vessel 'Saga Sea' (Jensen et al. 2010).

The working group welcomed Norway`s proposal and WG-EMM suggested that the research could be conducted using similar standards (e.g. a set of parallel acoustic transects that are run every year) to annual scientific surveys undertaken by the US AMLR Program and the British Antarctic Survey in subarea 48.1 and 48.3, respectively.

The working group also agreed that a regular survey in Subarea 48.2 would complement the annual surveys conducted by the US AMLR Program and the British Antarctic survey. Together these three surveys could form an integrated monitoring effort extending across the Scotia Sea and linking three areas containing major concentrations of krill that are the focus of the present commercial fishery. Such integrated effort could also make an important contribution to the Southern Ocean Observing System (SOOS) and provide valuable information for use within analysis of the international ICED Program (Integrated Climate and Ecosystem Dynamics- ww.iced.ac.uk).

This report describes the data collection during the cruise, presents raw data and preliminary results from the first of the five planned surveys with the Saga Sea, which was carried out by two scientists from the Norwegian Institute of Marine Research. The project is intended to constitute an integrated part of "NorChik", a Norwegian-Chinese Krill research project currently under establishment, and aims towards building time series of krill abundance and distribution patterns related to the topography, hydrography and abundance, distribution and behavior of krill predators, in the South Orkney Islands area.

Material and methods

Survey design, area and vessel

The commercial krill trawler 'Saga Sea' (Aker Biomarine ASA) departed Montevideo, Uruguay on the 27 January 2011 and commenced recording acoustic data at 0600 (UTC) 04. February at the northern initiation point of the most westerly of the predetermined transect lines near South Orkney Islands, CCAMLR subarea 48.2. The survey design included six parallel transects having northern most waypoints at 60.75°S and southern most waypoint at 61.75°S. Longitudes for transects 1 through 6 were, respectively, at 44°W, 45°W, 45.75°W, 46.5°W, 47.5°W and 48.5°W. The acoustic monitoring were terminated when all transects were covered at 0900 (UTC) on the 08. February and the cruise ended when reaching Port Stanley, Falkland Islands, on the 15. February with the tramper 'La Manche' (Aker Biomarine ASA).

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 the waters off Montevideo 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. However, occasionally ping interval requirements could not be met due to the system settings resulting in a higher interval (between 1 and 2 seconds). Nominal vessel speed was 10 knots. The transceiver settings are specified in Table 1. Acoustic data were sampled down to 500 m on both frequencies. However, there were disturbances on both echograms due to noise on the electrical grid (Figure 1). These problems were partly overcome by installing an Uninterrupted Power Supply and switching off some electrical devices. The 120 kHz echogram was undisturbed down to ca. 150 m and the 38 kHz down to ca. 400 m. Not much backscatter interpreted as krill was distributed lower than 150 m.

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	38.3
Sound speed (ms^{-1})	1456	1456
Sample interval (m)	0.186	0.186
Two-way beam angle	-20.6	-20.8
S_v transducer gain (dB)	25.68	24.72
Angle sensitivity alongship	21.9	21
Angle sensitivity athwartship	21.9	21
3 dB beamwidth alongship	6.75	7.34
3 dB beamwidth athwartship	6.42	7.07

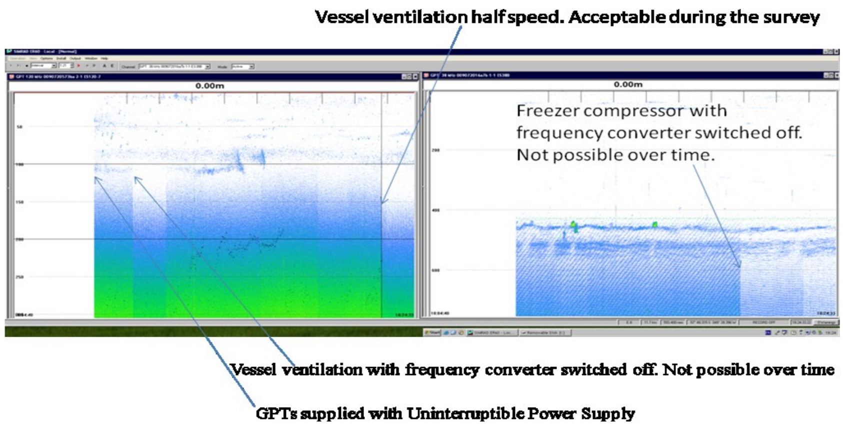

Figure 1. Echogram illustrating the noise from the electrical grid on the 120 kHz (left) and 38 kHz echograms. Note the different depth scales on the two echograms.

'Saga Sea' is also equipped with a high frequency (114 kHz) Simrad SH 90 sonar and raw data were logged continuously with the sonar pointing 90 degrees to starboard side in the 'Bow up/180° vertical mode'. In this mode data are acquired in a vertical slice and a horizontal slice respectively (Figure 2). However, analyses of the sonar data could not be done within the time frame of the present survey analyses.

