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Cruise report 2019828 - FV «Cabo de Hornos»

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Georg Skaret, chief cruiser

Background

This survey was conducted as part of an international effort to monitor krill in the Scotia Sea.

The aim of the joint effort was to 1) derive an estimate of abundance for Antarctic krill in the survey area, i.e. the subarea recognised as the primary distributional range of krill within Area 48, 2) to compare and contrast density distribution patterns of krill between the surveys in 2000 and 2019, 3) to compare distributions of krill and other biota in relation to oceanographic conditions, with particular focus on potential effects of climate variation and change, and 4) to enhance spatially and temporally relevant knowledge on interactions between krill and apex predators and the potential impacts of krill fishing (WG-EMM, 2018).

The survey was following the design and protocol used for the CCAMLR 2000 survey with a few exceptions (Fig. 1). See SC-CCAMLR (2018a, 2018b and 2018c) for more detailed information on the survey. The Association for Responsible Krill fisheries (ARK) agreed to contribute 42 survey days to the joint monitoring effort and rented the Chilean fishing vessel 'Cabo de Hornos' to be used as monitoring platform.

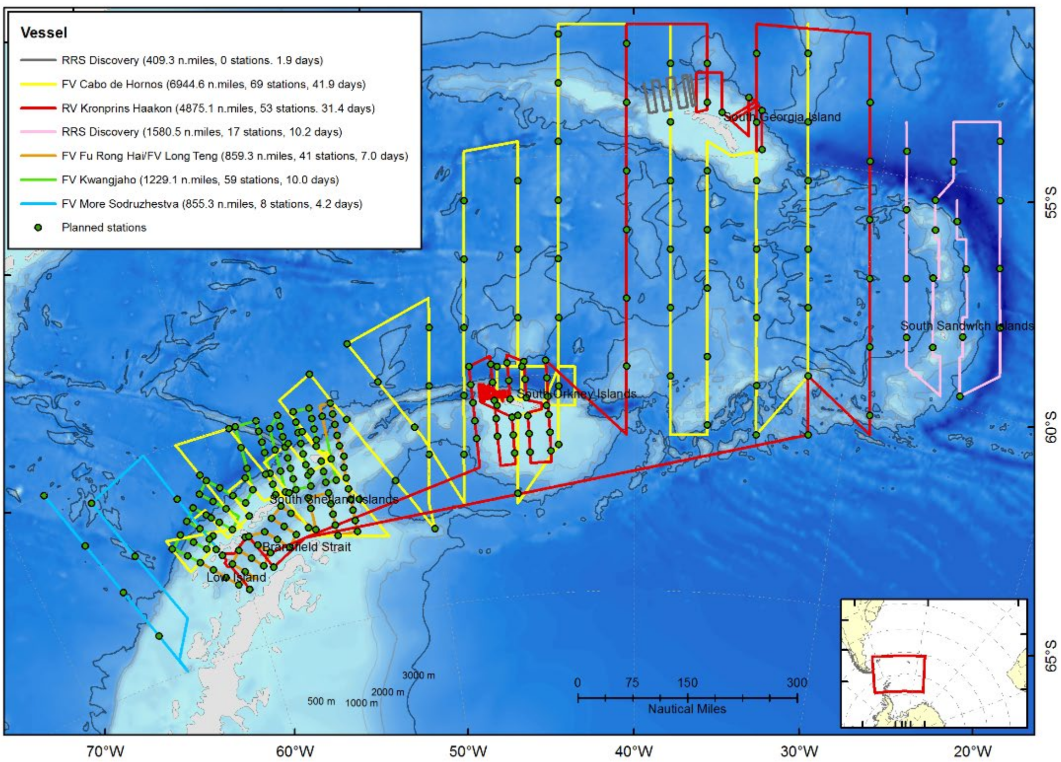


Fig. 1. Planned survey transects for all vessels participating in the 2019 Scotia Sea krill monitoring effort.

Material and methods

Vessel, timing and survey speed

FV ‘Cabo de Hornos’ is a 72.4 m long and 13.5 m wide, 2564 Hp commercial trawler (Fig. 2). The vessel left port in Punta Arenas on the 8 January 2019, and after calibration of the acoustic equipment, the vessel started on the first transect on the 16 January. Problems with the system controlling Revolutions Per Minute (RPM) of the engine were discovered on the 8 February north of the South Orkneys. The vessel needed to return to Maxwell Bay where a technician had been flown down from Spain. After ca. 2 days of reparations, the vessel could return to the monitoring work. In total 9 days had been lost, but the survey was extended and last day of return was set to 14 March in the morning.

Fig. 2. F/V ‘Cabo de Hornos’.

Navigation on transects

The vessel navigated after waypoints used for the CCAMLR 2000 survey. Waypoint positions relevant for the planned transects were extracted for every 25 km from the BAS site http://www.nerc-bas.ac.uk/public/mlsd/synoptic/index.htm The waypoints were converted to .gpx-format and imported to MaxSea navigation software on the bridge. Since the officers mostly used the TurboWin software for practical navigation, the waypoints were entered manually into this software as well.

Recordings of metadata

Metadata were collected every six hours at 6, 12, 18 and 24 UTC and followed the recommendations from ASAM (SC-CCAMLR, 2018c). The measurements taken were wind speed in knots, wind direction referred to true north (0°T), sea state (Beaufort scale code 0-12, see table in Appendix I), ice cover (Code 0-9, see table in appendix), cloud cover (Total fraction of the sky covered by clouds of all types in eighths of the sky. Code 0-9, see table in appendix A1), and outside air temperature in Celsius degrees. Wind speed was measured manually on the outside of the wheel house using a handheld wind meter. Collection of environmental metadata were done by marine mammal observer George McCallum during local daytime (12, 18 and 24 UTC), and by the officer in charge on the bridge during local night-time.

Acoustic data collection and processing

Equipment and settings

‘Cabo de Hornos’ is equipped with Simrad EK80 echosounders operating two frequencies (38 kHz; ES38B and 120 kHz; ES120-7). The transducers are hull positioned close to the bow of the vessel (See Fig. 3). The echo sounder settings used are shown in Table 1.

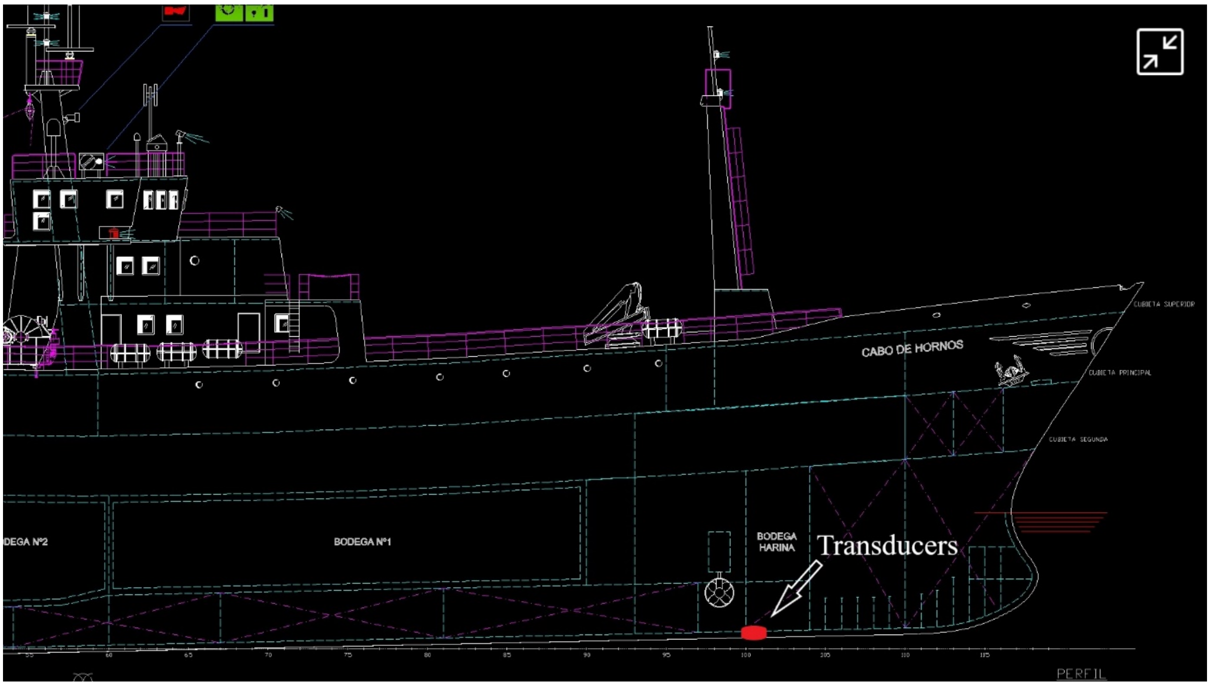


Fig. 3. Positioning of the transducers on board the ‘Cabo de Hornos’.

Table 1. Echosounder settings used during the survey.

Transducer type	**EK38**	**EK120**
Transducer depth (m)	4	4
Transducer power (W)	2000	250
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB/m)	0.01	0.027
Sound speed (ms^{-1})	1454	1454
Sample distance (m)	0.02908	0.02908
Two-way beam angle (dB)	-20.7	-20.7
s_V transducer gain (dB)	27.30	26.85
s_A correction (dB)	0.02	-0.03
Angle sensitivity alongship	23	23
Angle sensitivity athwartship	23	23
3 dB beamwidth alongship (deg)	6.97	6.59
3 dB beamwidth athwartship (deg)	6.97	6.65

Calibration

Calibration of the acoustic equipment was first attempted in Admiralty Bay, but drift ice entangling with the calibration wires caused problems, one sphere was lost, and calibration had to be suspended. In Potter Cove in Maxwell Bay, there were no ice and a full sphere calibration was carried out on the 15 January 2019. A new calibration was done during the reparation work in Potter Cove, Maxwell Bay on the 12 February, and finally a calibration was done in Cumberland Bay, South Georgia on the 3 March. After internal discussions among acousticians at the institute it was concluded that the first calibration was not ideal since a shackle was mounted above the sphere. Even if the shackle was small and mounted 7 m above the sphere it might have disturbed the transmitted signal and received echo. During the second calibration, the shackle was mounted below the sphere. During the last calibration, conditions were excellent, and no shackle was needed. During this last calibration we also had the best beam coverage, so the results from this calibration were used for integration. Calibration results are shown in Appendix II.

Noise

All interference noise due to instrument cross-talk was eliminated by switching off Furuno sonar and echosounder. Uninterruptable Power Supplies were set up for the Wide Band Transceivers (WBTs), and noise due to electrical interference on 38 kHz was strongly reduced. Overall, air bubbles in high seas were the most severe source of reduced acoustic data quality. On the 120 kHz, long vertical stripes or spikes extending from the bottom of the echogram towards the upper water column appeared under such conditions. On the 38 kHz these conditions caused attenuation or ‘empty’ pings. The frequency and strength of the noise were strongly weather dependent, and worst when the vessel was moving with heavy swell against the bow. Reduced speed under such conditions typically improved data quality some, and we attempted to adjust survey speed to ensure some progress while maintaining reasonable data quality. Preliminarily, the noise was filtered out during data processing (see details in the next section), but the appropriate filtering procedure needs to be discussed further in a larger expert group.

Processing

All acoustic data were processed using the Large Scale Survey System (LSSS; Korneliussen et al. 2016). All data were processed in KORONA and the processing included spike filtering and bottom detection. Details about the settings are found in Appendix III. As noted in the previous section, there were issues with the data which would need to be discussed in the CCAMLR community, in particular the method used for target discrimination (swarm-based method versus frequency response), and methods for noise removal.

The recommended CCAMLR method for target discrimination requires data from the frequencies 38, 120 and 200 kHz and uses frequency response to distinguish krill from other targets. We only collected data at 38 and 120 kHz. However, the response from these two frequencies can still be used for target discrimination, which has been validated in several studies (e.g. Madureira et al. 1993 and Watkins and Brierley, 2002). Targets which fall within a specific range of ΔS_v-values ($S_{v,120} – S_{v,38}$) will then be identified as *E. superba*. The method was applied on sample bins of 514 m horizontal*5 m vertical resolution (CCAMLR standard assuming 50 pings at 10 knots survey speed and a ping repetition rate of 2 sec^{-1}). The minimum and maximum ΔS_v-values defining the krill identification 'window' were calculated using the 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 in 10 mm bins from the trawl samples where 95 % of the length frequency 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.

Points to be aware regarding the acoustic data

There are some points one needs to be aware when analysing the acoustic data. The echo sounder clock was adjusted to UTC-time, but not synchronised with GPS-time. This is an internal pc clock, and it drifted during the survey. On the 07.02 the clock was running 4 minutes and 5 seconds late, and on the 09.03 4 minutes and 30 seconds. With even drift this means 0.83 seconds per day. The offset and drift were discovered too late to handle during the survey, and the clock was let to run.

The logger was not set to 0 at the start of the survey, but was reset to 0 at a later stage by a mistake. The logger should therefore not be used directly as for instance indication of sailed distance.

The echosounder draft (4 m) was set in EK80 at the beginning of the survey, but in the incorrect menu. This was discovered on the 20.01 and corrected. Prior to this date, the actual draft as it turned out had been set to 0 m.

Deployment of acoustic moorings

The Signature 55 had been deployed for a year. This instrument had been subject to a battery leakage immediately prior to deployment last year. The spill had been cleaned up and a new battery put in, but it was an open question whether the leakage still might have influenced the data collection. The instrument was successfully recuperated but on deck it was not possible to establish contact with it to see if it had been logging data. It was taken apart and proven that no data had been logged. By first sight after the instrument had been opened, the electronic seemed to be unaffected by any battery acid leakage. However, closer inspection showed that one of the three connectors on the communication printed circuit board (pcb) had been destroyed by the acid. After repairing the broken cable and cleaning up the all the pcb's with fresh water we were able to establish contact with the instrument. But a final test of data collection and storing to the SD card failed. Several e-mails between us and the service technician at the factory did not improve the situation. The electronic part, except transducers and sensors, will be sent to the factory for repair.

