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Introduction

During the CCAMLR WG-EMM (Convention on the Conservation of Antarctic Marine Living Resources, Working Group on Ecosystem Monitoring and Management) in July 2010, Aker Biomarine ASA offered to carry out a 5 day krill survey each year using their commercial krill trawler (Jensen et al. 2010). During subsequent years also Olympic ASA, the other Norwegian commercial krill fishing company, has as well offered ship time for this purpose. During the working group meeting a study method was designed, comprising a set of parallel acoustic transects with evenly distributed trawl stations along the cruise tracks. Regular surveys in Subarea 48.2 would complement surveys conducted in 48.1 and 48.3 by the German, American and British scientific surveys that are frequently carried out in these areas. Together this 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. This report presents applied methods and preliminary results from the fourth of the annual cruises made in the South Orkney Island waters using a commercial Norwegian fishing trawler as research platform.

Knowledge of indirect fishing mortalities, including organisms that die after either escaping or being discarded from fishing gear is essential for the management of krill stocks but such information is presently non-existent in the scientific literature. As a spin-off from the ongoing project NEAT (Net Escapement of Antarctic krill in Trawls) we present applied methodology from experiments made during this survey by modifying the survey trawl with a covered codend, and holding krill escapees on the surface in tanks to assess their escape mortality rates.

Material and methods

Survey design, area and vessel

The supply vessel “La Manche” (Aker Biomarine ASA) departed Port Stanley, Falkland Islands on the 18 January 2014. On the 22 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. The survey commenced on the 24 January at 0400 UTC and ended on the 30 January at 2200 UTC. The survey design around the South Orkney Islands included six parallel transects extending from the northernmost waypoints at 59.67°S and southernmost waypoint at 62.00°S. Longitudes for transects 1 through 6 are at 44°W, 45°W, 45.75°W, 46.5°W, 47.5° W and 48.5°W, respectively. In addition two extra transect lines were placed between the two easternmost transect lines, stretching from the southern coastline of Laurie Island to 62.00°S (Figure 1). After the completion of the survey the vessel started fishing commercially and this allowed for time to perform additional experiments as outlined in the coming text. Three colleagues (two from the British Antarctic Survey and 1 scientist from the Norwegian Polar Institute), performing telemetric studies of penguins, were also picked up from their field camp at Powel Island (Figure 1) on the 12 February. All scientist personnel were then returned to “La Manche” on the 15 of February off Signy Island, and the survey ended on the 18 February when the vessel reached Port Stanley, Falkland Islands.

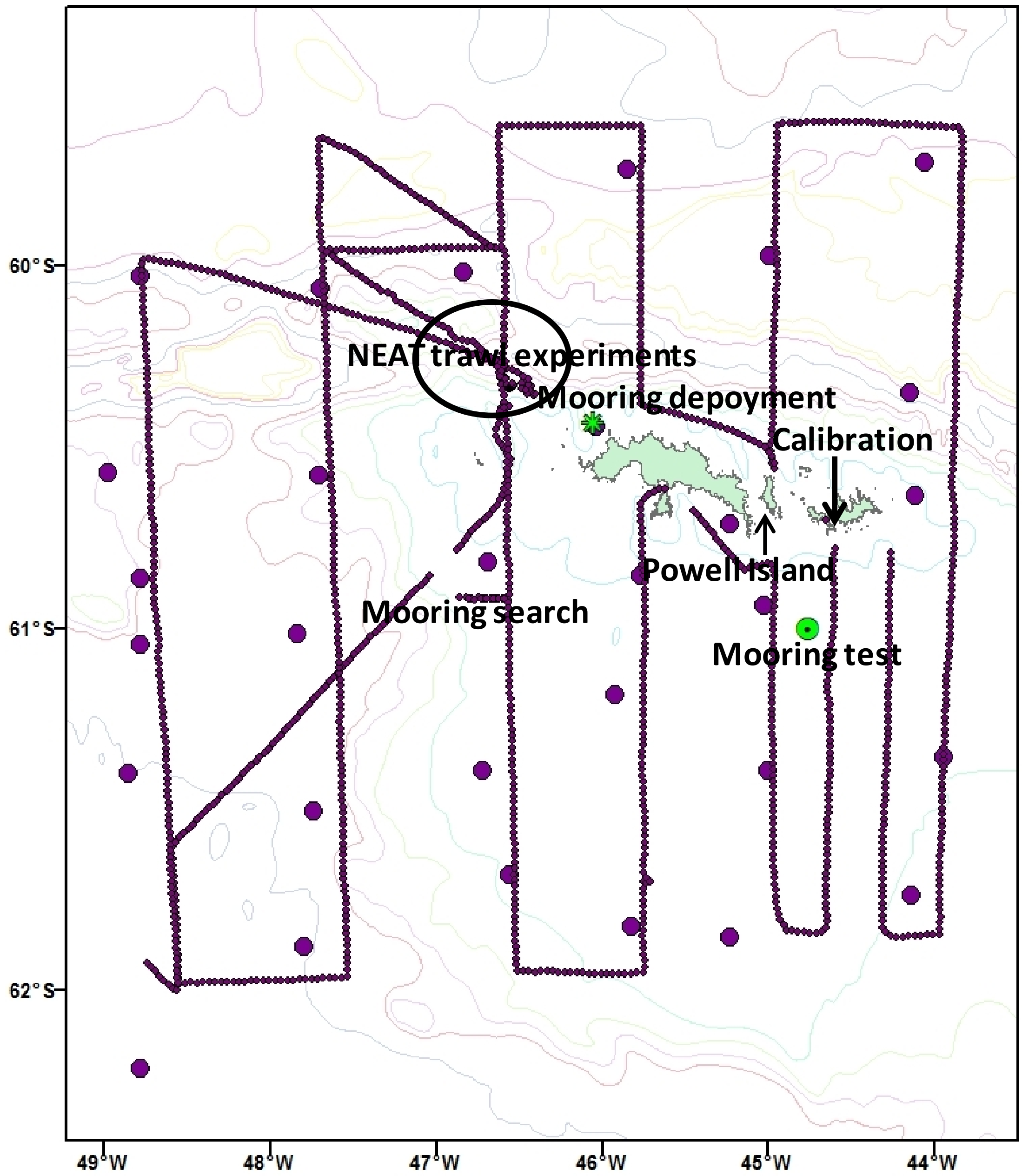


Figure 1: *Cruise lines, trawl stations (blue circles), large circle indicates the sample area for trawl escapement experiments and also for growth experiments, yellow star indicates final deployment position for acoustic mooring and yellow circle position for test deployment of mooring.*

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 transducers mounted in the vessel hull. The system was calibrated using this echo sounder set-up in Scotia Bay (60°46’S, 44°41’W) at Laurie Island on the 28 January 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. Prior to scrutinizing the acoustic data, pre-processing was carried out using the LSSS) the Large Scale Survey System)-software (Korneliussen et al. 2006). A dB-threshold of -82 nd depth range of 500 m was set prior to the pre-processing, and no-survey periods were excluded. The pre-processing consisted of several steps:

1) Correcting the raw samples to provide calibrated s_v-samples
2) Filtering out noise
3) Compensating for placement of transducers
4) Resampling the s_v-samples into bins
5) Automatic school detection
6) Automatic species identification (used as support during scrutinizing)

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)	5	5
Transmitted power (W)	2000	250
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	10.1	38.4
Sound speed (ms^{-1})	1450	1450
Sample interval (m)	0.186	0.186
Two-way beam angle	-20.6	-21.0
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

In the scrutinizing process, the acoustic backscatter was allocated to “krill” according to the acoustic frequency response, appearance and strength of the acoustic detections and the occurrence of krill in trawl haul samples. The allocation was done exclusively to krill for school regions detected during pre-processing and interpreted to be krill, or as a proportion of acoustic backscatter where an echogram section was interpreted to consist of a species mix. Regarding the frequency response, SG-ASAM recommended ratios between the frequencies 38, 120 and 200 kHz of r120/38=4.5±1.5; r200/38=4.0±1.5 and r200/120=0.91±0.03 for the identification of krill of 40-50 mm. These values were used as guidelines during the scrutinizing. The data were scrutinized on 38 kHz by a team of 2 persons during the survey. Prior to exporting, Sv-bins were summed over a depth range (10 m) and averaged over a distance interval (1 nautical mile). The exported integrated data thus provide a measurement of areal backscattering (sA in m2 nmi-2) due to krill over each 1 nautical mile distance along the survey track.

'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.

Biological sampling

On each of the 6 main transect lines, 5 trawl hauls were conducted every~25 nmi (N=30), 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 of the water 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 using a DeLaval spring scale (250 ± 1 kg). 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 using a Capere bench scale (5000 ± 1.0 g). 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.

Hydrographical sampling

To obtain profiles of temperature, salinity and fluorescence during the trawl hauls a SAIV CTD sensor with an interface unit and a sensor for measuring fluorescence was mounted in an open metal frame for protection and welded to the steel trawl beam (see Figure 2). The CTD device was logging continuously in 10-second intervals throughout the whole cruise.

Marine predator observations

Sightings for seabirds and marine mammals were carried out by 2 dedicated observers who combined observing and recording. Observations were made during all daylight hours (0600-2200 local time); in total approximately 65 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 approximately 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 sometimes from the Forward Port Quarter, depending upon glare. Where applicable 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 species dominated by ship-followers periodic counts were made of total individuals in sectors every 15 minutes. For whales the swim direction relative to the vessel was also recorded where possible. Meteorological conditions during observations were recorded (i.e. wind, sea state, visibility, glare). 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

In an experiment assessing escape mortality of krill the Macroplankton trawl was modified to a covered codend design (Figure 2) with a 16 mm netting, which is a standard mesh size used in commercial krill fishing gear, and a 7 mm meshed cover net to collect potential escapees from the 16 mm codend. The cover net was supported by two aluminum rings (Ø=4 m) to prevent the cover net from sticking to the 16 mm codend. The cover was mounted with a zipper for easy access to the codend catch. In the rear end of the cover net a 5.3 L MOCNESS bucket, with 500 µm mesh netting on the side walls, was attached to protect krill escapees from further mechanical exposure during the fishing process (Figure 2).

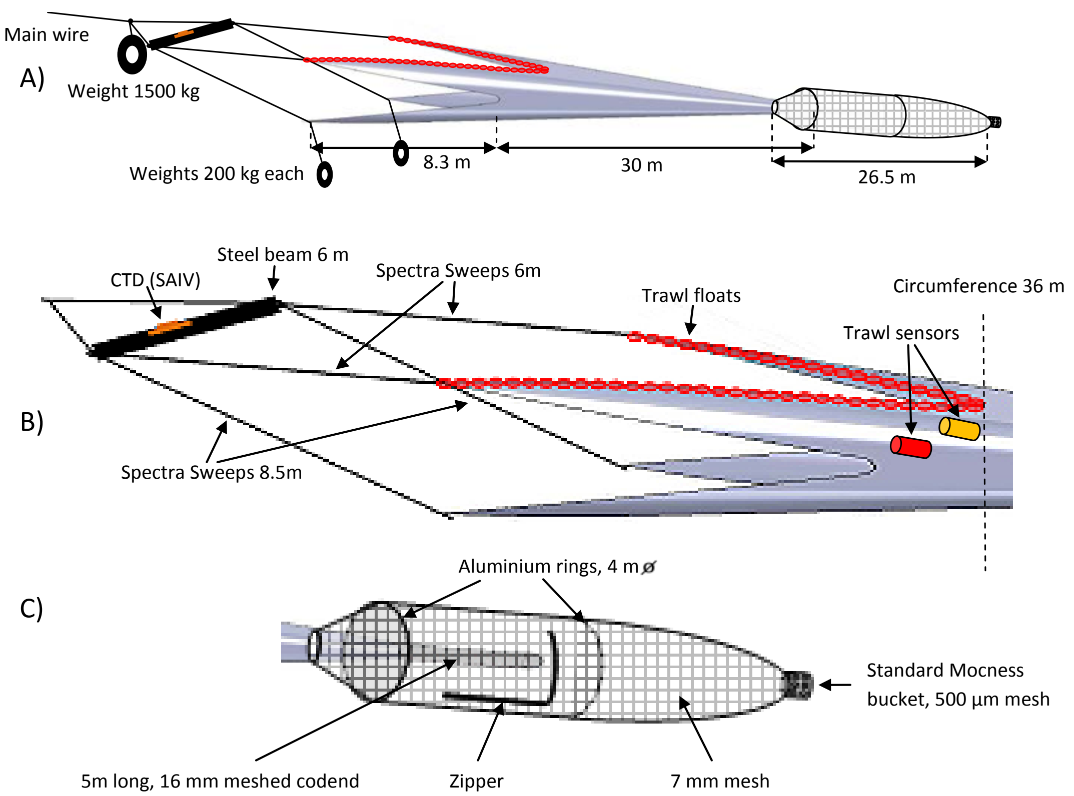


Figure 2: *Experimental setup. A) covered codend trawl system, B) towing point and mouth of the trawl indication position of sensors (CTD, Marport depth sensor), C) cover bag system.*

When a trawl was landed on deck, a random sample of krill from the MOCNESS bucket was promptly distributed into 3 plastic aquariums (16 L, perforated with Ø 5 mm holes) half filled with sea surface water. The plastic boxes were submerged into a 1000 L fish tank filled with surface sea water. The hydrological condition in the tank was continuously monitored with an oxygen sensor (Oxyguard Handy Polaris 2) and a mini CTD (Star–Oddi) (Figure 2). All water in the 1000 L tank was changed every 12 hour.