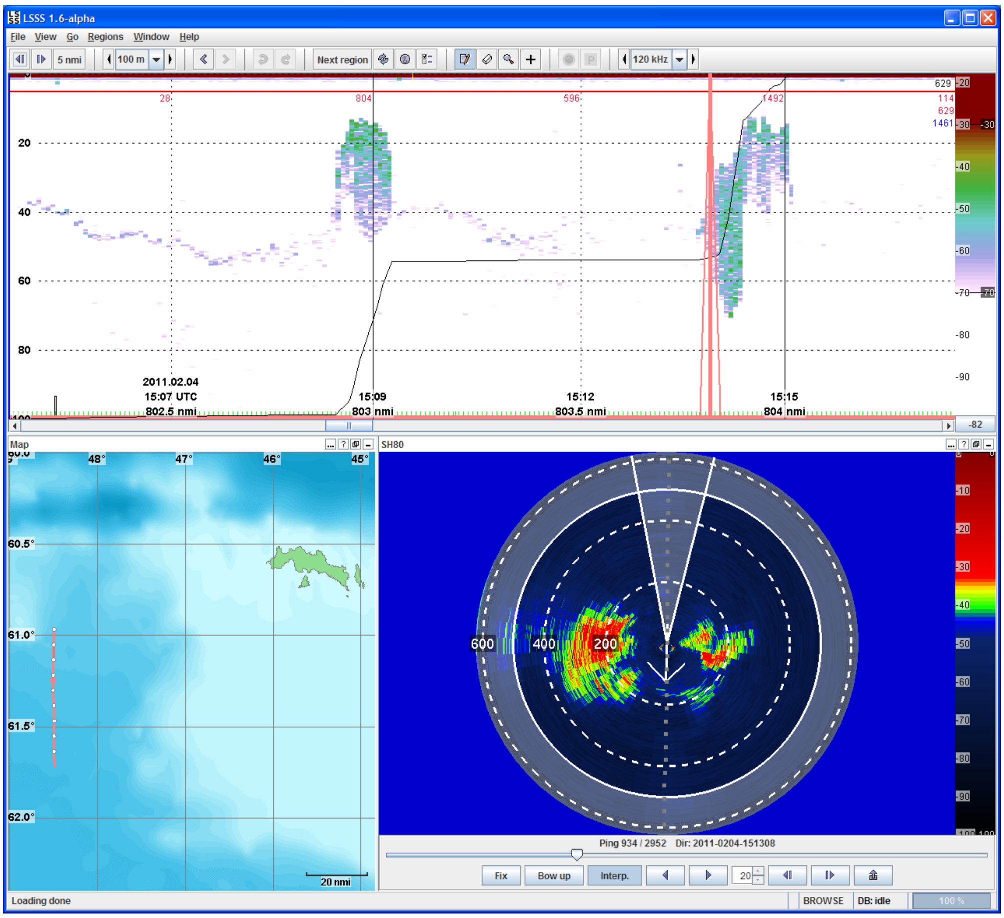

Figure 2. Scrutinizing SH 90 sonar data. The regular echo sounder echogram (120 kHz) is shown in the upper panel and the vertical red line indicates the horizontal position of the sonar beam. Lower right panel shows the echogram of the omnidirectional sonar beam pointing horizontally towards starboard side with a tilt angle of 6 degrees and a range of 600 m. The vessel bow points downwards. Lower left panel shows the selected part of the survey grid, west of the South Orkneys.

Analyses of the acoustic data

Only acoustic data collected between local sunrise and sunset were used (Demer and Hewitt, 1995), and noise was removed prior to further analyses.

Discrimination of targets

The acoustic data were first scrutinized according to the 'IMR procedure' where information from trawl catches, echogram appearance and frequency response is used to allocate the nautical area scattering coefficients (NASC; m^2 nmi^{-2}) to different organism groups. The acoustic backscatter was merely allocated to krill and non-krill.

Secondly, the method following the CCAMLR protocol for target discrimination was applied. This method takes advantage of the predictable frequency dependent volume backscattering strength (Sv; dB re m^{-1}) for krill within a specified range of body lengths. The range of ΔS_v-values ($S_{v,120}$ - $S_{v,38}$) is used to discriminate krill from other targets. We used the krill 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 krill targets it was included as krill.

The TS predictions of krill applied to calculate values of S_v at both frequencies were done using the simplified Stochastic Distorted Wave Born Approximation (SWDBA) package (Conti and Demer, 2006), but parameterized with the imaginary parts of the complex numbers included (SC_CAMLR 2009). The ΔS_v finally applied was based on a krill length range calculated in 10 mm bins based on krill TS predictions from a 95% PDF of krill length distribution based on the catches (SG-ASAM 2010). After the discrimination, the retained NASC-values were averaged for each nautical mile.

Target strength prediction

The NASC were converted to biomass density (g m^{-2}) using the simplified SDWBA model (Conti and Demer, 2006) according to the CCAMLR protocol. However, an alternative approach using a corrected version of the SDWBA package 20050603 and alternative parameterization was applied for comparison (SG-ASAM 2010). The alternative model run was carried out for a fixed distribution of orientation angles (*N[11,4]*), fixed material property contrasts (*h=1.0279* and *g=1.0357*), standard deviation of phase variability □: $sd_{\varphi 0} = \sqrt{2}/2$ radians, and TS values computed from σbs averaged over 100 realizations of the random phase. However, krill length and fatness coefficients were not fixed. The biological samples showed that subadults and adults were main population components in the samples with only low contribution from juveniles. Based on the assumption of two main population components present, parameter values for a two-component mixed distribution was estimated applying the R-package 'mixdist' (Macdonald and Fu, 2010; Figure 3). Three full model runs with different parameterizations were carried out: One for the mode with the smallest lengths (subadults; L = 36.11 mm, fatness = 20%), one for pregnant females that were found in the mode with the biggest lengths (pregnant adults; L = 49.36 mm, fatness = 40%), and one for non-pregnant adults in the mode with the biggest lengths (adults; L = 49.36 mm, fatness = 20%) (Figures 4 and 5). The three different runs were used to calculate weighted conversion factors (CF) from NASC-values to biomass density.

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

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 with coefficients derived from the three full-model runs:

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

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 selected sound speed (c). A to J are coefficients changing with different parameterization of the model (coefficients are given in Table 2).

Table 2. Coefficients of the Simplified SDWBA model with N[11.4] distribution of orientation angle for different lengths (mm) and fatness coefficients (%).

Length	36.11	49.36	
fatness	20	20	40
A	3.3009e+000 -2.1222e+001i	6.3668e+000 -1.8882e+001i	1.6349e+001 +2.0213e+001i
B	1.0386e-001 -4.4093e-002i	1.0479e-001 -3.4606e-002i	1.4785e-001 +1.7772e-002i
C	4.8341e-001 -1.6448e-001i	5.7109e-001 -1.7018e-001i	6.8795e-001 +2.4262e-001i
D	1.0374e-008	-2.5507e-009	3.9652e-009
E	-1.3194e-006	4.6208e-007	-9.5683e-007
F	5.6591e-005	-2.7420e-005	8.7961e-005
G	-9.4214e-004	5.2706e-004	-3.7806e-003
H	3.4423e-003	8.7825e-004	7.4640e-002
I	5.0216e-002	-7.3531e-002	-5.7933e-001
J	-7.9244e+001	-7.6369e+001	-7.7450e+001