Four instruments were deployed, and an overview of the deployment positions is found in Fig. 4. Detailed information on the deployment is found in Appendix IV. The ASL mooring was deployed at the inlet of 'Small Canyon' at position 60˚24.2625 S and 45˚57.9522 W at 497 m bottom depth and 292 m instrument depth. The Signature 100 was deployed on the western edge of the plateau north of 'Big Canyon' in position 60˚12.3399 S 46˚31.8146 W at 1094 m bottom depth and 234 m instrument depth. The other Signature 100 was deployed together with a SBE37 CTD in 'the big Canyon' position 60˚25.2993 S and 46˚38.0601 W at 480 m bottom depth and 270 m instrument depth. The Aural M2 hydrophone was deployed upstream at position 60˚35.2487 S and 44˚10.4422 W at 685 m bottom depth and 365 m instrument depth. This was supposed to be deployed together with the Signature 55, but the latter was not ready to be deployed due to the technical problems mentioned above.

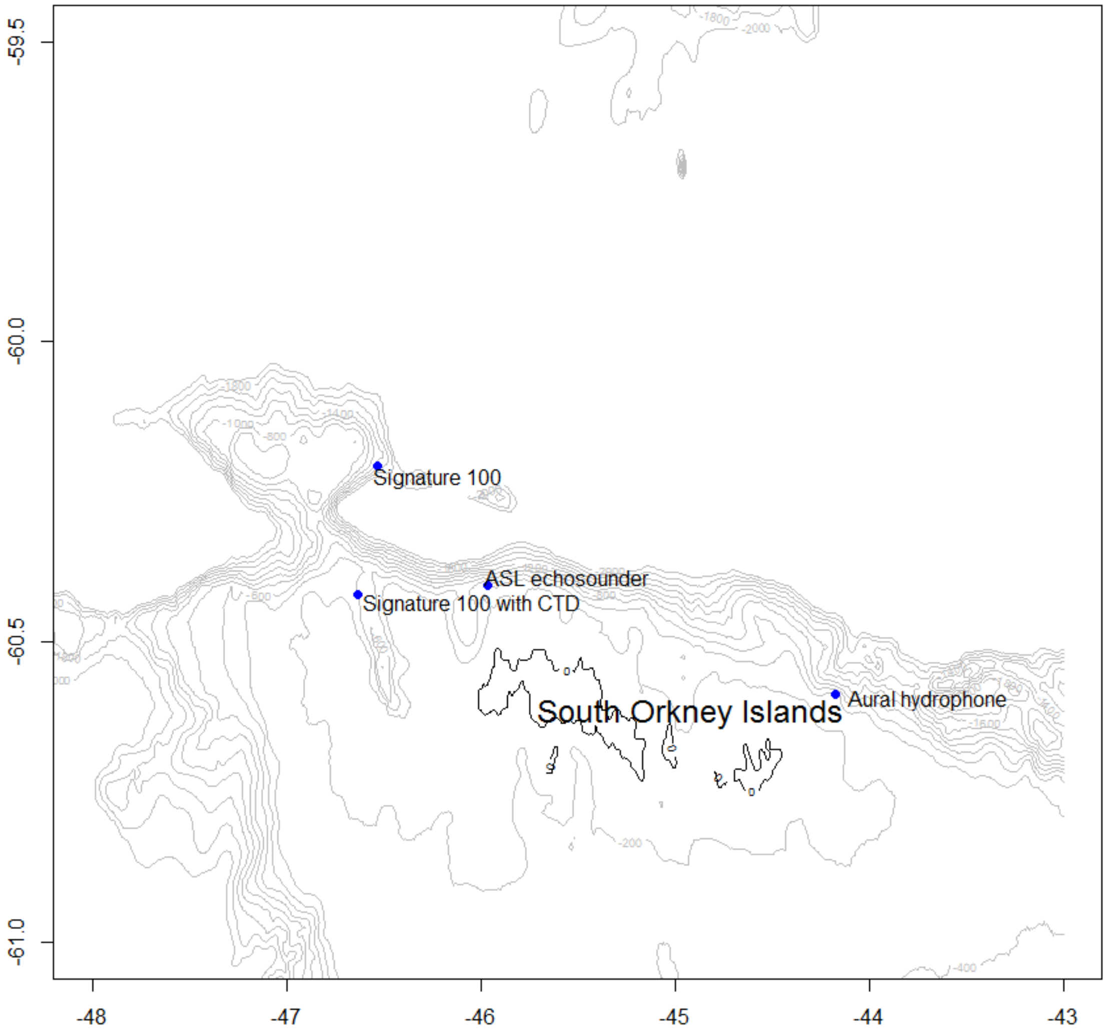


Fig. 4. Overview of mooring positions.

Biological data collection and processing

Trawl sampling

The trawl used for biological sampling had 7 mm meshed inner net made of polyamide (PA), 140 mm meshed PA net in the mouth, and 200 mm meshed outer support net in polyethylene (PE). The trawl was rigged in a similar manner as described in Krafft et al. 2018, but with some modifications (See figure 5). The trawl beam was mounted with chains distributed on both sides of the centre shackle along the length of the beam and the beam was also thicker than the original. Also, the weights on the trawl wings were distributed along the lower warps instead of wing tips. Normally during application in the South Orkney surveys, one trawl wire is mounted on the centre shackle of the beam. In our case, the trawl drum midships could not be used because our two containers were welded to the deck in the trawl path. We therefore used the two drums on each side of the vessel with the port wire connected to the port end of the beam and starboard connected to starboard end. In sum, trawl performance was very stable, and no obvious problems were experienced during any of the trawl hauls. A full trawl set including beam was brought along as a backup, but not used.

The trawl sampling for the most part followed the recommendations in Knutsen et al. 2018. Biological sampling was done with a krill trawl at local noon and midnight. However, if local noon or midday occurred during transits between transects, the trawl haul was done immediately prior to leaving a transect or immediately after entering a transect. On some occasions we also did target hauls in areas when the acoustics indicated significant aggregations of krill, but no *E. superba* were caught in the samples.

The trawl was lowered to approximately 200 m depth or ca. 20 m above the bottom at shallower depths. A ship speed of ca. 2 knots was maintained while hauling, and a wire speed of ca. 20 m/min. All hauls were monitored using a Marport trawl sensor and a CTD mounted on the beam. The haul profiles are shown in Appendix V.

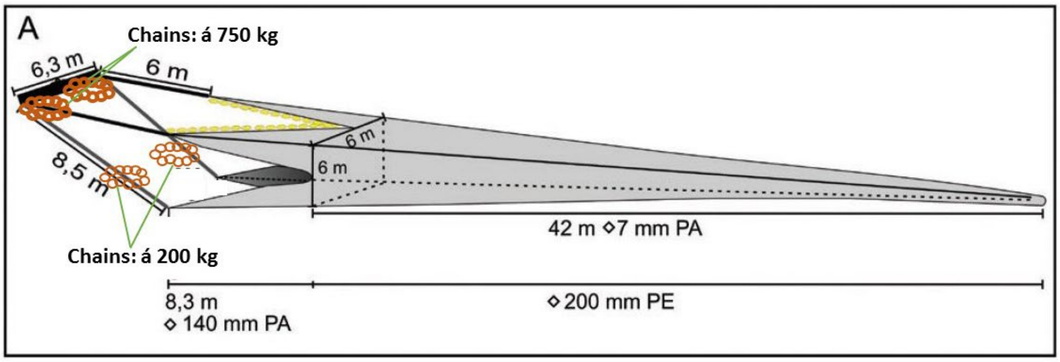


Fig. 5. Schematic drawing of the trawl dimensions and rigging.

Work-up of samples

The total weight of the net catch was measured. For catches with a total volume of less than 1 kg, the total sample was sorted. All the krill and salp specimens were counted and measured, and number of each taxonomic category weighed, immediately after the catch. The rest of the zooplankton were identified to the species level and counted, weighed and/or stored in 4% buffered formalin solution or 96 % Ethanol for later analyses. Samples that were too large to be sorted completely were subsampled by weight immediately after the catch, but first after analyzing and handling the larger components of the catch, e.g. fish, jellyfish or cephalopods if present. Due to differences in catch composition, the subsampling followed one out of two procedures:

• if the sample size was larger than 1 kg and the sample mainly consisted of krill, the total drained sample weight was first determined and recorded. Then a ca. 1 kg random subsample was taken from the total sample and all krill and salp specimens were counted from this subsample. For the remaining zooplankton fraction we followed the instructions noted above.

• if the sample size was larger than 1 kg and the sample mainly consisted of salps, we first measured the total drained sample weight, then sorted out all krill from the total sample, and counted and measured this (for measurement procedures see below). Finally, a subsample of ca. 1 kg, was taken randomly from the total sample and all salp specimens were counted from this subsample. For the remaining zooplankton fraction we followed the instructions noted above.

In addition, random subsampling of catches was undertaken and fixated in 4 % formaldehyde neutralized with borax.

Volume and weight measurements of krill
Wet weight of krill in the samples were weighed on fine scale Marel balance with an accuracy of 0.1 gram. For the first samples, the fine-scale balance was not available, and a 1 g resolution balance was then used.

Length measurements of krill
Krill total lengths were measured in mm according to the Discovery method (AT) from the anterior margin of the eye to the tip of the telson without the terminal spines. All measurements were done by one person to remove observer variation. In samples which contained less than 150 krill, all individuals were measured, and maturity stage identified. For larger krill catches a minimum of 200 krill were measured and staged.

Maturity staging of krill
Krill sex and maturity stages were identified using the classification of Makarov and Denys (1981, BIOMASS Handbook): Males are separated into three sub adult stages: MIIA1 (petasma vesicles are not divided, but appear as a small “bump” or “bubble” at the root), MIIA2 (petasma has developed the “bubble” to a split with one or two “fingers”), and MIIA3 (petasma root with two short “fingers” and an incipient formation of “wings” on the opposite hold), and two adult stages: MIIIA (petasma fully developed, with swollen “fingers” and with a “wing” overlap, ductus ejaculatori are also visible ventrally, but these are sealed and spermatophores cannot be squeezed out), and MIIIB (petasma as for MIIIA, ductus ejaculatori has spermatophores that can be pressed out, or with the duct passage open where spermatophores are already deposited). Females were separated into one sub adult stage: FIIB (thelycum is small and colorless), and five adult stages: FIIIA (thelycum is fully developed for spawning, red-pigmented and strongly chitinized), FIIIB (thelycum as FIIIA but fertilized with spermatophores), FIIIC (also with spermatophores, mature eggs or large ovaries visible under carapace, but carapace is not swollen), FIIID (with spermatophores, carapace is swollen, and this swelling extends into the first abdominal segment), and FIIIE (fully spawned, the ovaries are small, and the carapace is hollow). Juveniles, unlike all other stages, have no visible sexual characteristics (no visible petasma or thelycum).

Length and weight measurements and staging were done on freshly caught material.

Measurements on salps
All salps were removed from samples smaller than 1 kg and counted. From larger samples a random subsample of 1 kg was taken (see above). A minimum of 150 specimens per species was measured. The internal body length (see SL Figure 1 and Foxton 1966), was measured to the mm below with an accuracy of 1 mm.

Other zooplankton sampled
All other macro-zooplankton was identified to the species level, either from fresh material immediately after the catch or from preserved samples. After sorting the larger organisms from the sample/subsample, the smaller constituents (e.g. krill larvae) were sorted using dissecting microscopes. If possible a full sample or quantitative subsample of other zooplankton should be preserved. Length measurements were also carried out for all other krill species (tip of the rostrum to tip of the telson, mm below, 1 mm size class) and fish species.

Preservation of krill
Samples of krill were preserved for checking or future studies. The following strategy was adopted:
1. a sample of the krill that had been measured and staged was preserved in ethanol for genetic studies. (A minimum of 90% ethanol with a volume 10 times the volume of krill)
2. a quantitative subsample of krill which had not been processed was preserved in formalin as a back-up data set.

Preservation of other zooplankton
A quantitative subsample of other zooplankton was also preserved in formalin whenever possible.

Hydrographical data collection

A Seabird SBE37 CTD was mounted on the trawl beam and set up to log data on temperature, salinity, conductivity and pressure every 10 seconds during each trawl haul.

Marine mammal sightings

Marine mammal observation was done by a dedicated and experienced observer during daylight hours. Observations were done from the starboard side, since visibility here was significantly better than on port side. Primary search area was from 350 degrees Port to 45 degrees starboard, secondary search area from 45 degrees to 90 degrees starboard. Distances to whales were estimated by eye, and random checks on accuracy were made by using a stopwatch and comparing the distances using the ship speed and assuming no animal movement (See speed table at end of report). Distances estimated were seldom more than 200m out on long distances (1500m plus) and 100m out on shorter distances (under 1500m). A slight tendency to overestimate on long distances (>1500m) and a slight tendency to underestimate on short distances (<1500m) was noticed, but seldom outside the limits noted.

Marine mammals were recorded systematically using a modified Discovery protocol which differs somewhat from the normal Norwegian Ecosystem survey protocols, especially in the codes used. Any observations made by the dedicated whale observer were recorded as Code 6, any observations made by other survey personnel/crew were given code 8 and species identified positively by the whale observer. Marine mammals seen off effort were also recorded in the sightings DB and noted accordingly. Any sightings made on transit were also recorded when conditions permitted.

There were no working window wipers which made conditions for observing difficult during rain and snow. Once the rain or snow stopped, the windows were wiped manually. When conditions allowed, periods were spent observing outside in front of the bridge, since viewing conditions were better here.

The Norwegian 'Hval' software was used to record sightings data. A microphone is connected to a laptop which in turn is connected to a GPS. When the microphone is keyed, a Sound file is created with a timestamp and a position from the GPS. Data are then recorded verbally according to the protocol and replayed, and data punched into a database during off effort periods. Underway, there were some challenges when running the 'Hval' software on the computers available, and also with a poor microphone connection. A few effort hours were lost due to this. More details can be found in the survey diary.

Identification photographs of Marine mammals (i.e. humpback whale flukes) were recorded in the Marine mammal sightings DB with Image numbers.

Bird sightings

No protocol had been agreed beforehand with regards to bird sightings, so the protocol was worked out after discussions on board and through personal contact was made with the NPI dedicated bird observer who would be on RV 'Kronprins Haakon' during their second leg to Dronning Maud's Land.

It was decided that marine mammal observations have priority, and that flying birds should be recorded only when entering the field of vision (as opposed to actively searching a 90-degree arc) and the count integrated over 30 minute periods. In areas with middle to high densities of marine mammals, recording of birds was dropped completely by the whale observer. In addition, a snapcount of flying birds 180 degrees behind midships out to 300m was done every half hour.