After 24, 48 and 72 hours, dead krill was removed from the aquariums, counted and length measured (±1 mm) from the anterior margin of the eye to tip of telson excluding the setae, according to the 'Discovery method' (Mauchline, 1980). After 24 hours also notes about the body state (damaged/not damaged) of dead krill was assessed visually.

Additional krill survival experiments were conducted with krill caught with the commercial trawl gear during commercial fishing, from the 1–14 February, using the same methods for survival experiments as described above, only with prolonged holding periods (3–5 days). FV *Saga Sea* operated two 16 mm meshed and 220 m long trawls with continuous pumping through a 20 cm diameter and 300 m long vacuum hose from the codends to a sieve onboard, which enabled sampling of krill before the catch entered a buffer tank below deck. It is calculated that it takes 10–12 minutes for the krill to travel from the trawl mouth to the production deck, when there is no catch accumulation in the codend.

Individual krill growth experiments

Live krill were taken directly from the pump-system, and incubated in individual containers in the 1000L fish tank on deck. The incubated krill were inspected daily for moulting, and moulted krill and exoskeletons were fixed in ~ 4% formaldehyde. By comparing uropod lengths from the moulted krill with the uropod lengths from the exoskeletons, it is possible to assess growth rates. Water in the big container was changed daily, and the individual experiments were run for a total of 5 days. The first 2 experiments were initiated shortly after the end of the scientific survey, approximately at the mouth of the "canyon-area" (Figure 1), and yielded moult-rates of 0.051 and 0.057 moults per ind per day. Experiment 3 was started after the completion of the first 2 experiments, on February 06.

Deployment of acoustic mooring

A test deployment of an acoustic mooring (Acoustic Zooplankton Fish Profiler, ASL Environmental Sciences Inc ser no. 66062) was made on 28.01.2014 at 15:45 UTC anchored in 136 m water depth at location 60° 48.9 S and 044° 38.6 W., south of Signy Island (Figure 1). It was recovered 3 hours later. The deployment, release, recovery and retrieval of data recordings were a success. The anchor consisted of two steel railway wheels welded together (total weight=500 kg). The buoy consisted of a custom-built welded steel frame holding 12 trawl floats (15" Panter dk) (Figures 3 and 4). The final deployment with the instrument set to log until it is recovered (next year) occurred at 60.24.291S and 45.56.306W, 16:25 UTC on the 11 February (Figure 1). The bottom depth was at 530 m and cable length from the anchor to the transducer was 200 m (Figure 4).

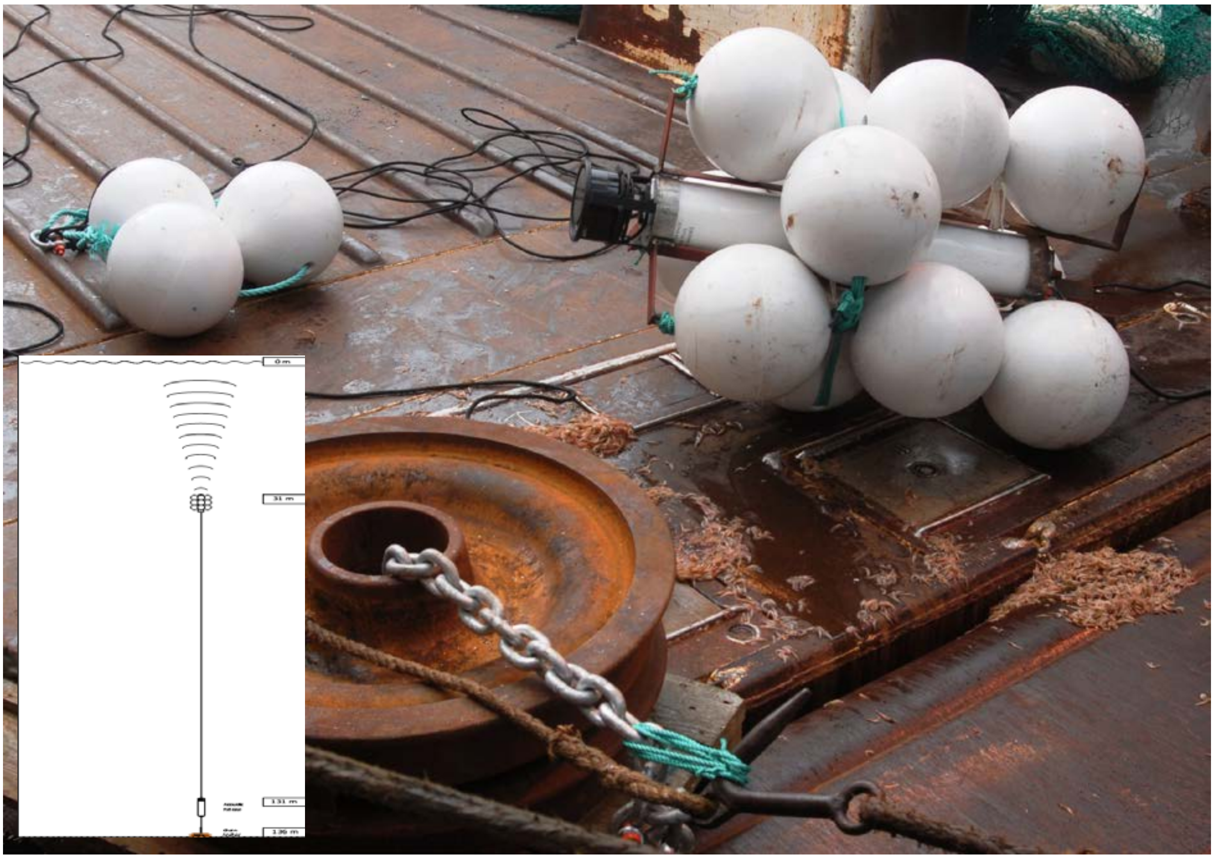


Figure 3: *Acoustic zooplankton profiler on buoy, ready for deployed for one-year data recording.*