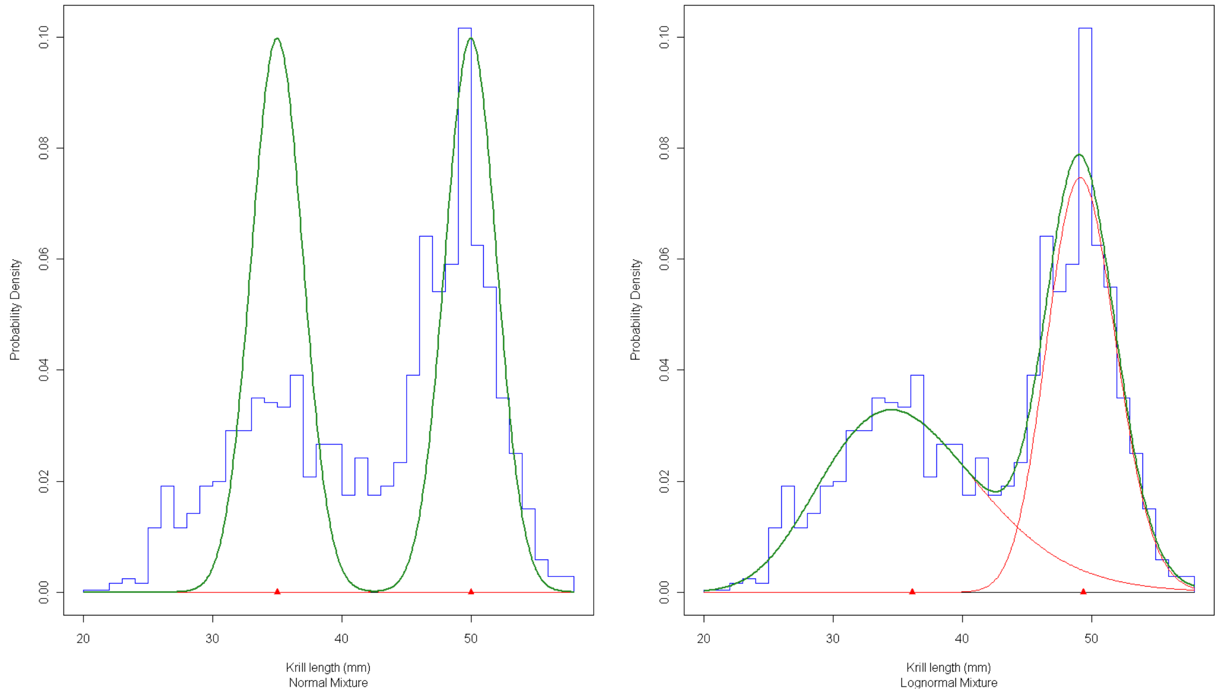

Figure 3. Krill length histograms based on all samples combined. Based on the assumption of two main population components (subadults and adults), parameter values for a two-component mixed distribution was estimated applying the R-package ‘mixdist’. Starting points for mean values (red triangles), standard deviation and proportion (green lines) are shown in the left panel, and fitted values in the right panel.

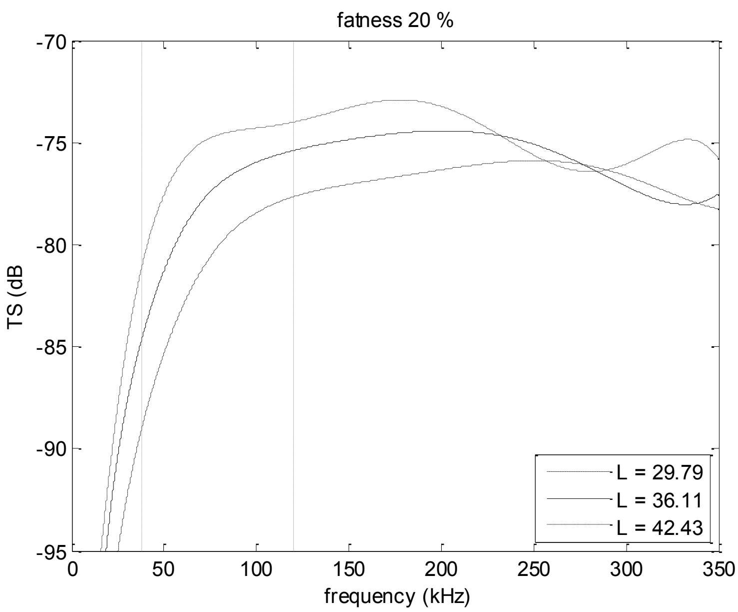

Figure 4. Simplified SDWBA with N[11.4] distribution of orientation angle for shorter modal length (mm) and 20 % fatness coefficient. The vertical dashed lines indicate the operative frequencies 38 and 120 kHz.

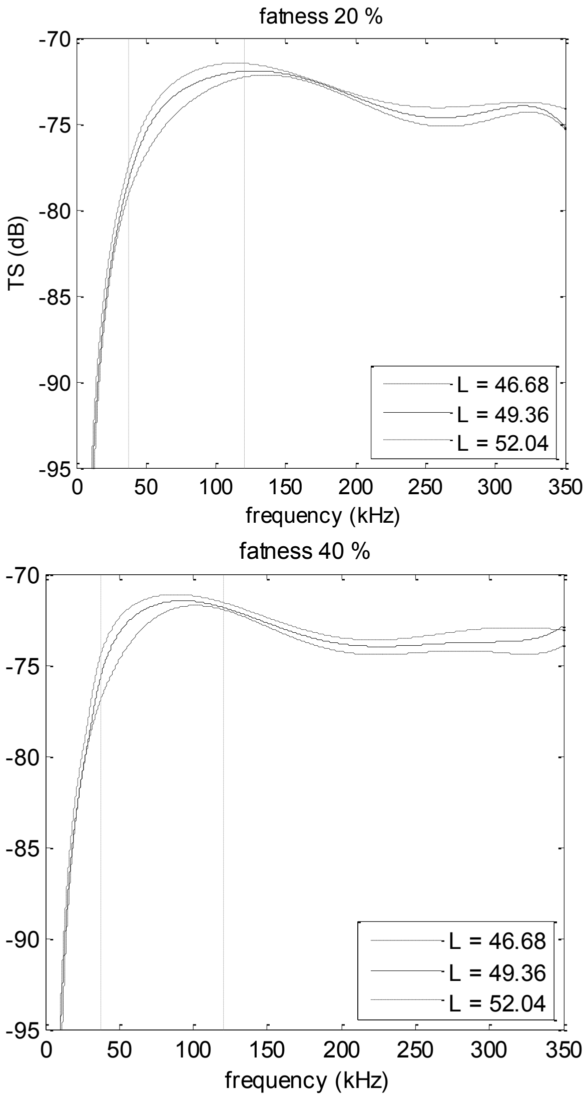

Figure 5. Simplified SDWBA with N[11.4] distribution of orientation angle for longer modal length (mm) and 20 fatness coefficient (%). The vertical dashed lines indicate the operative frequencies 38 and 120 kHz.

Biological sampling

Each transect line extended 105 nmi (nautical mile) and a trawl haul was conducted every 20 nmi (N=30), using a "Macroplankton trawl"; a fine-meshed plankton trawl having a 38m^2 mouth-opening and a mesh size of 3 mm from the trawl-opening 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 was shallower than 200 m) and then hauled at vessel speed of 2.5-3 knots.

The Saga Sea was equipped with a twin trawl beam system making comparative analysis of krill size selectivity between two trawls hauled simultaneously possible. The "Macroplankton trawl" and a commercial trawl having a 400 m^2 mouth-opening and a mesh size of 16 mm from the trawl-opening to the rear end were deployed when clean acoustic krill registrations were made (n=4).

When a trawl-catch was landed on deck, Macrozooplankton and Micronekton were sorted, identified to species or to nearest possible taxonomic group and samples were preserved on borax-buffered formalin (4%). For *E. superba*, the length of the 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. Measurements of body length and sex and maturity were determined for a total of 1,225 animals from the “Macroplankton trawl” and for an additional 398 individuals captured with the commercial trawl. Samples were also preserved on borax-buffered formalin (4%) for later taxonomic verifications. Based on visual inspection of the content of each landed trawl haul as well as analyzed subsamples, a subjective proportional estimate of the quantity (biomass) of different taxa was made.

Hydrography

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

Marine mammal observations

Sightings for whales, penguins and seals were executed by 1-2 observers, trained scientific personnel as well as a trained crew member, during all light hours (0600-2000 local time), in total 59 hours. Observations were from the bridge at 10 knots along transects and during transit between transects, however no such recordings were made while trawling. The TNASS observation regime were applied (Palka and Hammond 2001; Lawson and Gosselin 2009) including recordings of time, position, meteorological conditions (wind, visibility, glare), distance at first sight, angle from vessel, swim direction relative to vessel, best estimate, max estimate, number of calves, species and behavior. A sighting was noted based on direct observation with the naked eye and binocular, and documentations were made with film and photo.