In addition to underway sightings, birds were recorded behind the vessel at the moment the trawl net was set and when it resurfaced. Observations were done out to 50 m on either side of the stern and 50m behind the vessel. According to the protocol, this should have been done from the stern of the ship but practical conditions (cables, pulleys, winches) made this impractical, so these observations were made from the wing of the bridge or from inside the bridge. The ship has bird scaring devices mounted on both sides of the stern.

Experiments measuring acoustic density contrast (*h*) and sound speed contrast (*g*) in krill

The sound speed (*g*) and density (*h*) of *E. superba* are important parameters going into the model for estimating krill target strength. As part of the Antarctic Wildlife Research Fund (AWR) funded project 'Accurate krill biomass estimation using spatio-temporal acoustic target strength modelling', we carried out sound speed and density measurements on board on fresh krill. The experiments are based on the 'acoustic properties of zooplankton' (APOP) system described in Chu and Wiebe (2005). It is a measuring system that involves indirect measurements, including measurements of the acoustic travel time and densities of fluids with different densities (See schematic overview in Figure 6). More detailed descriptions of system set-up and protocol can be found in Appendix VI.

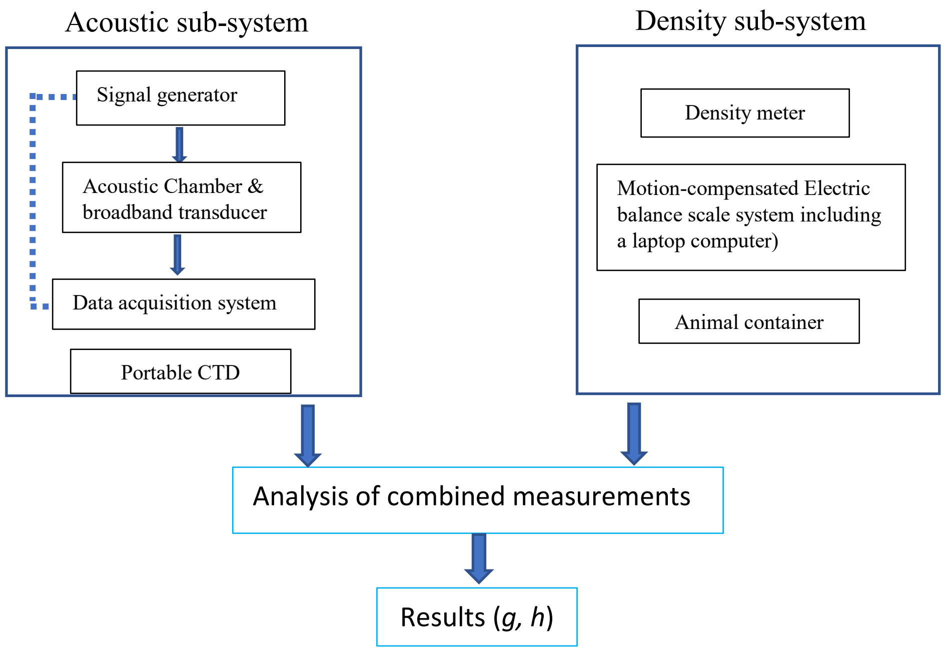


Fig. 6. Diagram of the APOP system.

Results

Survey coverage and progress

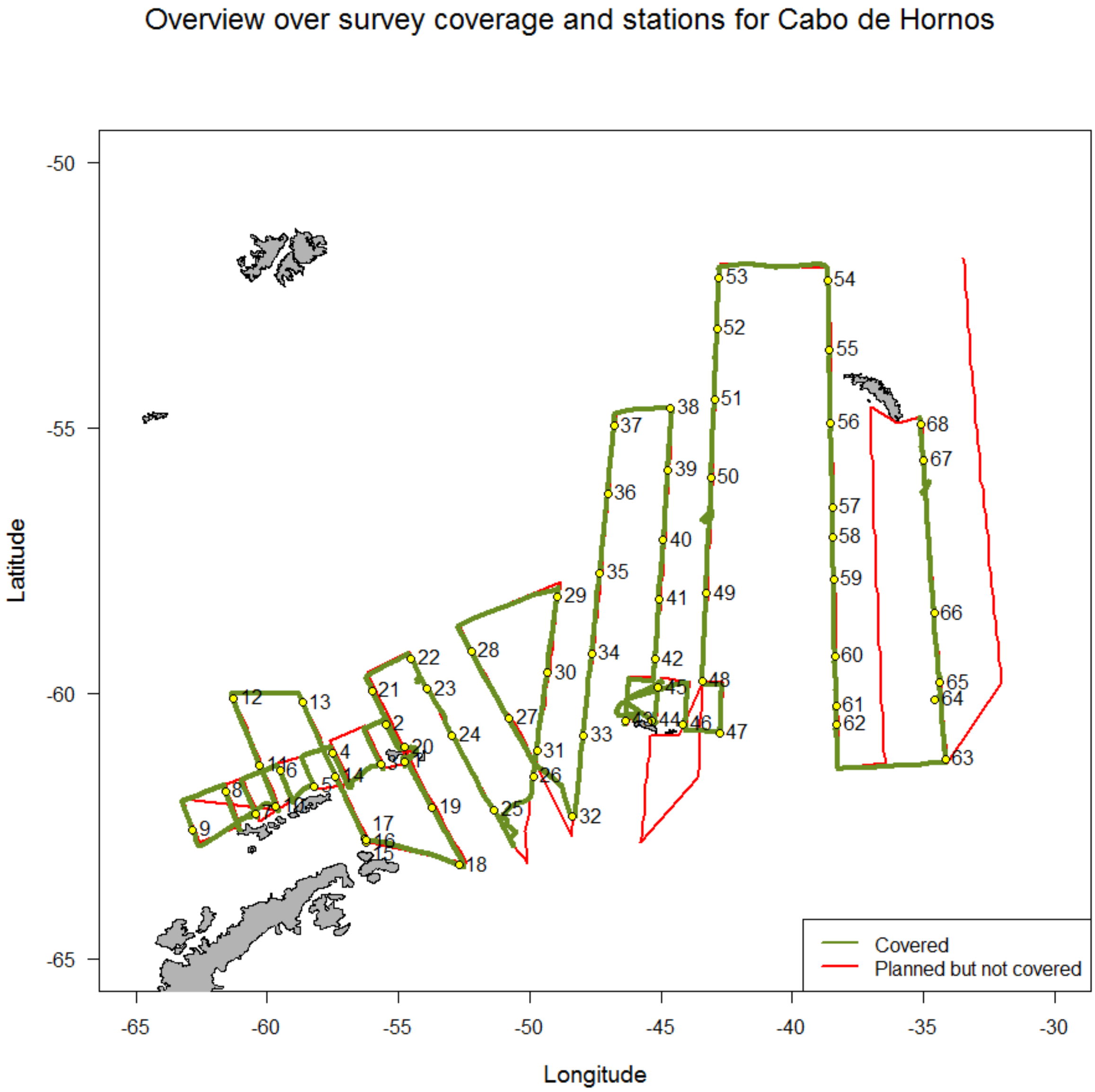


Fig. 7. Overview over planned and covered transects for Cabo de Hornos, and locations and numbering of stations.

Survey speed varied between 4 and 9 knots depending on wind, waves and current. With wind and waves against the bow the vessel needed to slow down to try and maintain decent quality of the acoustic data. On four occasions the vessel needed to stop and await better weather conditions. During the first half of the survey prior to the interruption, the vessel maintained an average speed of 6.86 knots including the trawling but excluding time spent for rig work. During the second part of the survey, an average speed of only 5.78 knots could be maintained, mostly due to bad weather. Approximately 80 % of the planned survey coverage was completed (see figure 7). The progress of the survey is shown in figure 8.

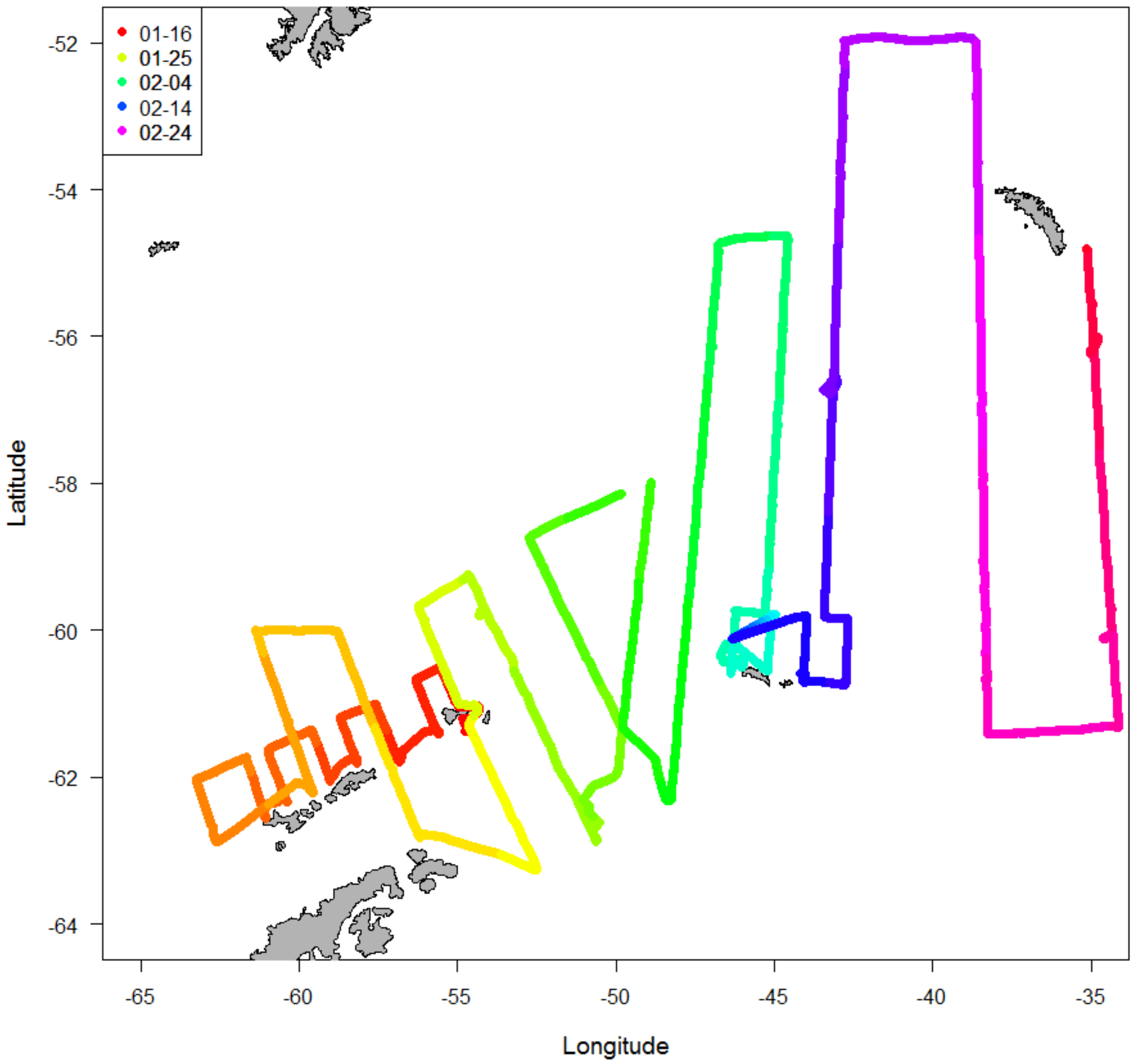


Fig. 8. Survey progress map for the South Shetland section with the colours corresponding to dates given in upper left corner**.** The monitoring of the South Shetland sector started on the 16.01 (red colour) south of the Elephant Island, and the transect work ended in the evening of the 02.03 east of South Georgia. Black dots mark trawl stations with associated station number. Note that there was a 9-day break off between 08.02 and 17.02 due to engine problems.

Environmental conditions (weather and ice)

The weather conditions were mostly decent for surveying in the South Shetland sector of the surveyed area (See figure 9). Only one time the vessel needed to stop and await better weather during this first part of the survey. In the South Orkney sector, there were longer periods with bad weather, and in the South Georgia sector the weather was bad. Three times during this last survey period, the vessel had to stop and await better weather.

There was little ice encountered, occasionally an iceberg in the way would force us to leave the transect for a while, but only in the area south-west of the South Orkneys (between 47 and 51 degrees W) did drift ice force us to turn around and prematurely end a transect (see figure 7).

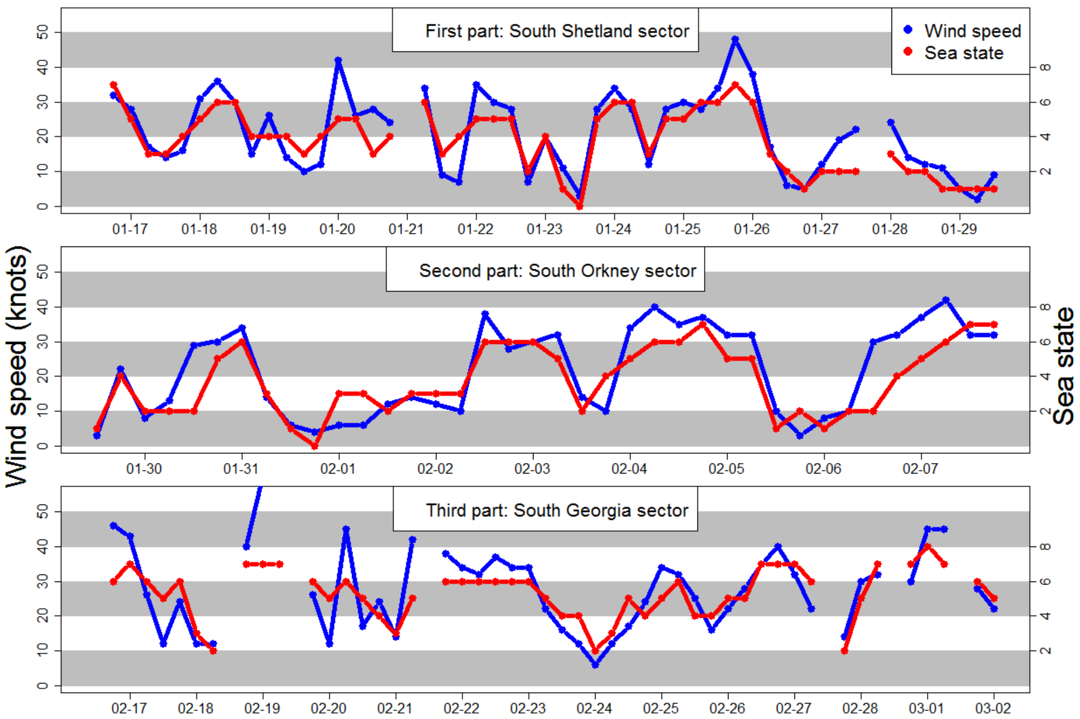


Fig. 9. Wind speed and sea state measured through the survey period.