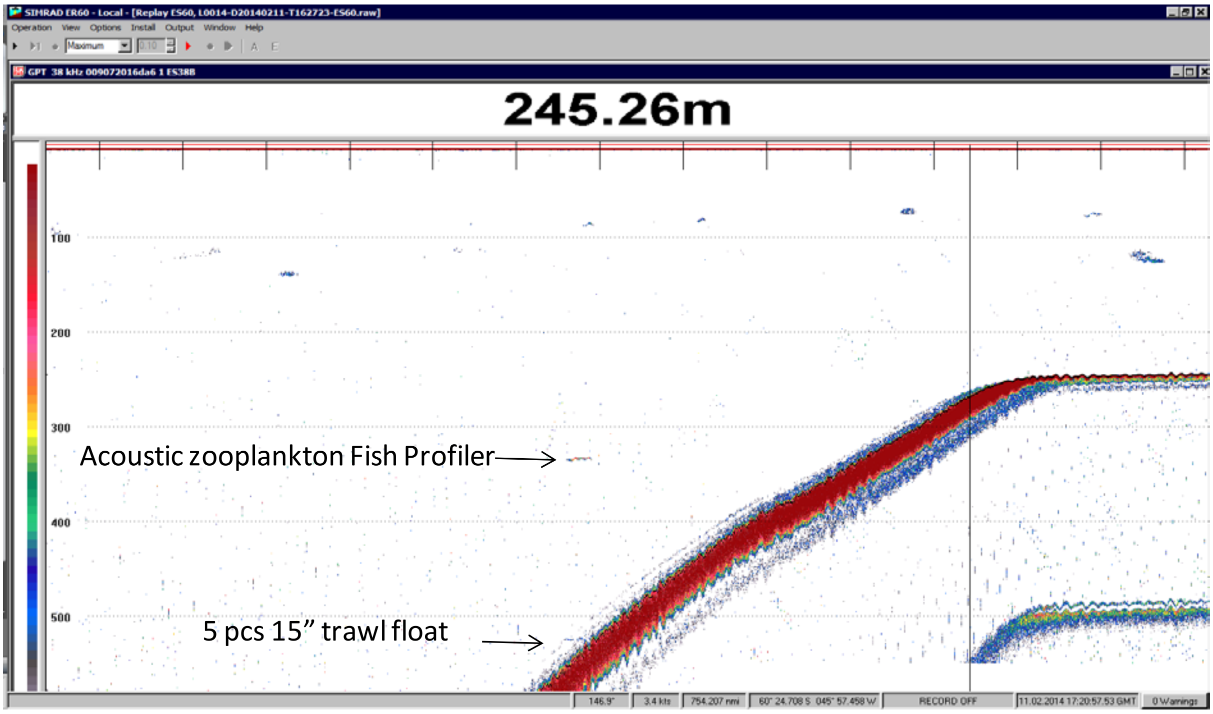


Figure 4: *Acoustic image of the deployed zooplankton profiler.*

Recovery attempt of British Antarctic Survey Signy mooring

On the 27.01.2014, 02:25 UTC at location 60.575337 S and 46.51749 W (Figure 4) an attempt was made to recover a Sediment trap P3 mooring that had not been successfully recovered by British Antarctic Survey cruise JR 291 in November 2013.

The following releases were attempted:

Release 1: Sn: 1357 ARM: 092C Release 0955 Diagnostics: 0949

Release 2: Sn 1358 ARM: 092D Release: 0955 Diagnostics: 0949

We did not make any contact with the releases, could not find any sign of the mooring buoy (expected at 150 to 250 m below the surface) on any of the ship's acoustic systems.

Preliminary Results

Acoustics

The abundance and distribution of krill based on acoustic recordings are shown for the 38 kHz in Figure 5. Also clear examples of air breathing predators foraging on krill swarms can be observed on the echograms (Figure 6).

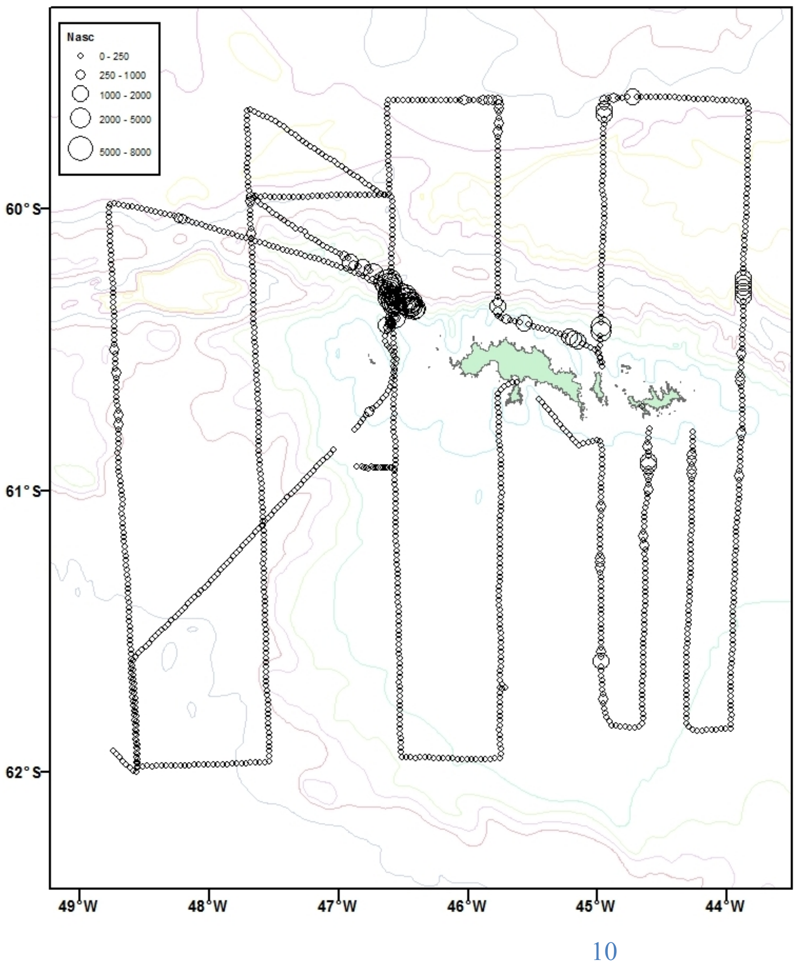


Figure 5: *Distribution of Nautical Area Scattering Coefficients (NASC (m^2/nmi^2) allocated to krill based on the 38 kHz recordings. The data were collected during January 2014 in the South Orkney Island waters.*