Results and discussion

Acoustics

Distribution of acoustic krill recordings according to the ‘IMR procedure’ for acoustic discrimination is shown in Figure. 6.

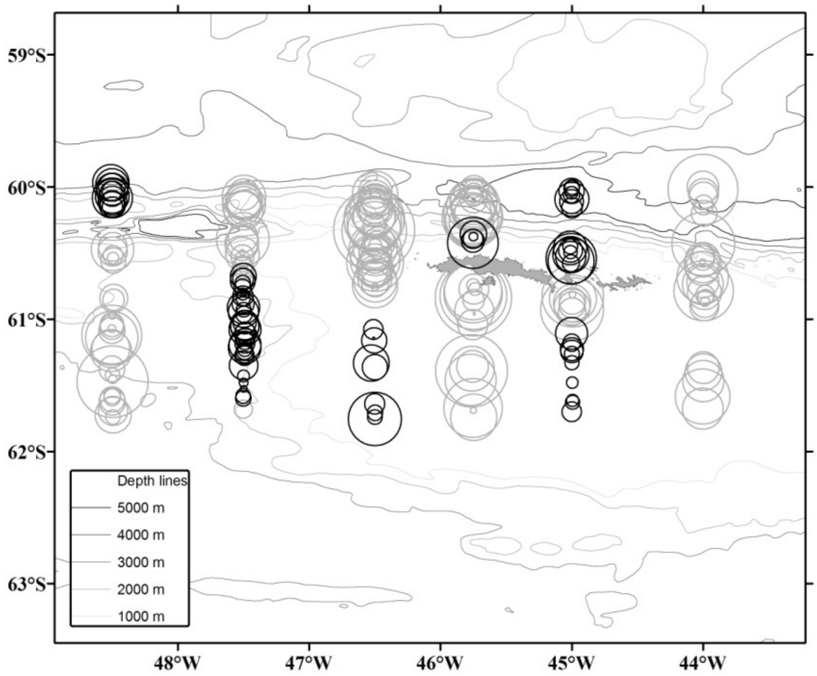

Figure 6. Distribution of Nautical Area Scattering Coefficients (NASC) allocated to krill according to 'IMR procedure' of discrimination. Black circles denote dark hours, and grey circles daytime hours. The data were collected during 4-8 February 2011 in the South Orkney Island waters.

The biomass estimates calculated according to the CCAMLR protocol, IMR procedure and with alternative model and parameterization are shown in Table 3 for both 120 and 38 kHz. Krill biomass estimates will be recalculated according to the most recent CCAMLR protocol for the WG EMM in July 2011.

Table 3. Biomass density (BM density) with variance and total biomass (BM) with CV for 120 kHz (a) and 38 kHz (b). Biomass is calculated according to the CCAMLR protocol, using the IMR procedure for krill discrimination and using an alternative model and parameterization (see text).

a)

	120 kHz			
	BM density (g/m2)	Var	BM (mill. tons)	CV (%)
CCAMLR protocol	123.5	827.3	7.3	23.3
IMR procedure	139.8	1441.3	8.3	27.2
CCAMLR Alternative model parameters	87.3	413.4	5.2	23.3

b)

	38 kHz			
	BM density (g/m2)	Var	BM (mill. tons)	CV (%)
CCAMLR protocol	60.4	129.8	3.6	18.8
IMR procedure	63.4	208.7	3.8	22.8
CCAMLR Alternative model parameters	57.5	117.6	3.4	18.8

Biological sampling

From a total of 30 sampling stations, three trawl stations did not contain any zooplankton, in one occasion this was due to net failure. The dominating species in the net samples were *Salpa thompsoni* (Order Salpida), three species from Order Euphausiacea (*E. superba*, *Thysanoessa macrura* and *E. frigida*) with *E. superba* as the dominating species. There were occasionally also large catches of Order Mysida and smaller elements of Phylum Chaetognatha, Order Gymnosomata (*Clione sp.*), Order Amphipoda (*Cyllopus sp.*, *Vibilia antarctica*, *Primno sp.*), Order Decapoda, Phylum Cnidaria (*Calycopsis sp.*, *Diphyes sp.*, and Cnidaria indet.) and Class Actinopterygii (*Notolepis sp.*, *Electrona antarctica* and *Dacodraco hunteri*) (Figures 7 and 8).

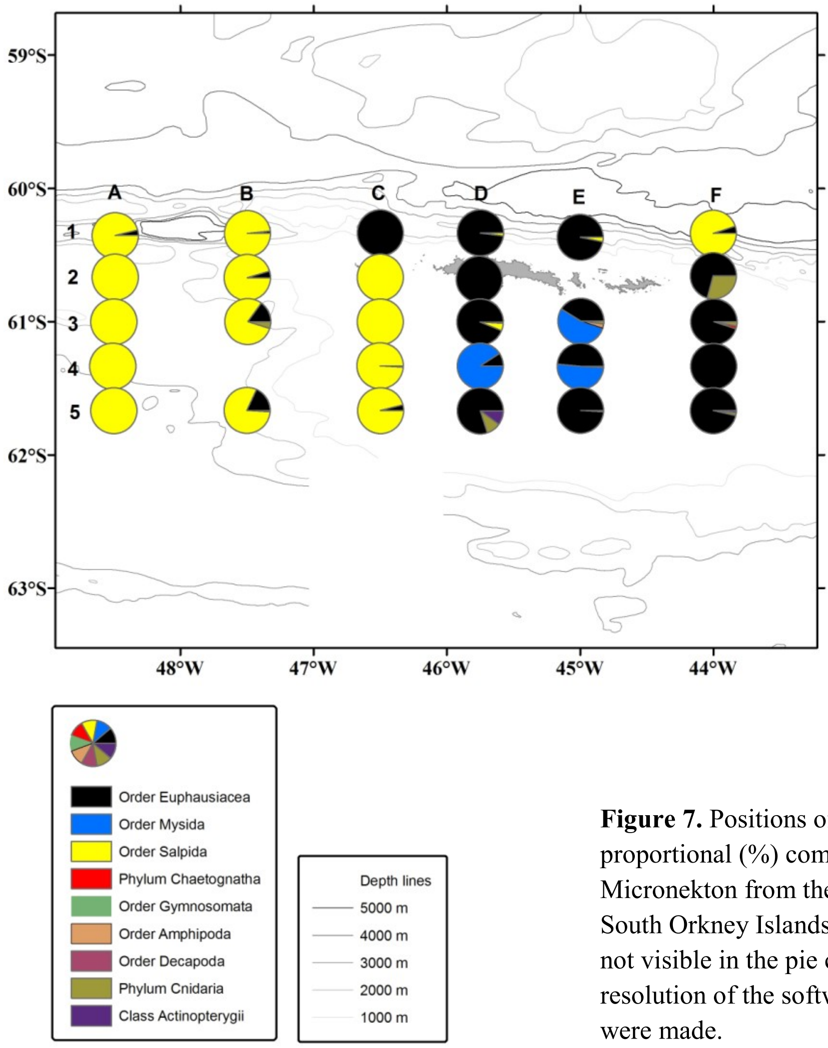

Figure 7. Positions of trawl stations (A1-F5) with proportional (%) composition of Macrozooplankton and Micronekton from the period 4-8 February 2011 in the South Orkney Islands waters. Presence of taxa < 1% is not visible in the pie chart due to restrictions of the resolution of the software ArcView, where the figure were made.