Hydrographical conditions

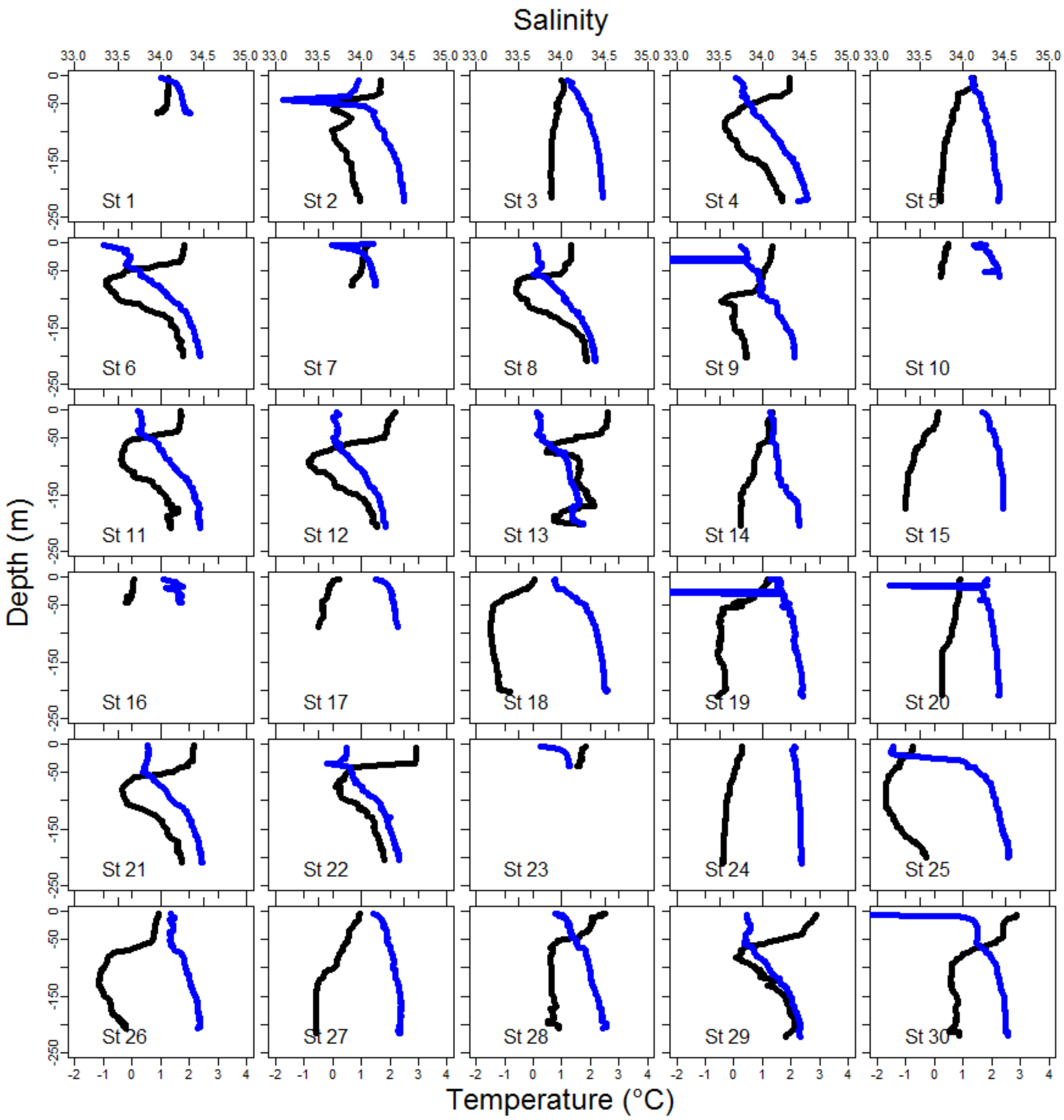


Fig. 10 a) Profiles of temperature (black) and salinity (blue) from the CTD-casts.

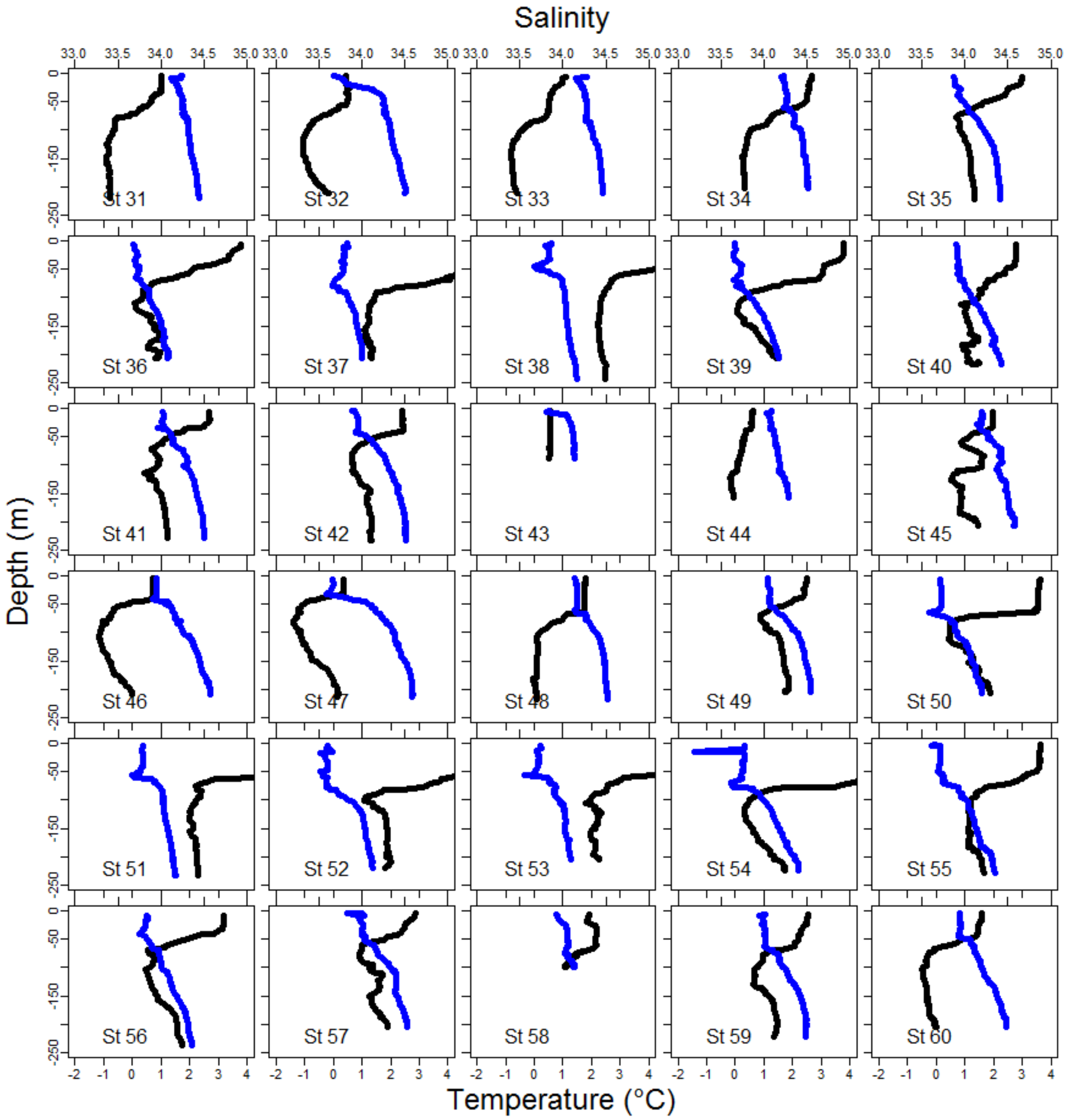


Fig. 10 b) Profiles of temperature (black) and salinity (blue) from the CTD-casts.

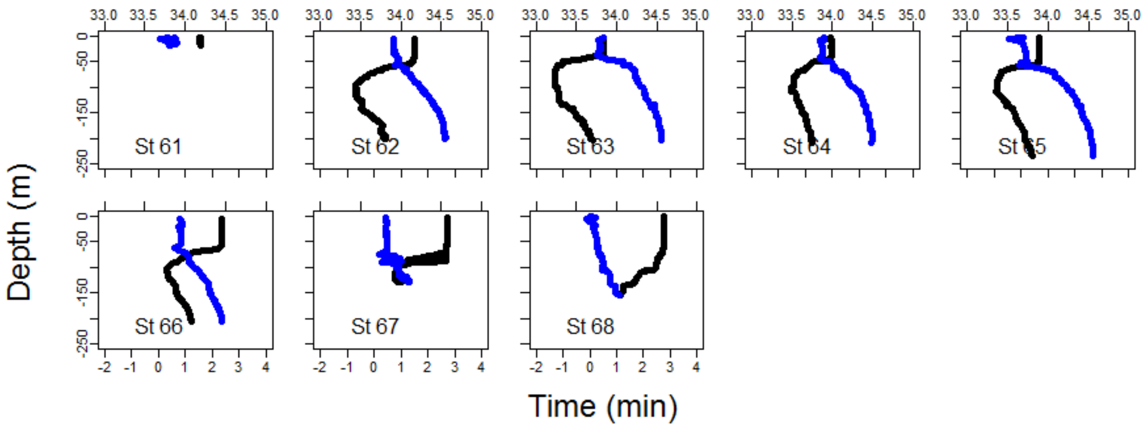


Fig. 10 c) Profiles of temperature (black) and salinity (blue) from the CTD-casts.

Acoustic recordings

The distribution of the krill as indicated from the acoustics is shown in figures 11 a) and b). In the South Shetland section, there was a clear dominance of krill around the shelf, in particular north of the islands. The highest concentrations were found north of the Elephant Island. Krill abundance was in general indicated to be lower in the South Orkney and South Georgia section, but with a few hotspots north of the South Orkneys and south east of the South Georgia.

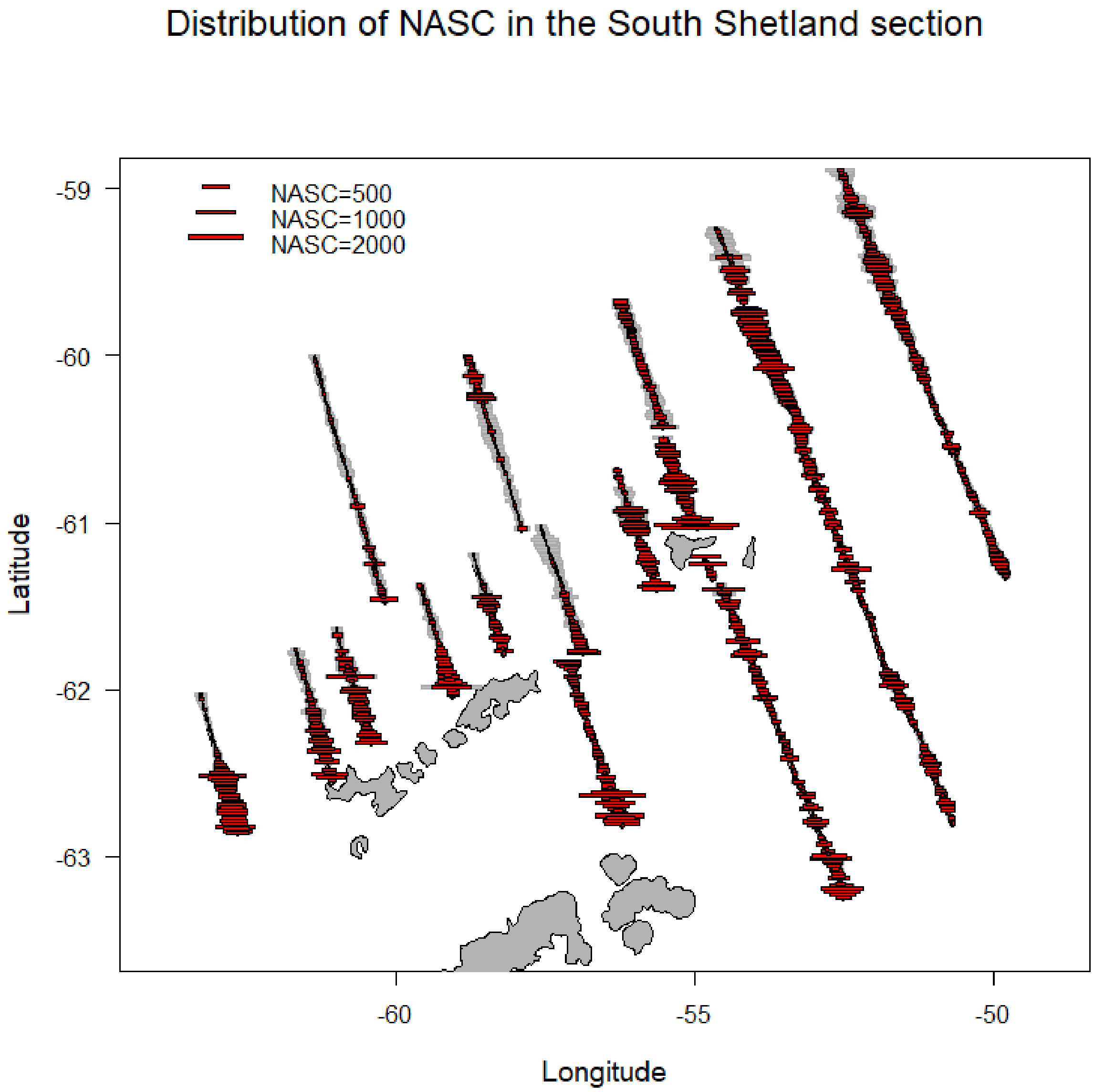
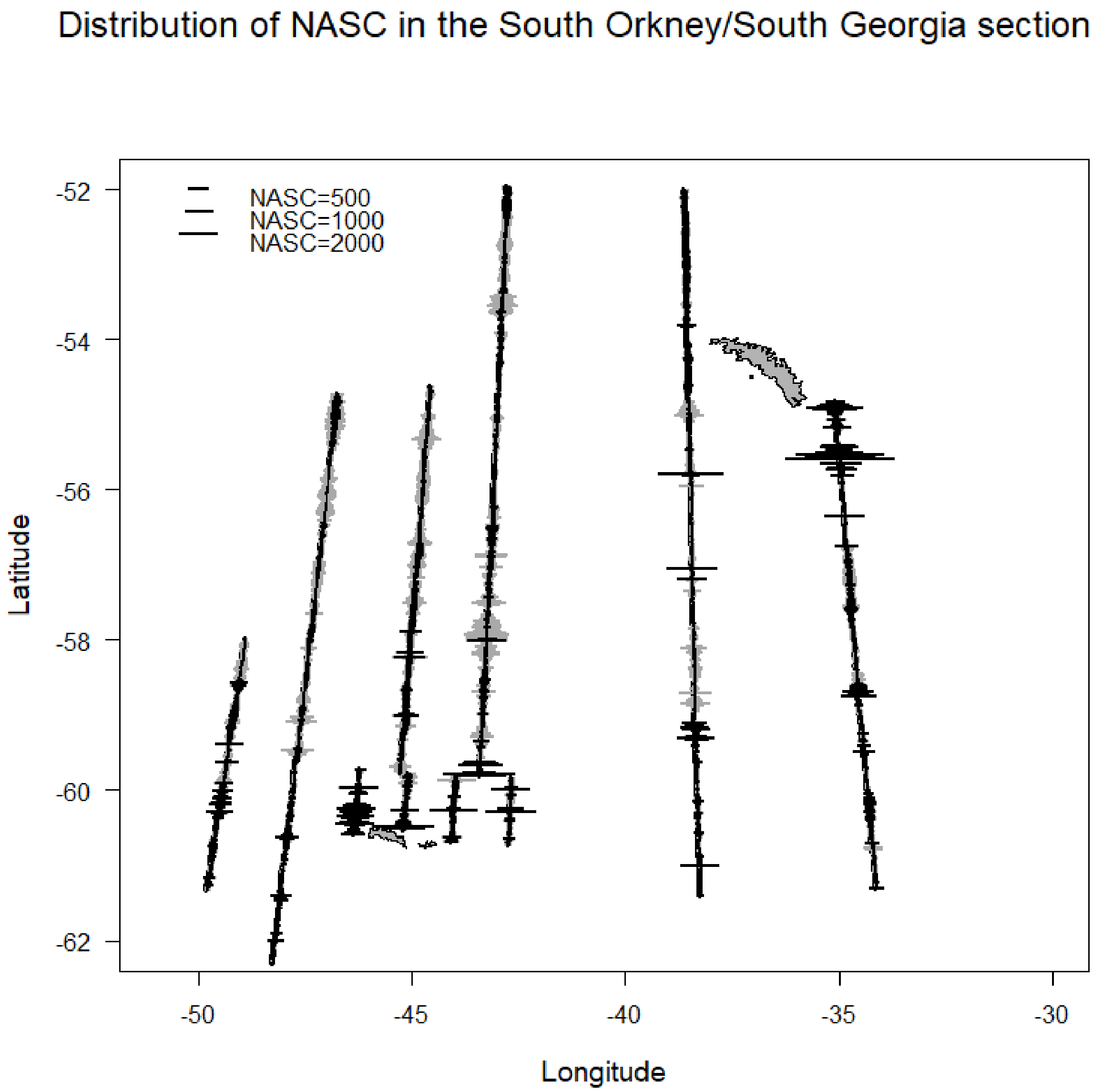