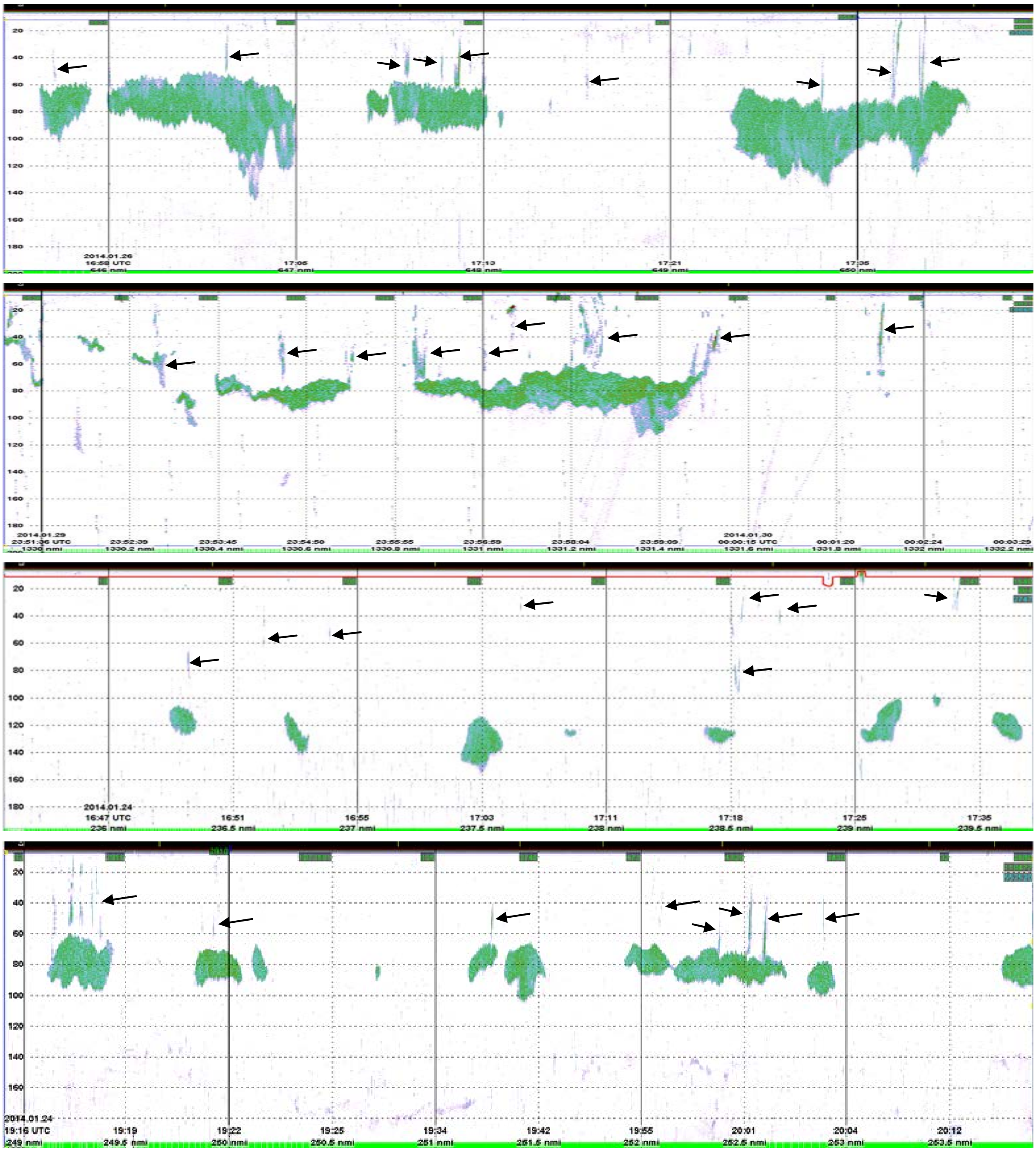


Figure 6: *Examples of air breathing predators foraging on krill swarms.*

Biological sampling

Of the total number of 30 trawl stations, two hauls contained no macro-zooplankton (Figure 7). Euphausiids dominated in the total catch with *E. superba* as the dominating species (Figure 8). A total of 26 stations contained specimens of *E. superb* and *Thysanoessa macrura* occurred at twenty stations. *Salpa thompsoni* was found at 14 stations. Amphipods were also common in the catch. Fish occurred in lower abundance compared with previous surveys performed.

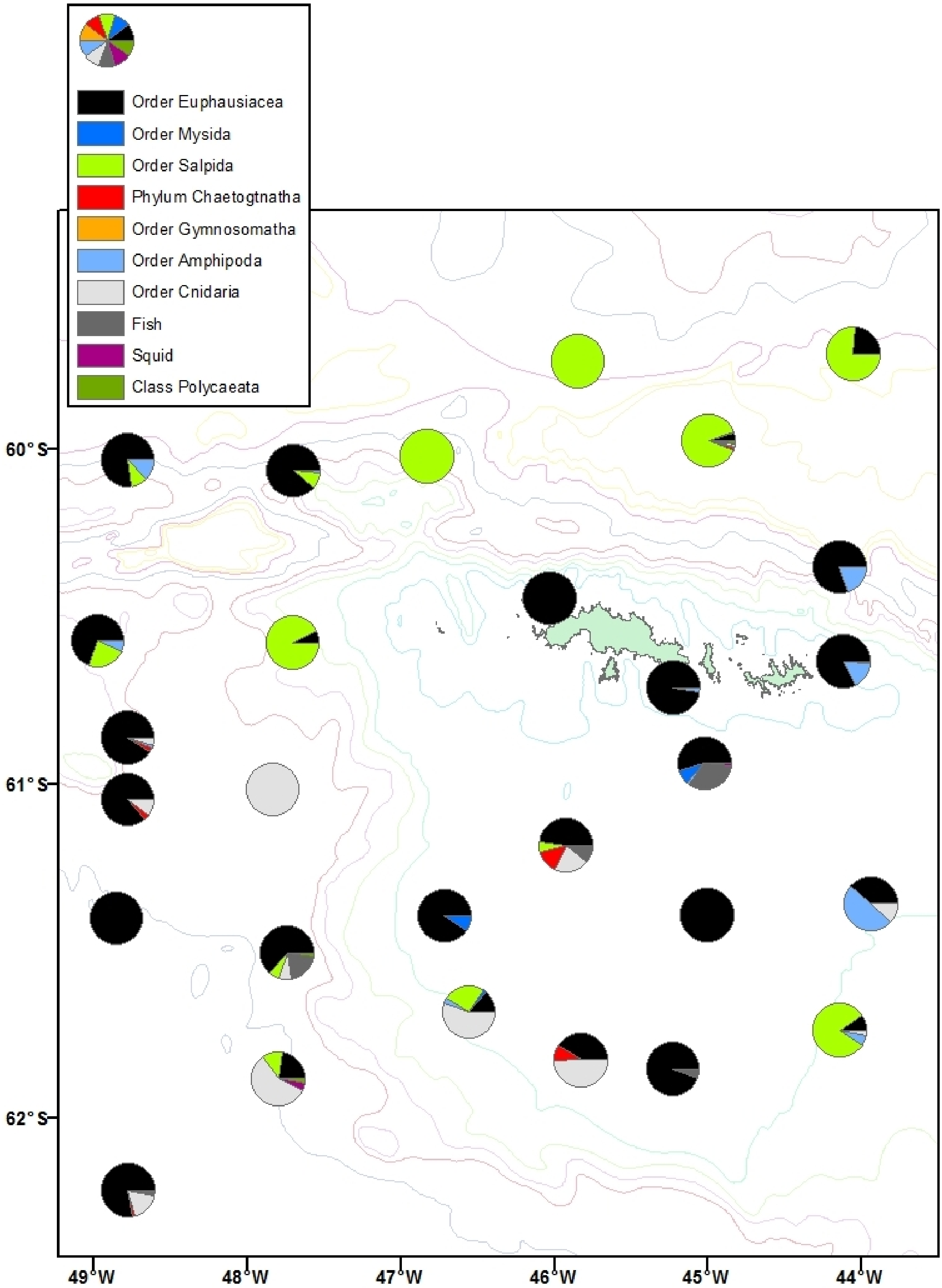


Figure 7: *Proportional (%) composition of Macrozooplankton and micronekton found in the catch from trawlstations at South Orkney Islands, January 2014.*