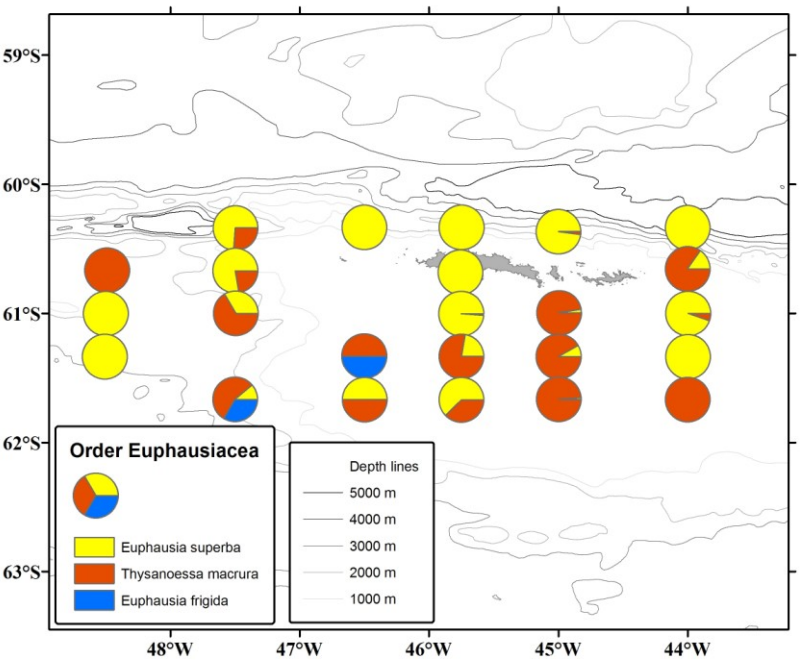

Figure 8. Distribution and the proportional (%) composition of three species from the Order Euphausiacea captured during 4-8 February 2011 in the South Orkney Island waters. Presence of taxa < 1% is not visible in the pie chart due to restrictions of the resolution of the software ArcView, where the figure were made.

A total of 23 stations contained specimens of *E. superba* (Figs. 7 and 8). The average *E. superba* body size was 43.3 ± 8.2 mm (SD), ranging between 22 – 59 mm (Table 4). The sample comprised 19.4% juveniles, 33.9% sub adults, and 55.7% adults, with a male versus female sex ratio of 3:2 (Figures 9 and 10). Adult males with spermatophores (25.8% MIIIB), and adult females ready to spawn (15.0% FIIID) dominated in the trawl catches (Table 4).

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 4-8 February 2011.

Krill maturity stages	**No. in sample**	**Proportion (%)**	**Total length ± SD**
Juvenile stage 1	128	10.4	29.0 ± 2.6
Male subadult MIIA1	134	10.9	34.8 ± 2.7
Male subadult MIIA2	130	10.6	39.0 ± 3.1
Male subadult MIIA3	45	3.7	45.0 ± 3.7
Male adult MIIIA	39	3.2	49.9 ± 2.5
Male adult MIIIB	316	25.8	49.4 ± 2.5
Female subadult FIIB	106	8.7	36.1 ± 3.3
Female adult FIIIA	3	0.2	48.3 ± 6.7
Female adult FIIIB	52	4.2	48.2 ± 4.1
Female adult FIIIC	67	5.5	48.5 ± 2.9
Female adult FIIID	184	15.0	50.3 ± 3.4
Female adult FIIIE	21	1.7	50.6 ± 3.5
Total	1,225		

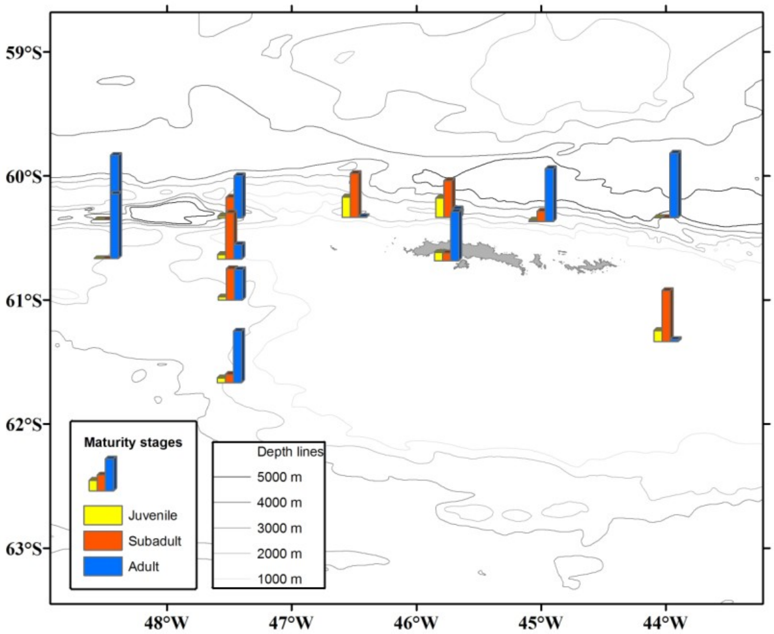

Figure 9. Distribution of the maturity stages of *E. superba* captured during 4-8 February 2011 in the South Orkney Island waters (included stations with sample size >50 ind.).

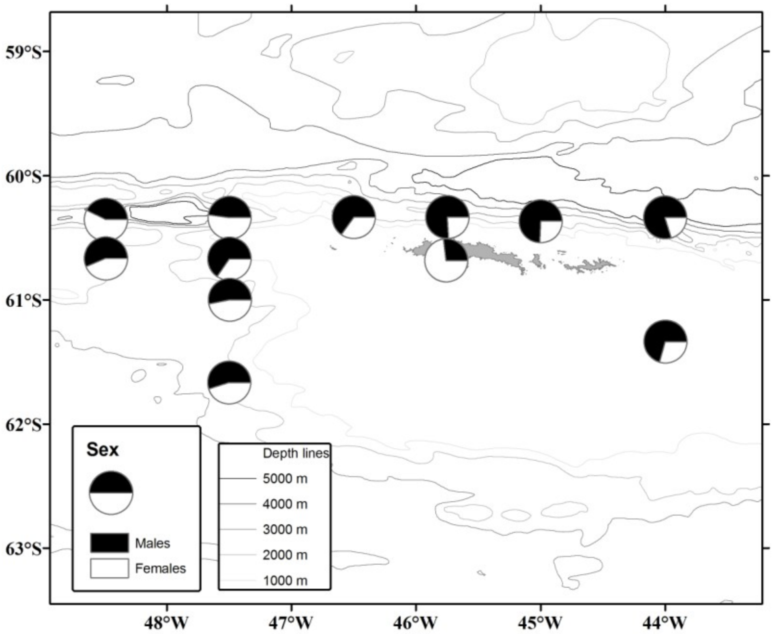

Figure 10. Distribution and proportion of *E. superba* males and females from the trawlstations made during 4-8 February 2011 in the South Orkney Island waters (included stations with sample size >50 ind.).