Fig. 11 a) Distribution of acoustic backscatter (Nautical Area Scattering Coefficient; NASC; m^2nmi^{-2}) integrated over 1 nautical mile, allocated to krill (red) and other targets (grey). The NASC-values are square root transformed.



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Biological data

Distribution of target groups in catch

Euphausia superba dominated in the trawl hauls in the stations at or close to the South Shetland Island shelf (See fig. 12 a). In the areas north of the shelf, salps dominated. In a few stations other targets dominated, mostly amphipods or fish. In the South Orkney/South Georgia sector salps dominated in a large sector to the west (See fig. 12 b). *E. superba* dominated the samples north of the South Orkneys and in some stations around the South Georgia. To the east many stations were dominated by amphipods.

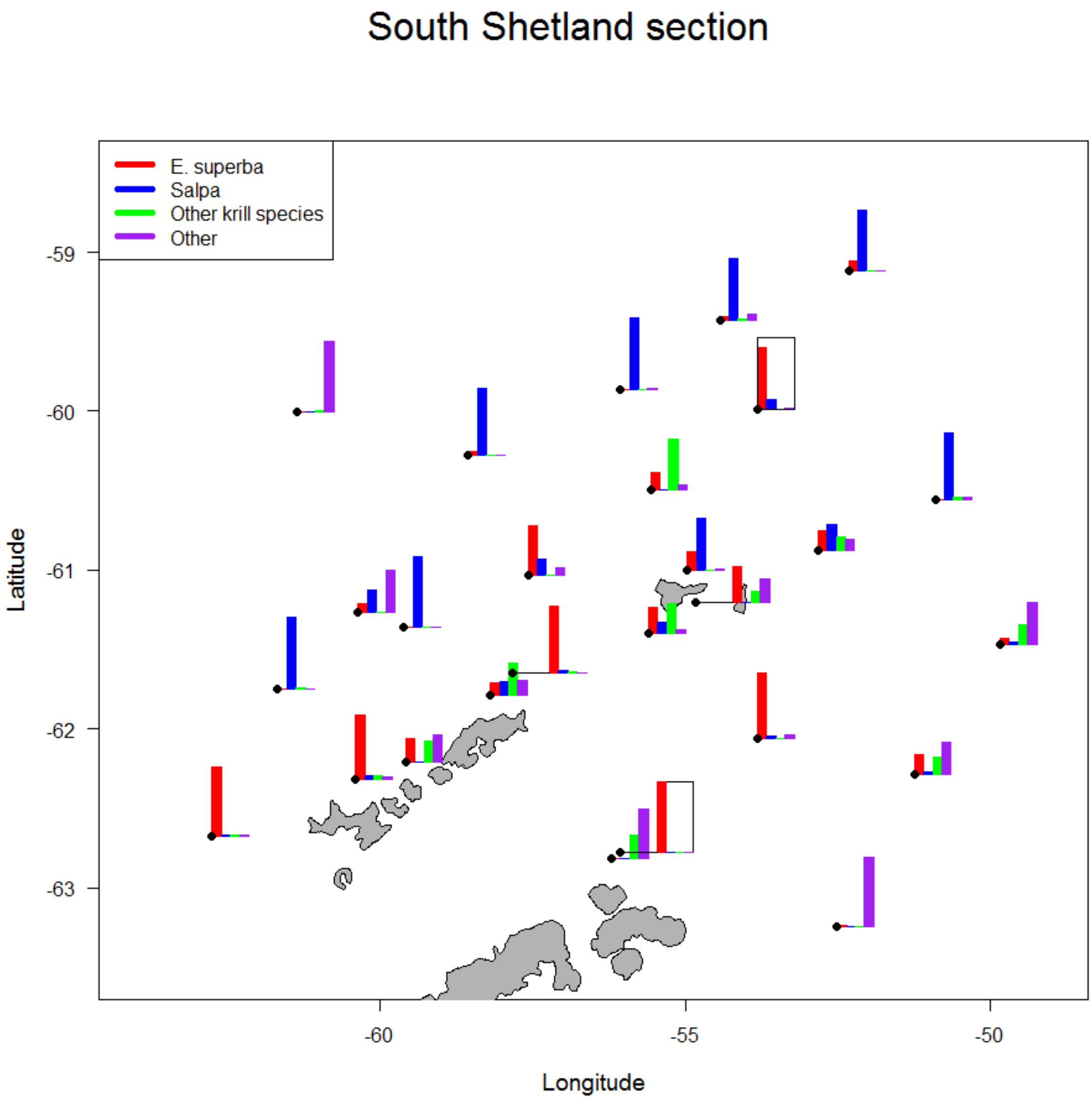

Fig. 12 a) Distribution of target groups in catch based on fraction of total weight. The histograms which are framed mark target hauls. The black dots always mark the station position, but some of the histograms are slightly shifted to the right for increased readability.

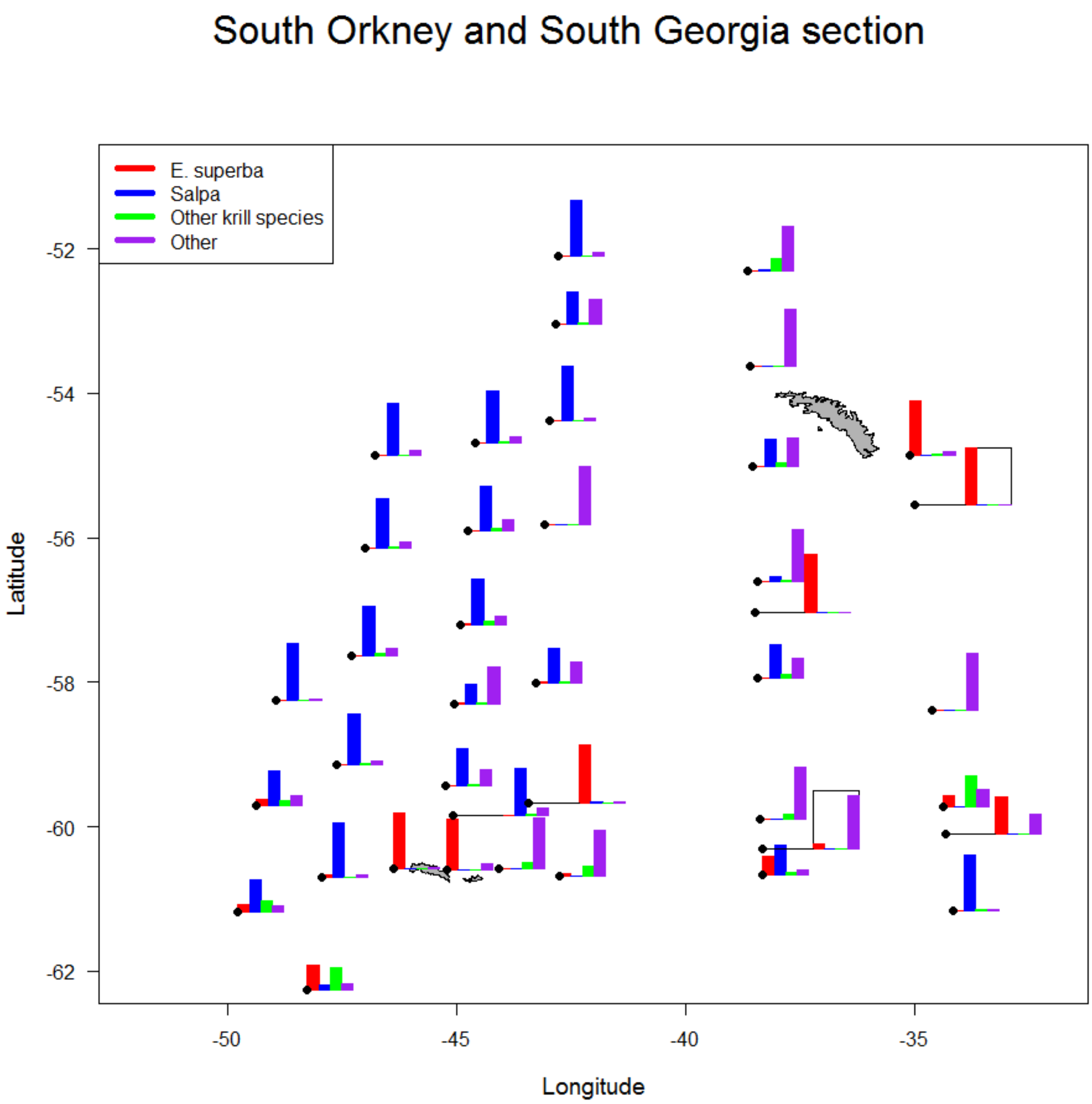

Fig. 12 b) Distribution of target groups in catch based on fraction of total weight. The histograms which are framed mark target hauls. The black dots always mark the station position, but some of the histograms are slightly shifted to the right for increased readability.

Length distributions of Euphausia superba

Overall, the length distribution of krill was dominated by two size modes, one with animals between 40 and 50 mm and one with very large animals between 50 and 60 mm (Fig. 13). Very few animals <35 mm were sampled. The geographical distribution of the size modes showed that large animals dominated in the South Shetland section except around the peninsula where smaller krill were found (Fig. 14 a). Large animals were also found to the west of the South Orkneys (Fig. 14 b), whereas smaller animals were dominant in the samples on the South Orkney shelf. In the South Georgia section, the animals between 40 and 50 mm were dominating in the samples.