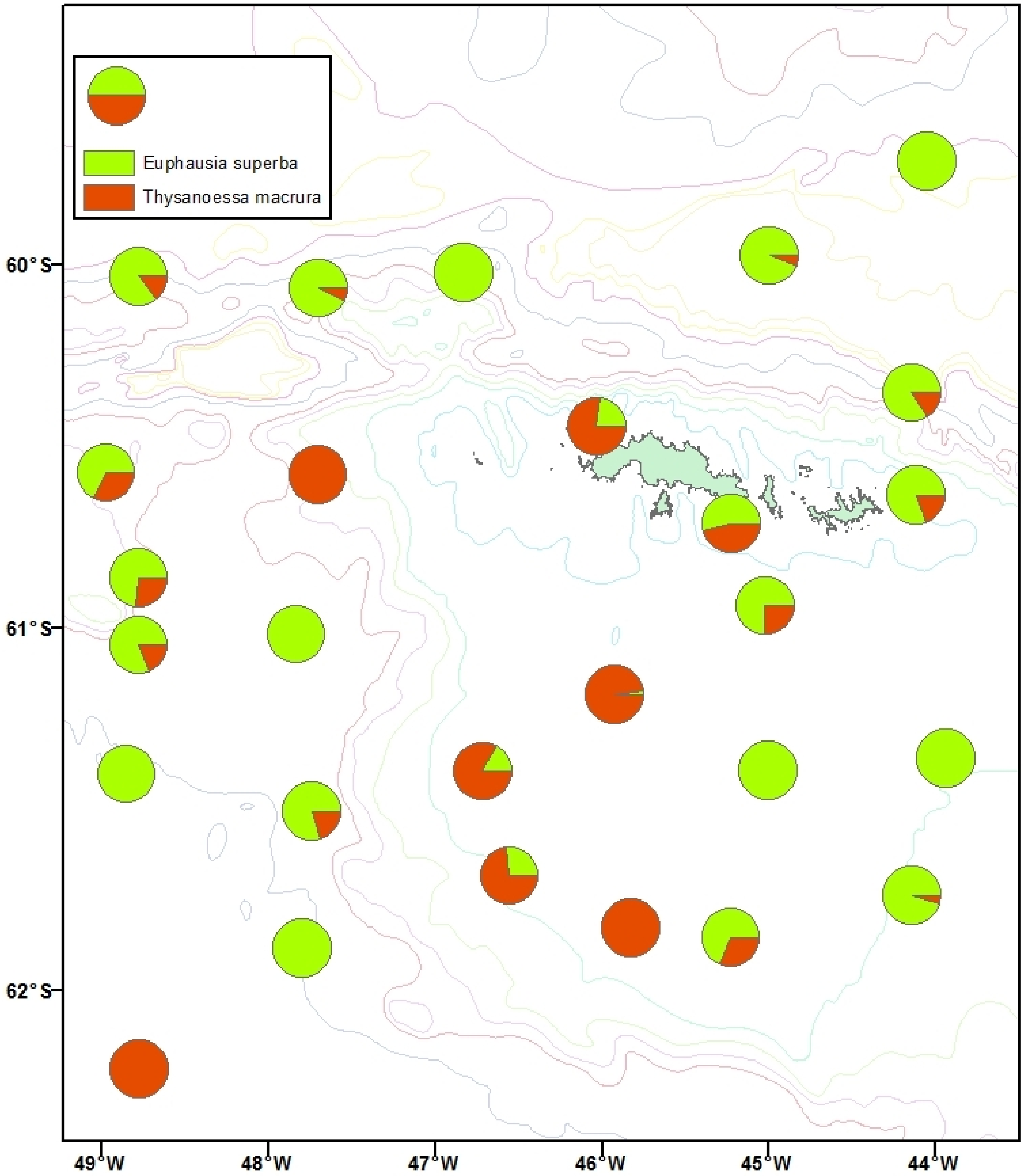


Figure 8: *Distribution and the proportional (%) composition of species of the Order Euphausiacea found in trawl catches performed at South Orkney Islands, January 2014.*

Table 2: Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctic krill caught in the South Orkney Islands area, in January 2014.

Krill	No.	Proportion	Total length
Juvenile stage 1	70	4.1	31.1 ± 2.7
Male subadult MIIA1	153	9.1	35.4 ± 2.6
Male subadult MIIA2	149	8.8	39.5 ± 3.3
Male subadult MIIA3	70	4.1	43.8 ± 2.9
Male adult MIIIA	178	10.5	45.1 ± 4.0
Male adult MIIIB	250	14.8	48.4 ± 3.6
Female subadult FIIB	146	8.6	37.8 ± 3.6
Female adult FIIIA	99	5.9	42.7 ± 3.9
Female adult FIIIB	138	8.2	44.9 ± 3.9
Female adult FIIIC	255	15.1	45.4 ± 3.9
Female adult FIIID	181	10.7	46.6 ± 3.8
Female adult FIIIE	40	2.7	46.4 ± 3.7
Total	1689		

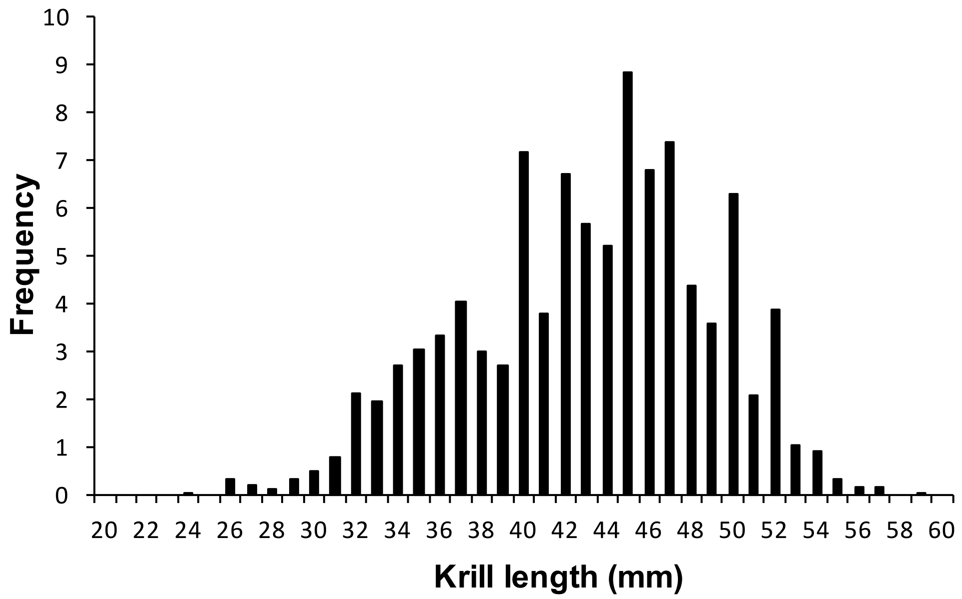


Figure 9: *Length frequency distribution of Euphausia superba, caught using a macroplankton trawl during survey in the South Orkney island waters, 2014.*

The average body size of *E. superba* was 43.1 ± 5.9 mm, ranging between 24-57 mm (Table 2, Figure 9). The sample comprised 4.1% juveniles, 30.7% subadults and 65.2% adults, with a male versus female sex ratio close to 1:1 (48.2% males and 51.8% females) (Figure 9 and 10). Adult males at stage MIIIB (14.8%) (petasma as for MIIIA, ductus ejaculatori has spermatophores that can be pressed out, or with the duct passage open where spermatophores already are deposited), and adult females at stage FIIIC (15.1%) (also with spermatophores, mature eggs or large ovaries visible under carapax, but carapax is not swollen) dominated in the trawl catches (Table 2).