A comparison of length frequencies of krill catches between a scientific trawl having 3 mm mesh size (Macroplankton trawl) and a 16 mm mesh sized commercial trawl was carried out on the stations C1, E1, D1 and F1 (see Figure 7). The result is shown in Figure 11.

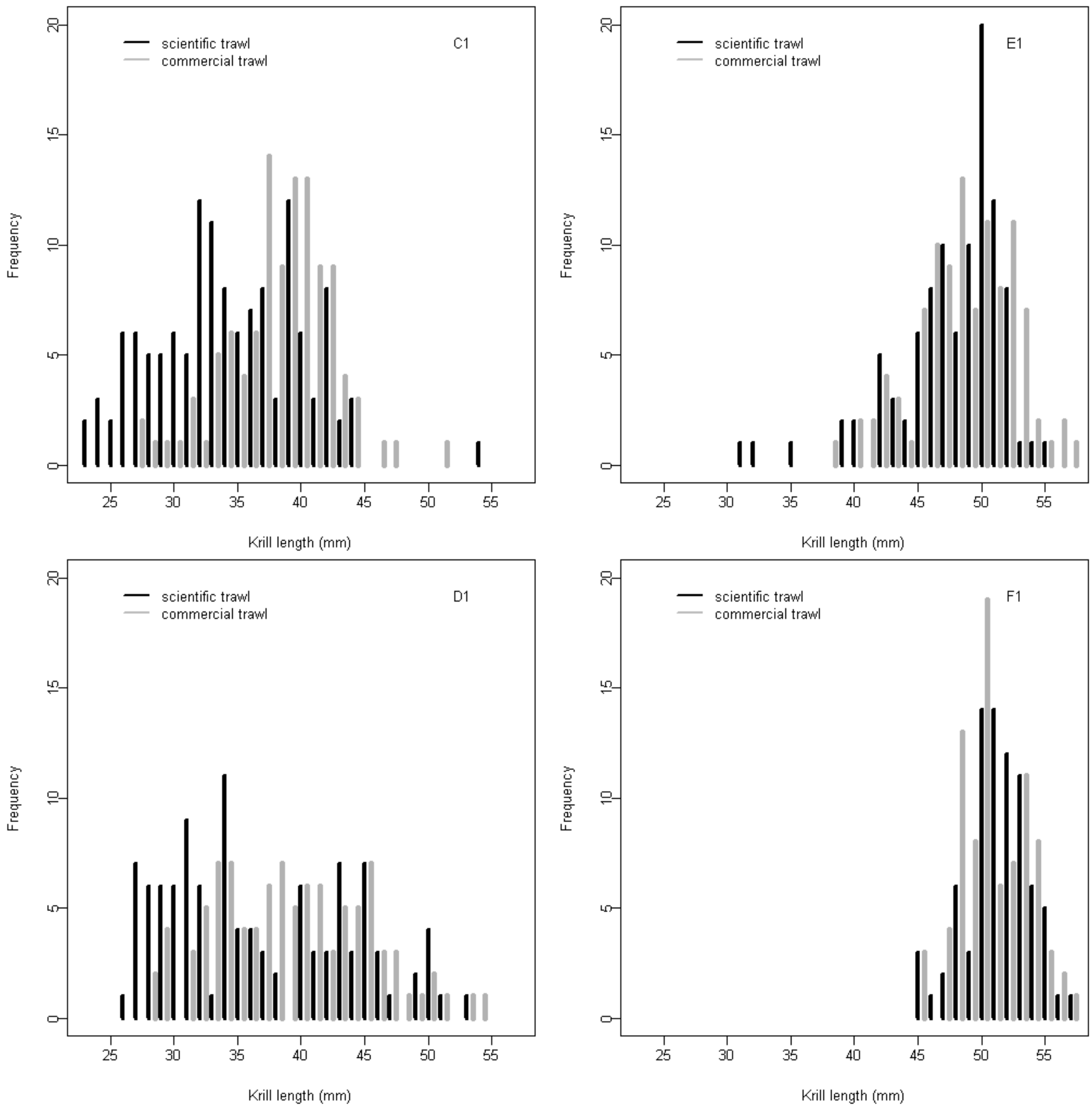

Figure 11. The length frequency distribution of *E. superba* caught by a scientific trawl having 3 mm mesh size (black) (Macroplankton trawl) an **F** d 16 mm mesh sized commercial trawl (grey). The stations C1, E1, D1 and F1 were the 4 most westerly and northernmost trawl stations performed during 4-8 February 2011 in the South Orkney Island waters.

Hydrography

The hydrographical profiles are shown in Figure 12, and temperatures at surface and 200 m depth in Figures 13 and 14.