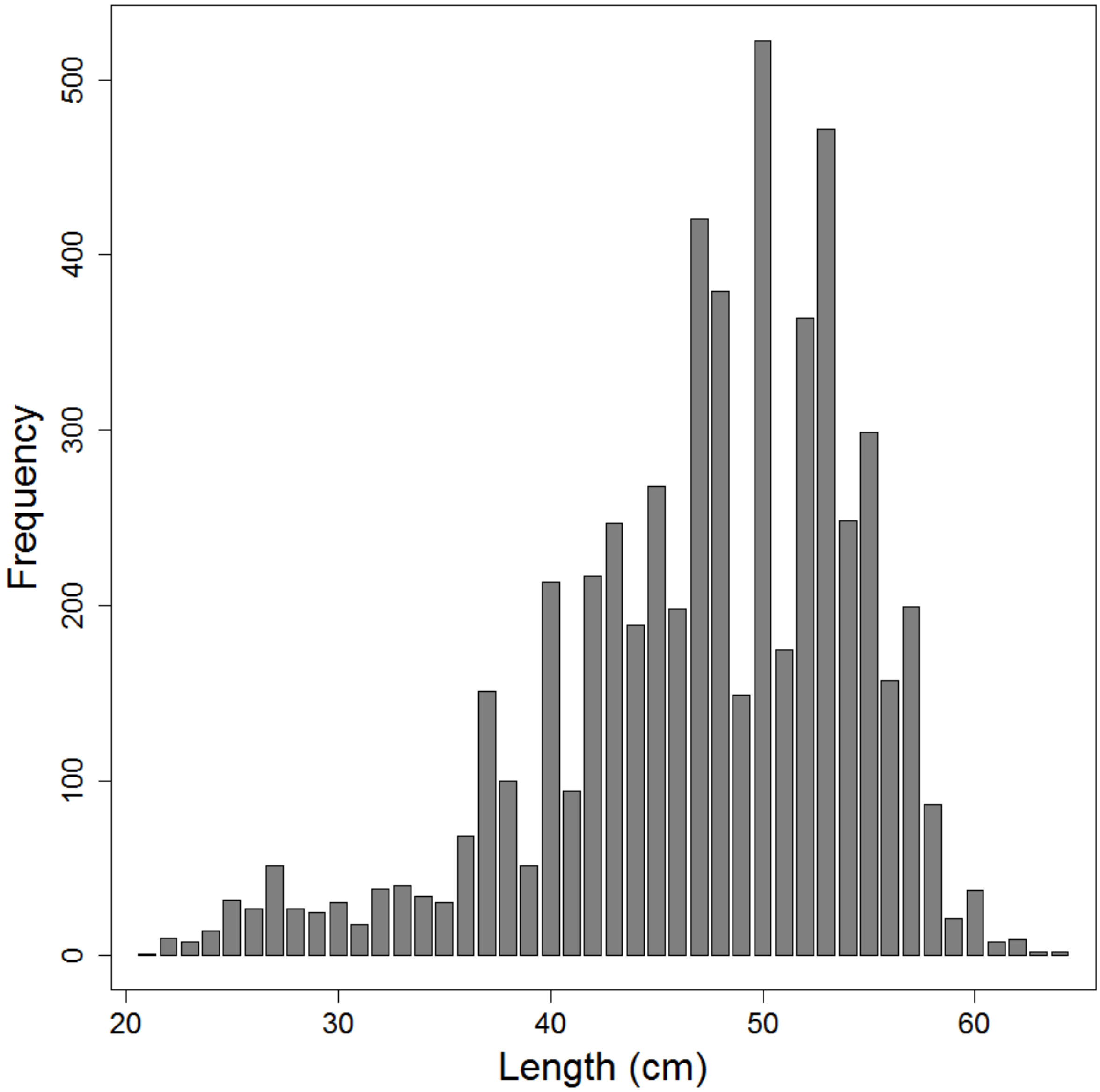

Fig. 13. Krill length distributions, summary over all samples.

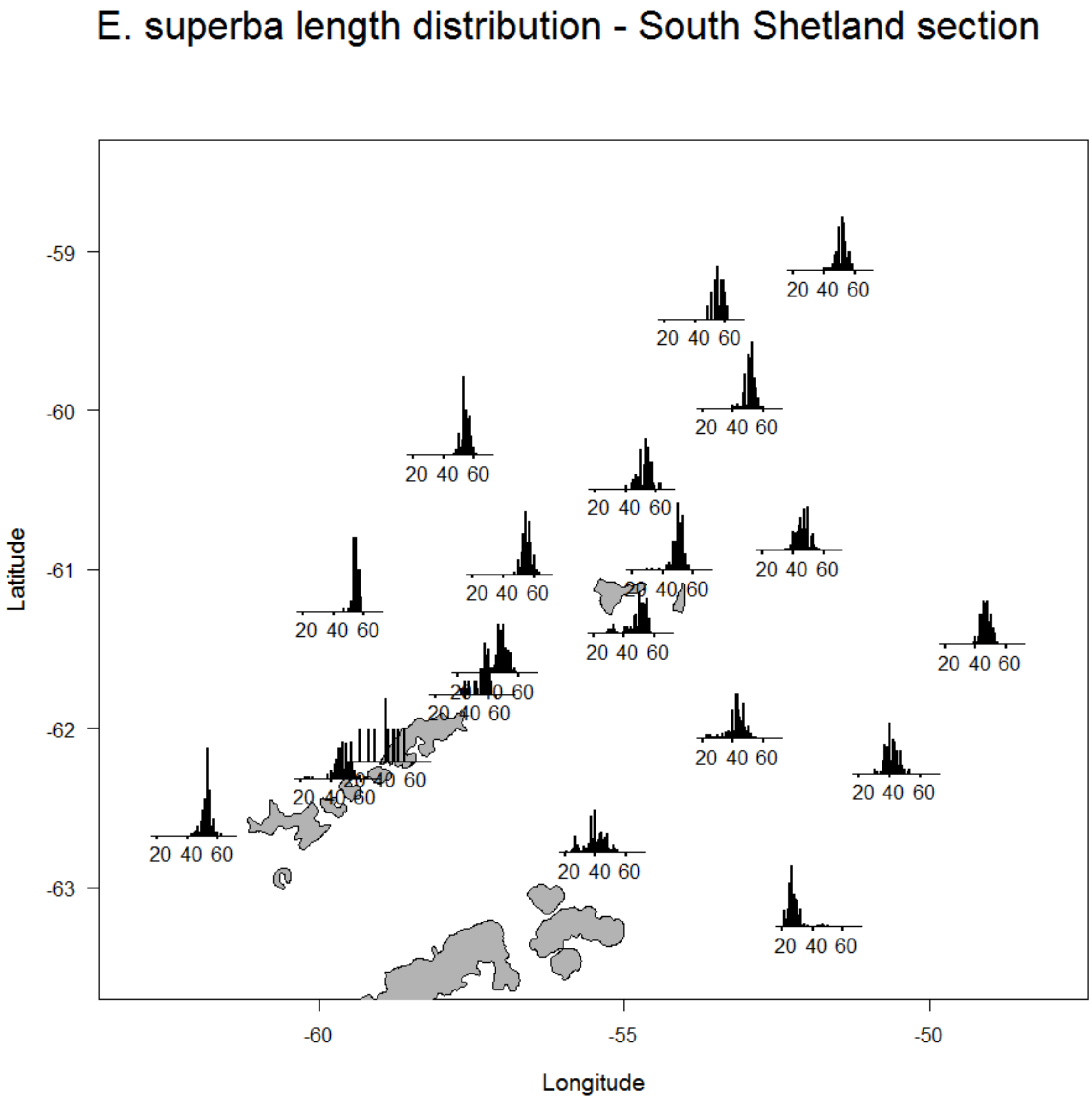

Fig. 14 a) Geographical distribution of krill length distributions – South Shetland sector. Only included stations with >9 individuals sampled.

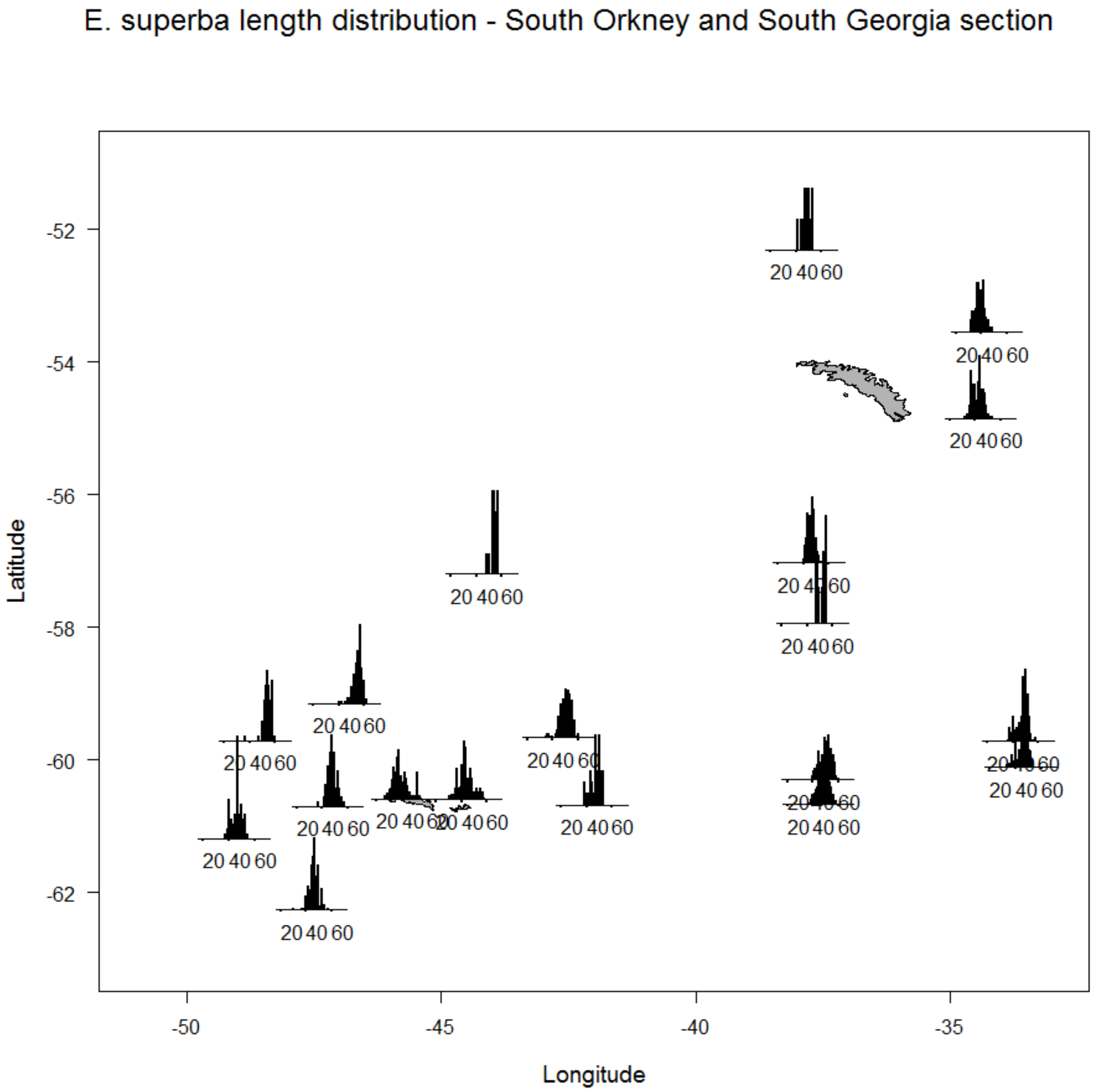

Fig. 14 b) Geographical distribution of krill length distributions – South Shetland sector. Only included stations with >9 individuals sampled.

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Marine mammal observations

Marine mammal sightings from the bridge were carried out as long as weather and light conditions permitted, and the effort periods are shown in figure 15 a). Humpback whales were mainly observed south of the Elephant Island, north of the tip of the Peninsula and around the South Georgia (Fig. 15 b). Fin whales were the most commonly observed whale during the survey, most occurrences were around the South Orkneys, but also around the tip of the Peninsula and around South Georgia (Fig. 15 c). Seals were by far most commonly observed around South Georgia, but with occurrences also around South Orkneys and around the Elephant Island (Fig. 15 d).

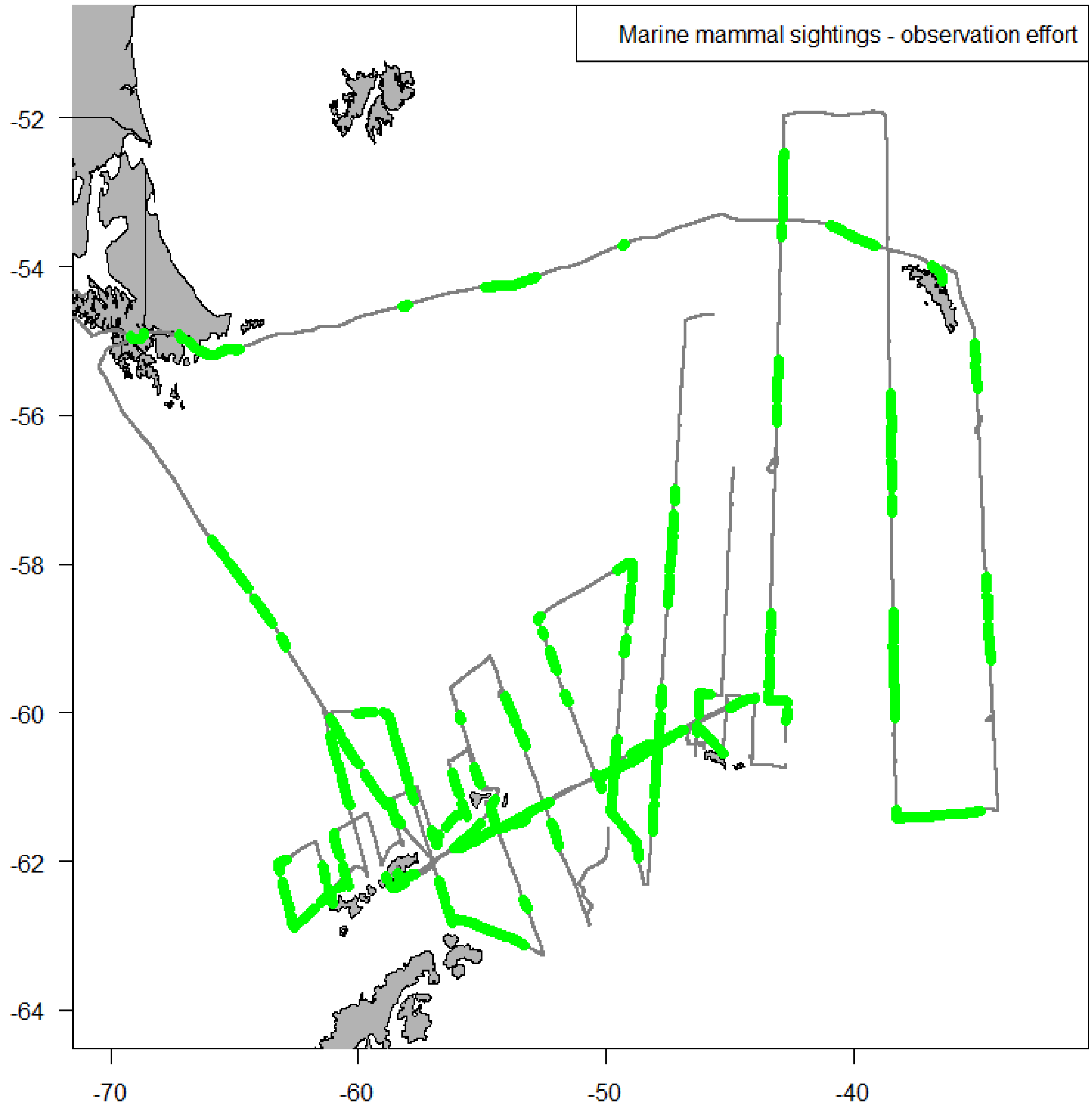

Fig. 15 a) Marine mammal observations, distribution of observation effort (green) along the survey track.