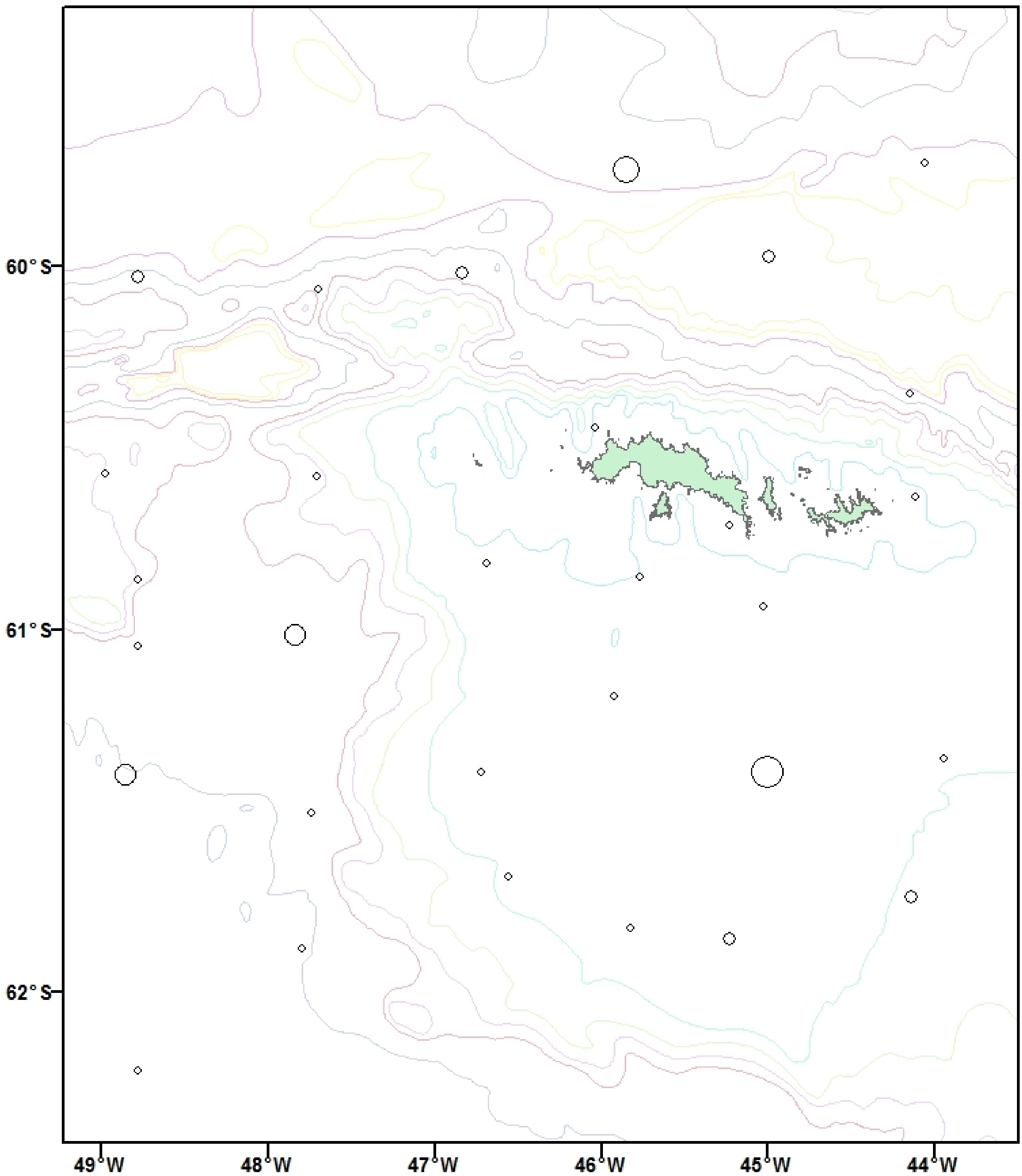


Figure 10: *Total catch (log transformed data) from trawl stations performed in the South Orkney Island waters, 2014.*

Marine predator observations

A total of 19 species of marine predators were recognized (Table 3). Notable species included 87 fin whales observed along the cruise tracks, 42 humpback whales, 418 Antarctic fur seals, 1568 southern fulmars, 2230 chinstraps and 20 Adelie penguins (Table 5 and Figure 13).

Table 3: *Numbers of observations and sightings of marine mammals and seabirds during January 2014 at South Orkney Islands.*

Species	**Count of Observations**	**Count of animals**
Antarctic fur seal	324	418
Fin whale	35	87
Humpback whale	21	42
Southen bottlenose whale	-	-
Southern right whale	-	-
Southern fulmar	97	1568
Antarctic petrel	1	10
Antarctic prion	162	1374
Antarctic tern	4	4
Black-browed albatross	156	171
Black-bellied storm petrel *	-	-
Cape petrel	222	2205
Grey-headed albatross	17	17
Light-mantled sooty albatross	25	25
Chinstrap penguin	448	2230
Adelie penguin	11	20
Southern giant petrel	166	195
Sheathbill	6	13
Skua	10	10
Snow petrel	23	78
Wandering albatross	9	10
White-chinned petrel/Southern shearwater	208	243
Wilson's storm petrel *	-	-
Unidentified albatross	1	1
Unidentified penguin	-	-
Unidentified storm petrel *	166	339
Unidentified seal	-	-
Unidentified whale	17	27

* Mostly identified storm petrels were Wilsons storm petrels, but we were not able to identify more than a few properly.