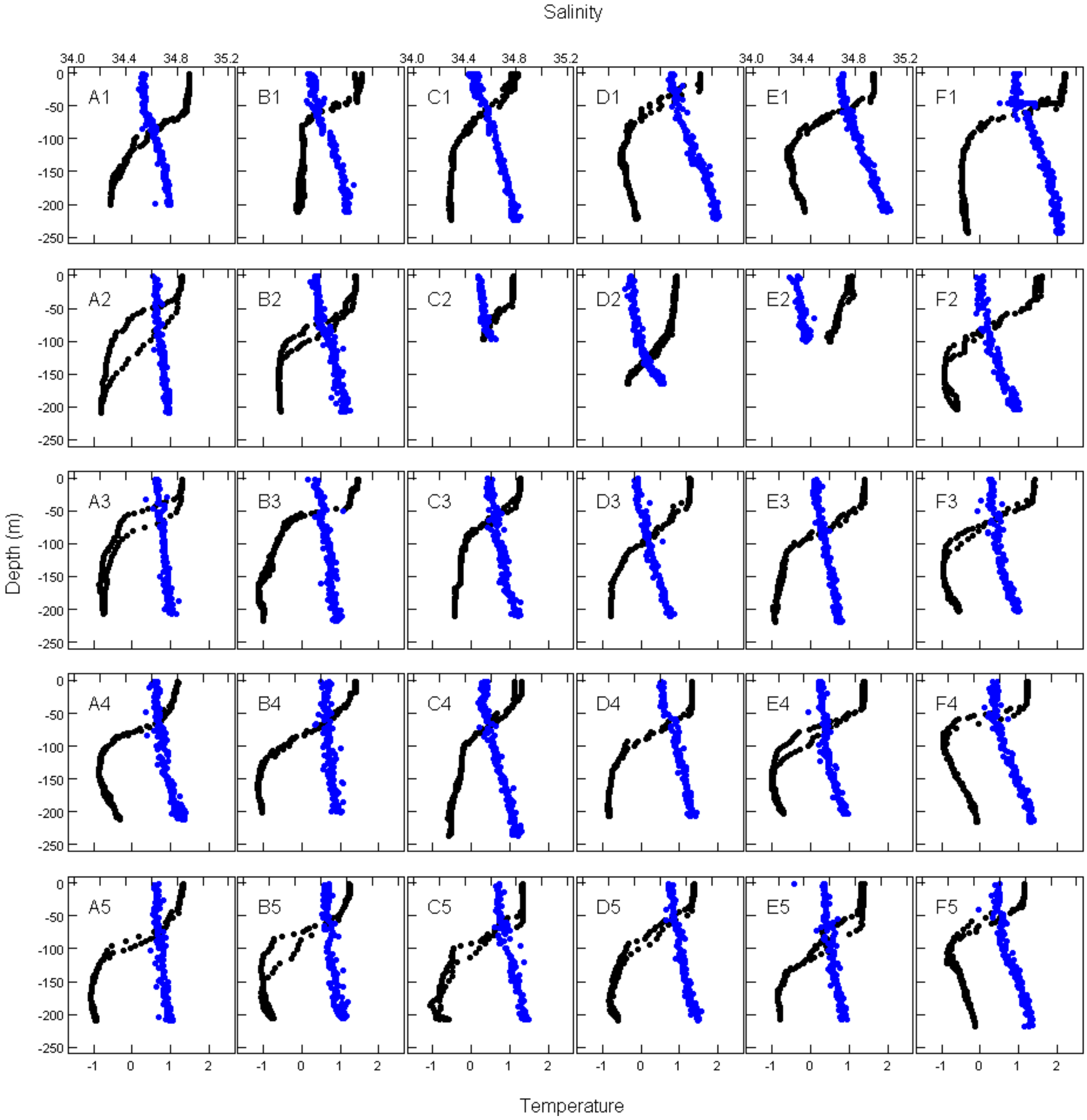

Figure 12. Temperature (black) and salinity (blue) profiles at the survey stations.

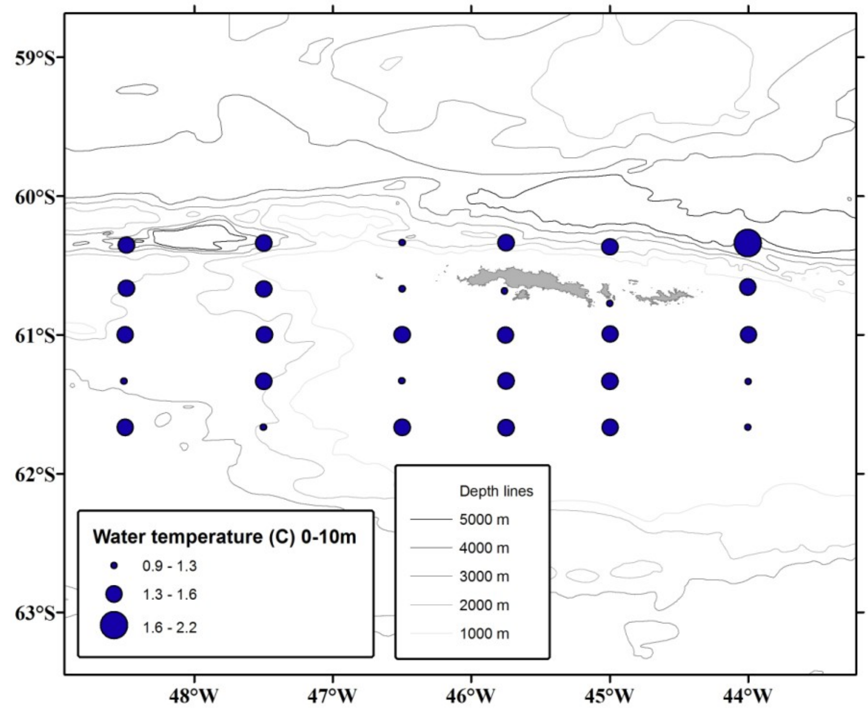

Figure 13. Surface (0-10m) temperatures (C°) sampled with a SAIV CTD attached to a trawl during 4-8 February 2011 in the South Orkney island waters.

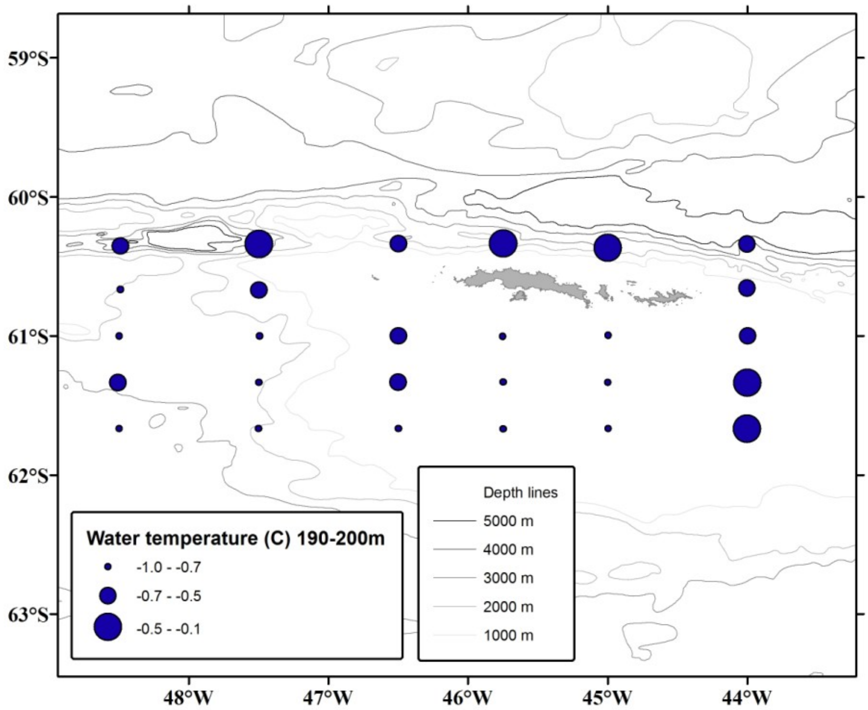

Figure 14. Water temperature (C°) at 190-200m depth sampled with a SAIV CTD attached to a trawl during 4-8 February 2011 in the South Orkney island waters.

Marine mammal and penguin observations

A total of 103 fin whales (*Balaenoptera physalus*) were observed along the cruise tracks, 458 Chinstrap penguins (*Pygoscelis antarcticus*) and 104 Antarctic fur seals (*Arctocephalus gazella*) (Figures 15-17).