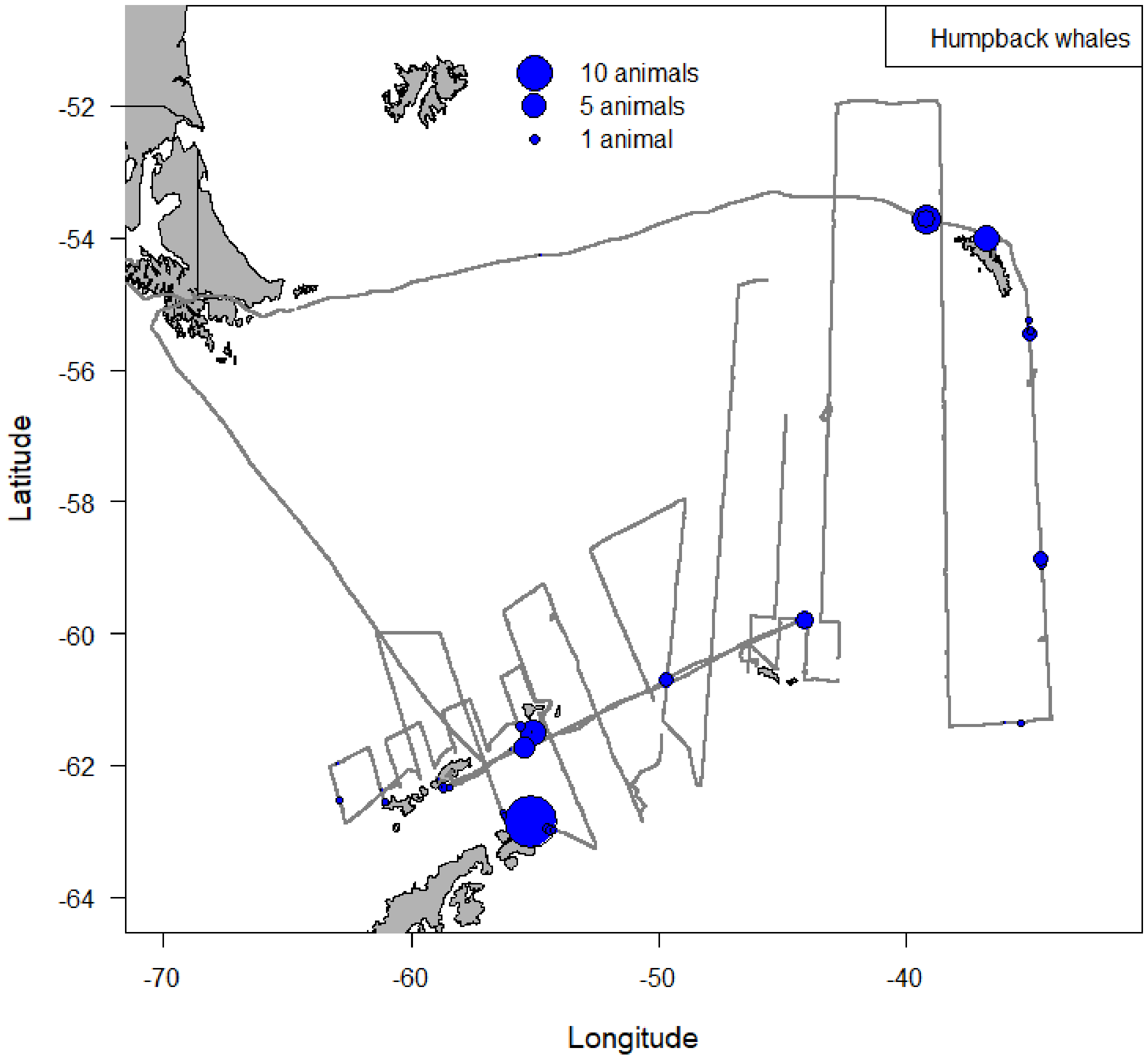

Fig. 15 b) Distribution of humpback whale sightings along the survey track.

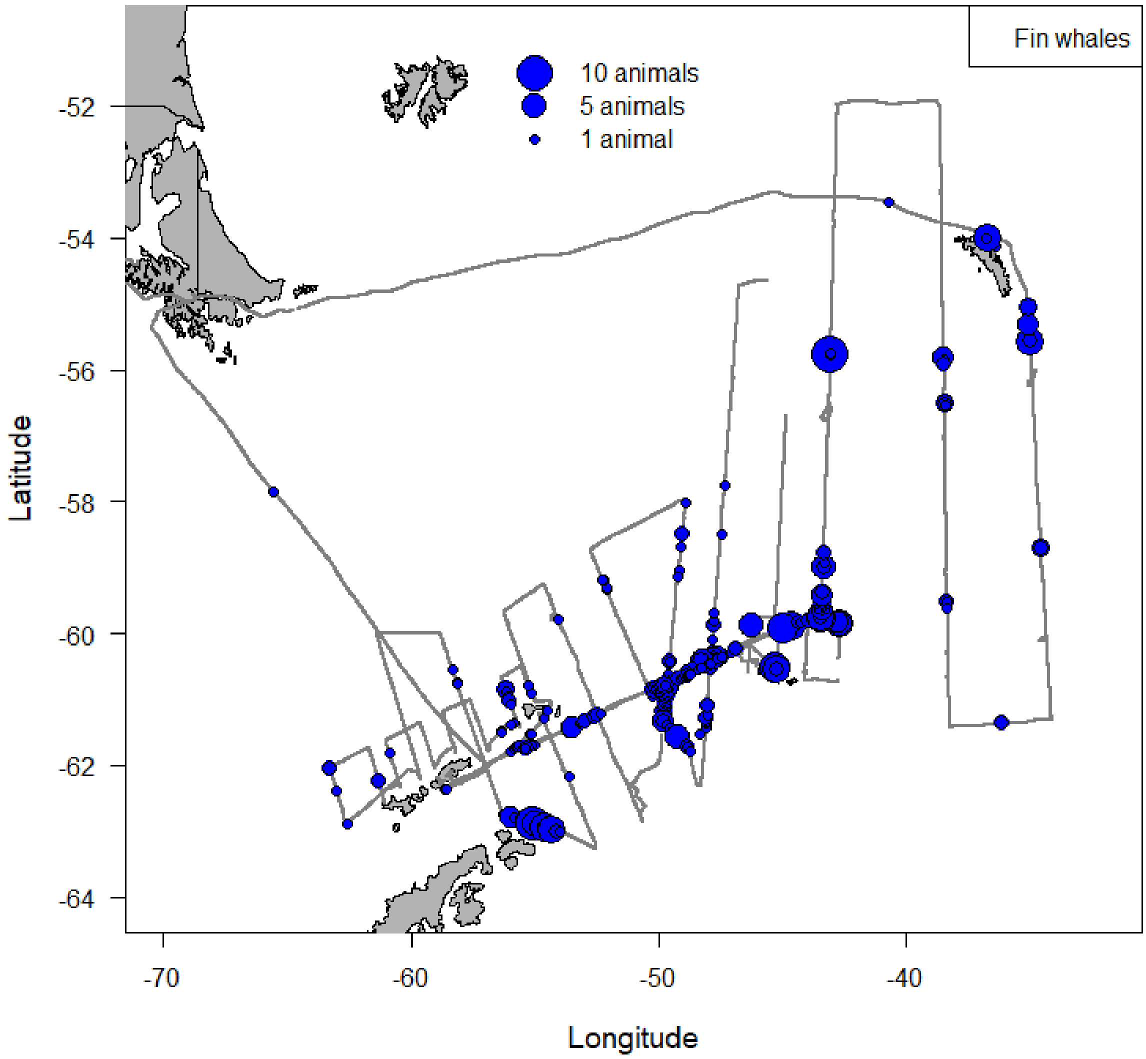

Fig. 15 c) Distribution of fin whale sightings along the survey track.

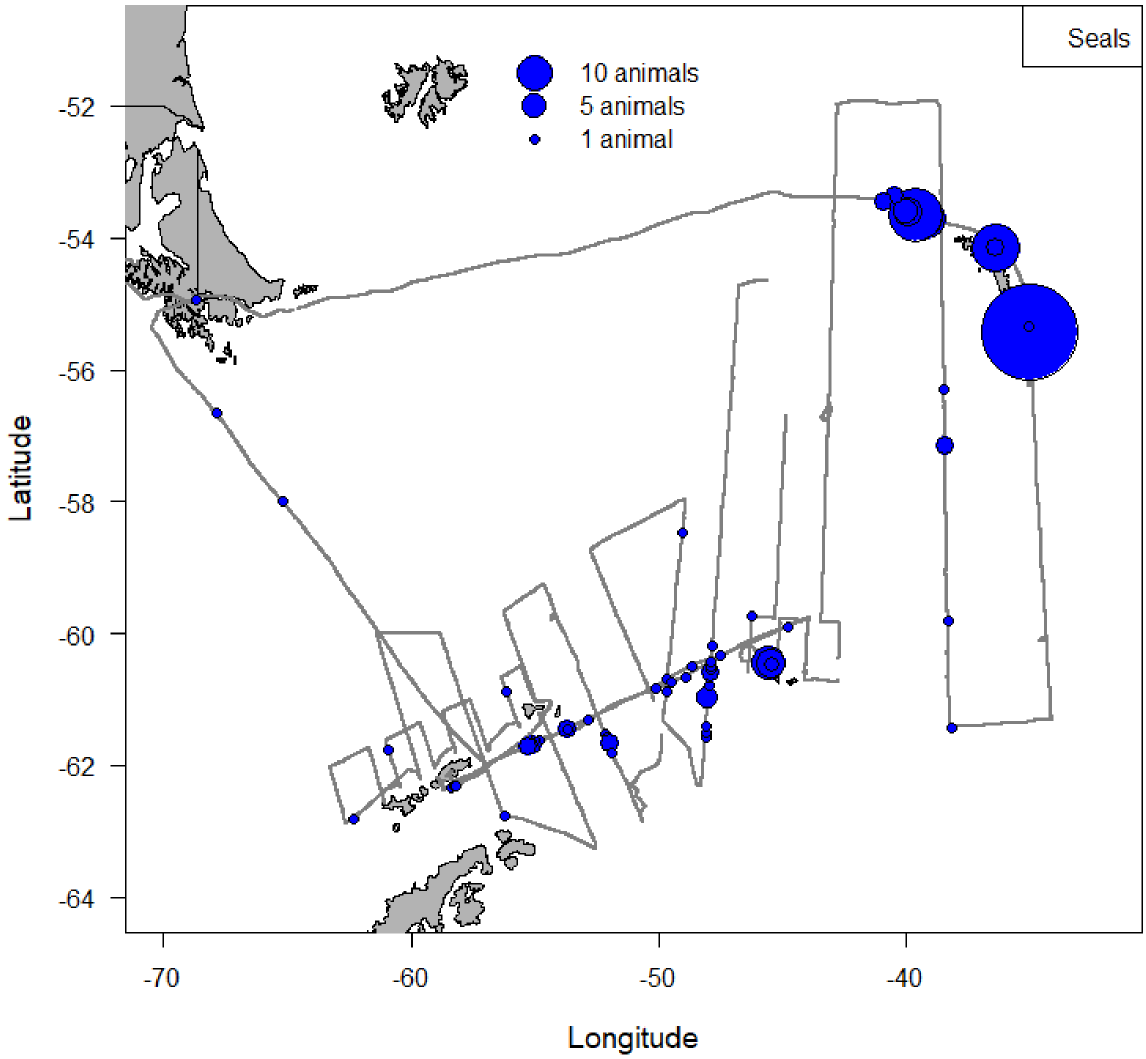

Fig. 15 d) Distribution of seal sightings along the survey track.

Bird observations

Distribution of flying bird observations is shown in Figure 17 a). The highest occurrences were sighted north of the South Shetland Islands and south of South Georgia. Few penguins were sighted during the survey, but with occurrences around the Elephant Island and north of the South Orkneys (Fig. 17 b).