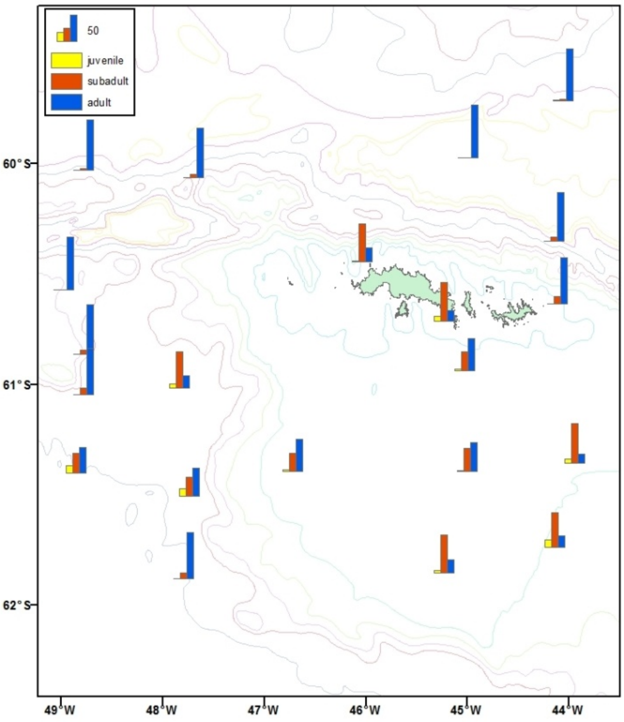


Figure 11: *Distribution of the maturity stages of* E. superba *captured during January 2014 in the South Orkney Island waters (included stations with sample size >50 ind.).*

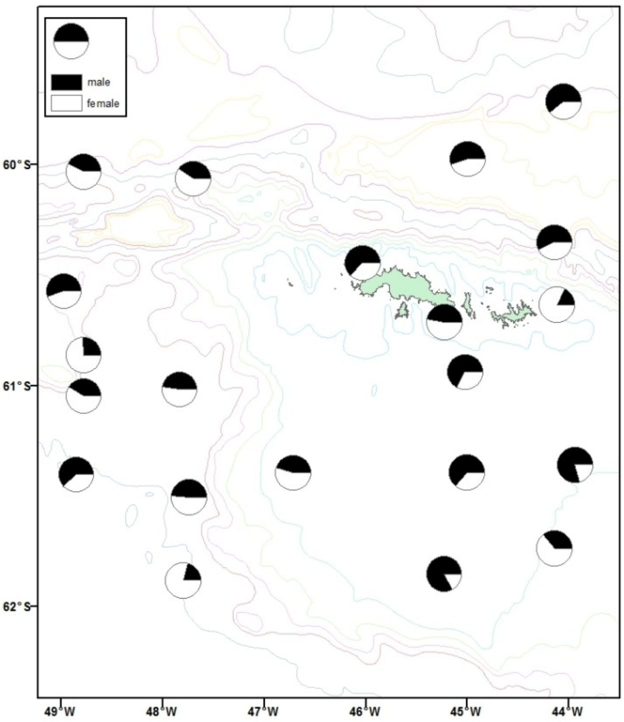
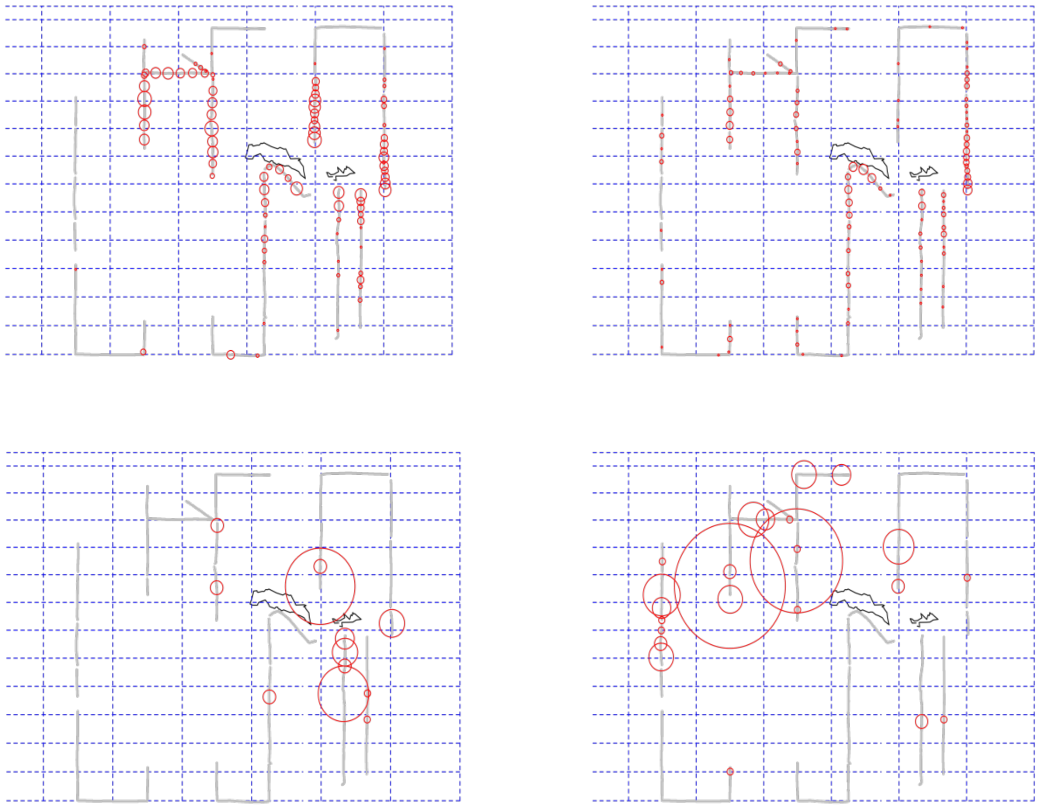


Figure 12: *Distribution and proportion of* E. superba *males and females from the trawlstations made in January 2014 in the South Orkney Island waters (included stations with sample size >50 ind.).*



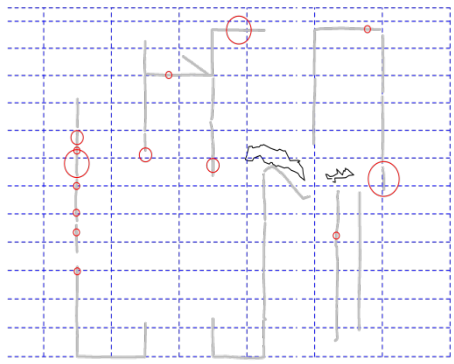


Figure 13: *Observations of Antarctic fur seals (*Arctocephalus gazella*) (upper left, log transformed counts), chinstrap penguins (*Pygoscelis antarcticus*) (upper right, log transformed counts), humpback whales (center left), fin whales (*Balaenoptera physalus*) (center right) and unidentified whales (lower). Counts have been summed over 30 minute periods, and trackline surveyed is indicated in grey.*

Acknowledgements

We extend our gratitude to Aker BioMarine ASA for providing “Saga Sea” and its crew for disposal to this survey free of charge. We are most grateful to the captain, officers and crew onboard the vessel for all the help to solve many technical and practical challenges during the cruise. We also thank Stephen Westcott (MRAG, England) for time and effort put into the collection of predator data.

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