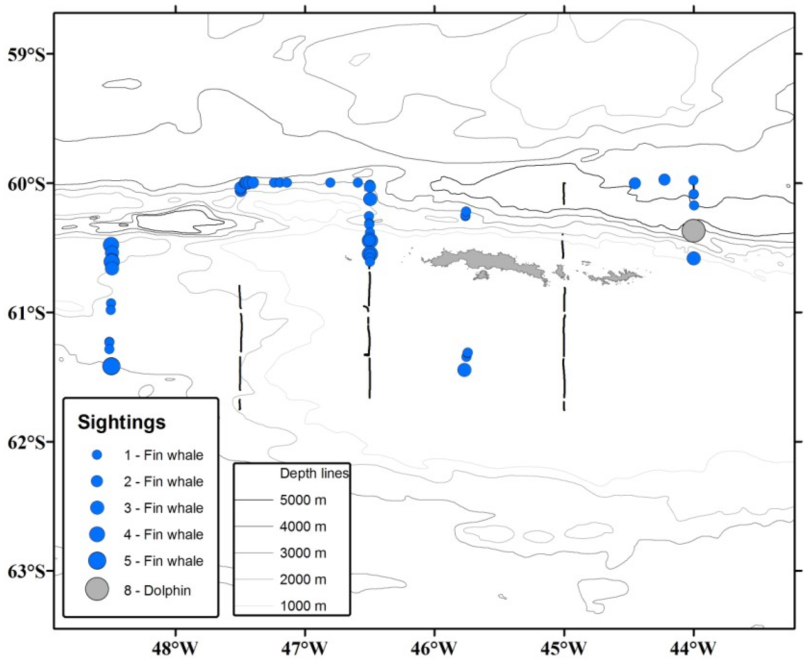

Figure 15. Sightings of Fin whales and dolphins during 4-8 February 2011 in the South Orkney island waters. Small black dots indicate night hours.

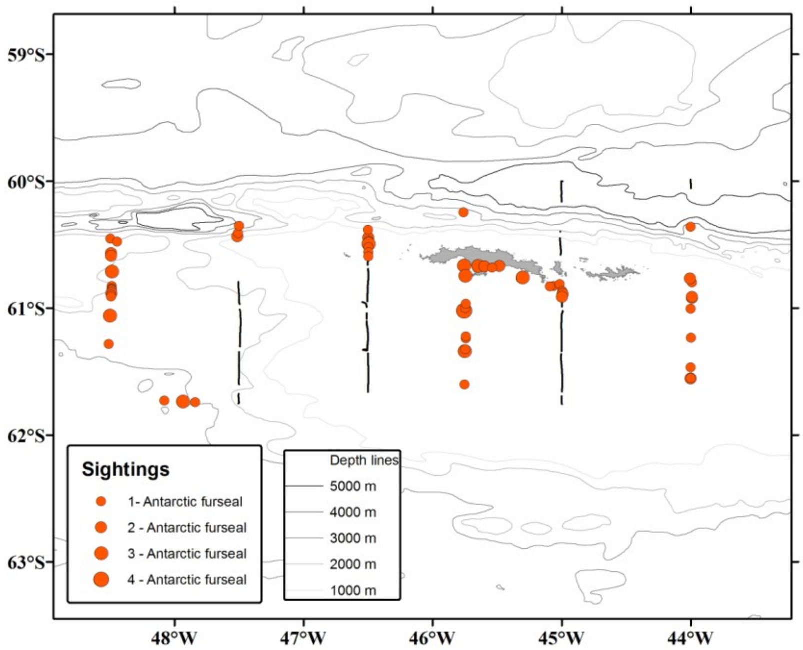

Figure 16. Sightings of Antarctic furseals during 4-8 February 2011 in the South Orkney island waters. Small black dots indicate night hours.

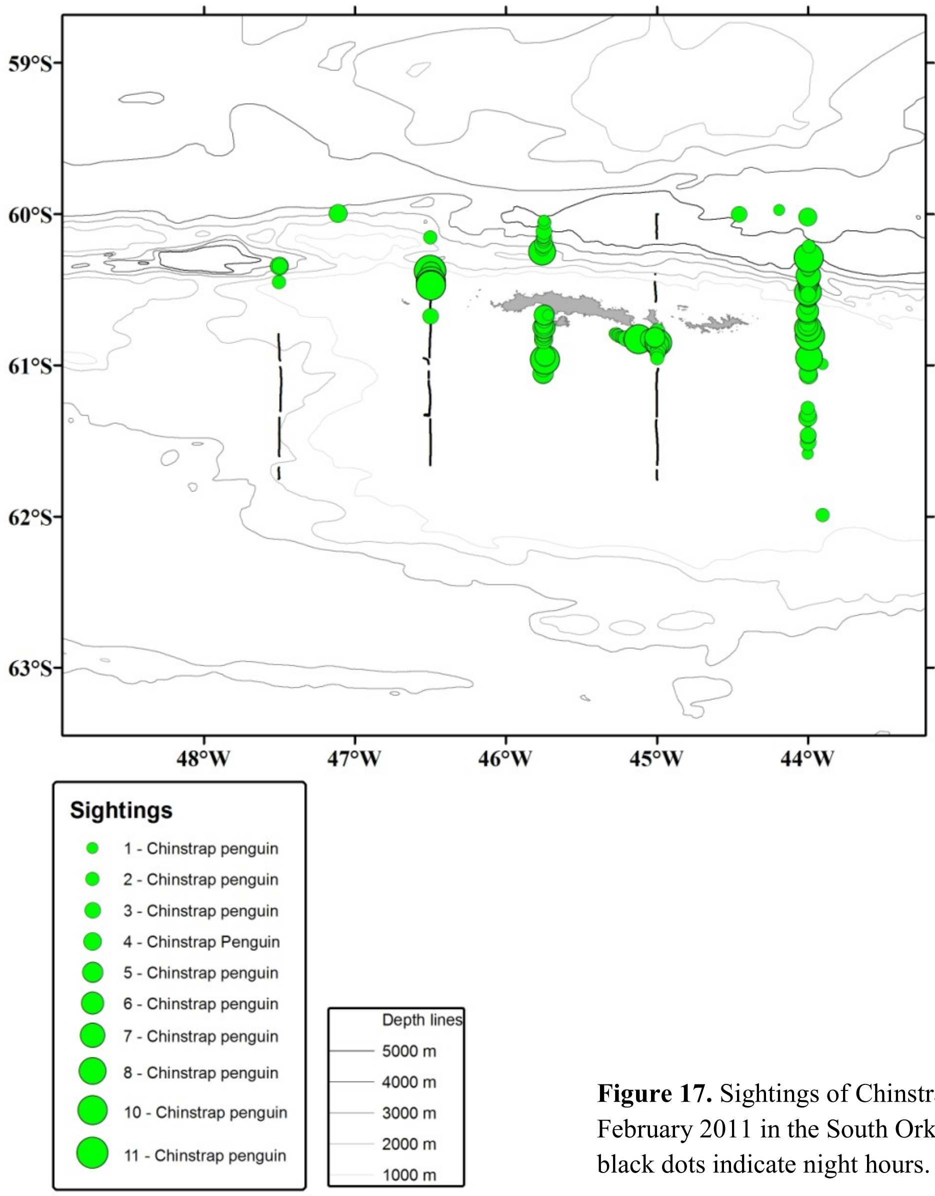

Figure 17. Sightings of Chinstrap penguins during 4-8 February 2011 in the South Orkney island waters. Small black dots indicate night hours.

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