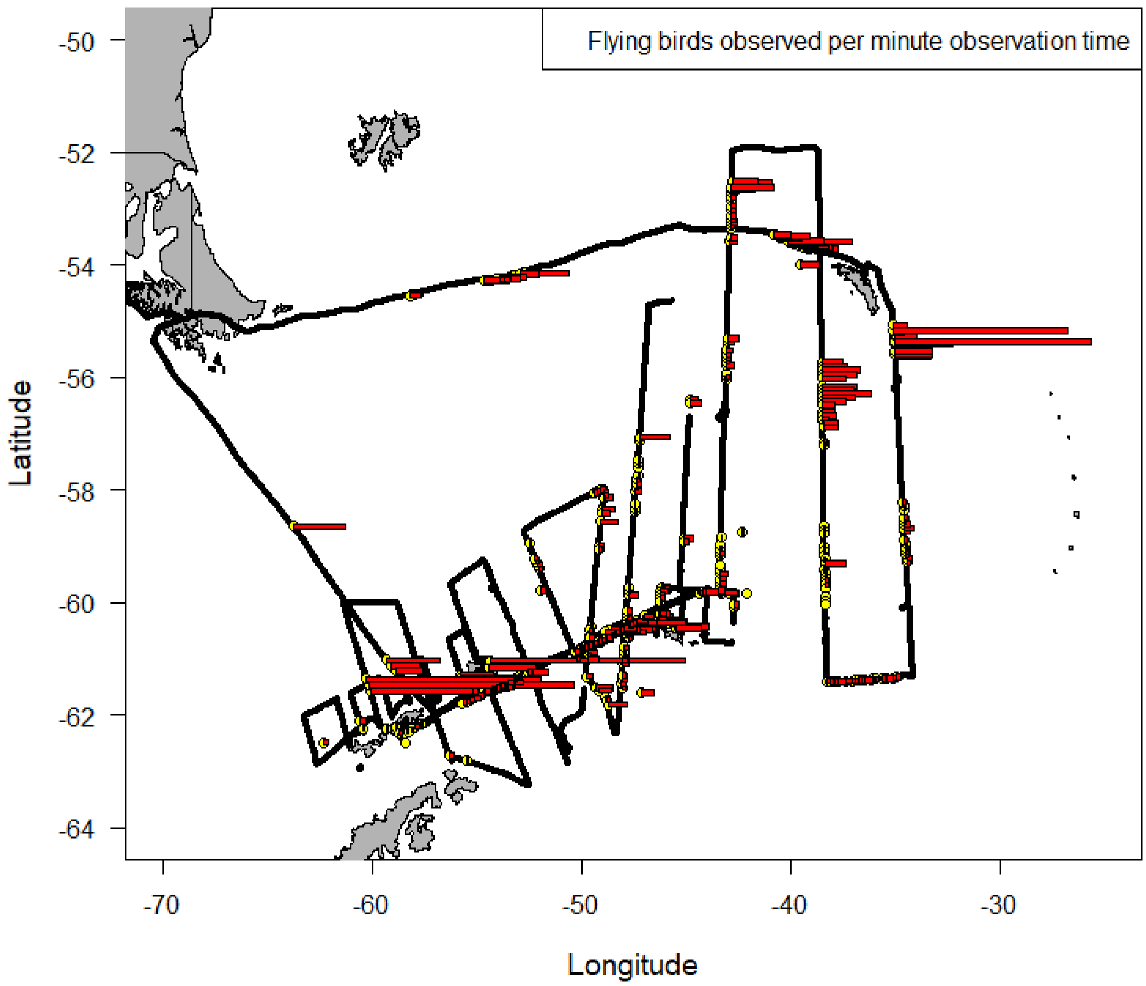

Fig. 17 a) Distribution of flying bird sightings. The horizontal bars are proportional to the number of flying birds observed per minute within an effort period. Yellow dots mark effort periods.

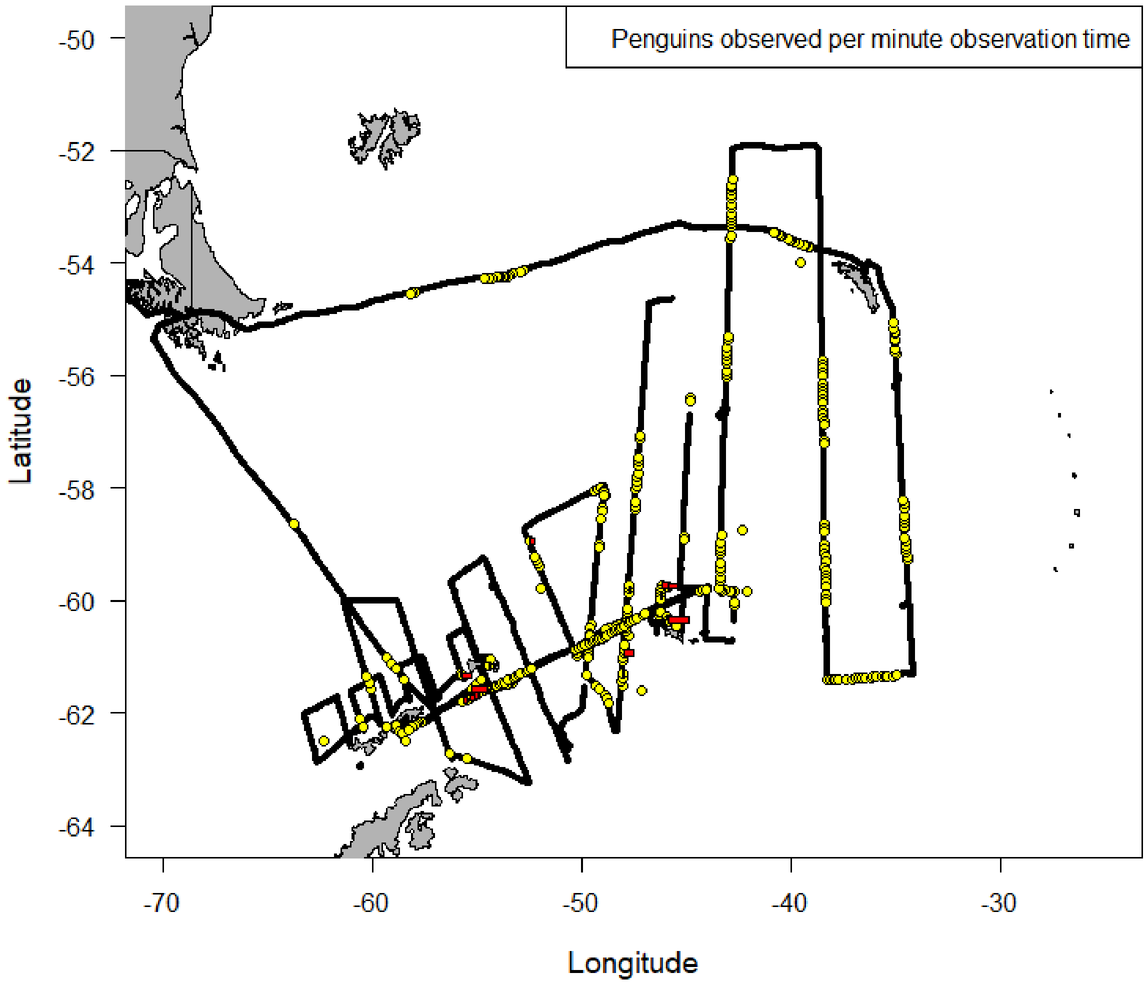

Fig. 17 b) Distribution of penguin sightings. The horizontal bars are proportional to the number of penguins observed per minute within an effort period. Yellow dots mark effort periods.

Acknowledgements

We are very grateful to the chief mate, and other officers and crew on board 'Cabo de Hornos' for excellent assistance and a good mood during the survey.

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Appendix

I) Tables used for collection of environmental metadata

Table AI_1. Beaufort scale used for describing sea state

Code for Wind Speed, ff

Code Figs. (Knots)	Mean Speed	Beau-fort	Description	Sea criterion when sea fully developed	Probable ht. of waves in m (ft) Average			
					Average		Maximum	
00	00	0	Calm	Sea like a mirror	-			-
01 - 03	02	1	Light Air	Ripples with the appearance of scales are formed, but with-out foam crests	0.1	(¼)	0.1	(¼)
04 - 06	05	2	Light breeze	Small wavelets, still short but more pronounced, crests have a glassy appearance and do not break	0.2	(½)	0.3	(1)
07 - 10	09	3	Gentle breeze	Large wavelets, crests begin to break; foam of glassy appearance; perhaps scattered white horses	0.6	(2)	1	(3)
11 - 16	13	4	Modt. breeze	Small waves, becoming longer; fairly frequent white horses	1	(3½)	1.5	(5)
17 - 21	19	5	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	2	(6)	2.5	(8½)
22 - 27	24	6	Strong breeze	Large waves begin to form; white foam crests are more extensive everywhere (probably some spray)	3	(9½)	4	(12)
28 - 33	30	7	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	4	(13½)	5.5	(19)
34 - 40	37	8	Gale	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind	5.5	(18)	7.5	(25)
41 - 47	44	9	Strong gale	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility	7	(23)	10	(32)
48 - 55	52	10	Storm	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes a white appearance; tumbling of the sea becomes heavy and shock-like; visibility affected	9	(29)	12.5	(41)
56 - 63	60	11	Violent Storm	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected	11.5	(37)	16	(52)
64 and over	–	12	Hurricane	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	14	(45)	-	

Note: For wind of 99 knots or greater, use 99 for ff, and report wind speed in group 00fff; e.g. for a wind from 100° true at 125 knots, dd = 10, ff = 99, and fff = 125.

Table AI_2. Ice coverage

Code for Concentration or Arrangement of Sea Ice, c_i

Code Figures			
0	No sea ice in sight		
1	Ship in open lead more than 1 nautical mile wide, or ship in fast ice with boundary beyond limit of visibility		
2	Sea ice present in concentrations less than $3/10$ ($3/8$); open water or very open pack ice	*Sea ice concentration is uniform in the observation area*	*Ship in ice or within 1/2 nautical mile of the ice edge*
3	$4/10$ to $6/10$ ($3/8$ to less than $6/8$); open pack ice		
4	$7/10$ to $8/10$ ($6/8$ to less than $7/8$); close pack ice		
5	$9/10$ or more, but not $10/10$ ($7/8$ to less than $8/8$); very close pack ice		
6	Strips and patches of pack ice with open water between	*Sea ice concentration is* ***not*** *uniform in the observation area*	
7	Strips and patches of close or very close pack ice with areas of lesser concentration between		
8	Fast ice with open water, very open or open pack ice to seaward of the ice boundary		
9	Fast ice with close or very close pack ice to seaward of the ice boundary		
/	Unable to report, because of darkness, lack of visibility, or because ship is more than ½ nautical mile away from the ice edge.		

Table AI_3) Cloud cover

Code for Total Cloud Cover, N

Code figs.	Fraction of sky covered
0	Cloudless
1	1 eighth or less, but not zero
2	2 eighths
3	3 eighths
4	4 eighths
5	5 eighths
6	6 eighths
7	7 eighths or more but not totally covered
8	8 eighths, sky completely covered by clouds
9	Sky obscured by fog, snow, or other meteorological phenomena
/	Cloud cover indescernible for reasons other than Code fig. 9, or observation is not made

Remarks: A mackerel sky (Altocumulus, stratocumulus, or cirrocumulus covering the whole sky) should be coded as N = 7, since breaks are always present in these cloud forms. When observing clouds through fog, base your estimate for N on the amount of clouds that can be seen through the fog. When a completely clear sky is observed through fog or haze, report N as 0.

II) Results from the acoustic calibration

Table AII_1) Summary of calibration results.

Cite and date	Setting	38 kHz	120 kHz
Maxwell Bay 15.01.2019	**Gain**	26.79	27.27
	Sa correction	-0.02	-0.01
	TS RMS error	0.14	0.24
	Beam width alongship	7.79	6.23
	Angle offset alongship	0.03	-0.14
	Beam width athwartship	7	6.67
	Angle offset athwartship	-0.07	0
Maxwell Bay 12.02.2019	**Gain**	27.17	26.94
	Sa correction	0.02	0.01
	TS RMS error	0.13	0.13
	Beam width alongship	6.59	6.63
	Angle offset alongship	-0.14	0
	Beam width athwartship	6.37	6.33
	Angle offset athwartship	-0.02	-0.11
Cumberland Bay 03.03.2019	**Gain**	27.3	26.85
	Sa correction	0.02	-0.03
	TS RMS error	0.04	0.04
	Beam width alongship	6.97	6.59
	Angle offset alongship	-0.09	-0.03
	Beam width athwartship	6.97	6.65
	Angle offset athwartship	0.04	-0.01

III) Settings used for processing acoustic data in module KORONA in LSSS

Order of KORONA modules run during pre-processing:

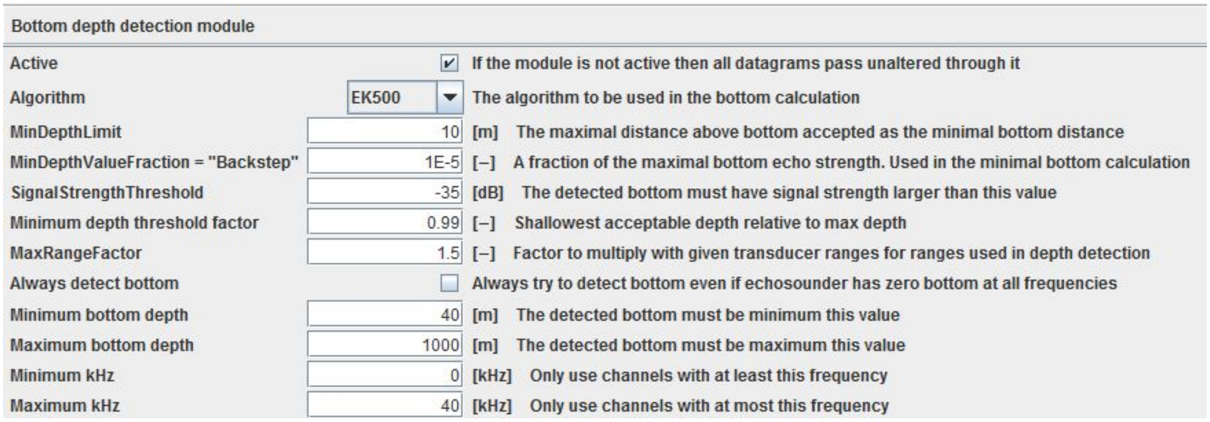
1) **Data reduction** – max range 38 kHz: 1000 m, max range 120 kHz: 500 m
2) **Complex to real**
3) **Spike filter**

Filters spikes		
Active	☑	If the module is not active then all datagrams pass unaltered through it
LogarithmicValues	☑	Use log(sv)(checked) or sv (not checked)
ShowDetails	☑	Shows more detailed settings (OnlyLast,AutomaticDepthRange,StartDepth,EndDepth)
OnlyLast	☐	When true, only last channel is processed, if false all channels are processed
ChannelsToProcess	-1	[#] Process the n last channels (-1 for all channels)
AutomaticDepthRange	☐	If true and Bottom detection module is used then the range goes to the detected seabed.
StartDepth	10	[m] Start depth (or range) for filter
EndDepth	520	[m] End depth (or range) in meter for filter
TotalDelta	10	[dB] Minimum difference of current sample to search window median to be spike candidate
VerticalDelta	10	[dB] Minimum difference of search column median to (most) neighbouring pings to be spike candidate
Debug	☐	Sets value to 0 where spikes are detected
VerticalUnit	DISTANCE	Unit for the height of the search window and the search columns
VerticalMedianSearchDistance	1.3	[m] Half the height of the search column in meters
WindowMedianSearchDistance	6.6	[m] Half the height of the search window in meters

4) **Temporary computations begin**
5) **Fill missing data**
6) **Smoother**

Performs smoothing by convolution		
Active	☑	If the module is not active then all datagrams pass unaltered through it
OnlyLastChannel	☐	If selected only the last channel is processed, otherwise all channels are processed
MaskPelagic	☑	Exclude samples above bottom
MaskBottom	☑	Exclude samples below bottom
MaskSecondBottom	☑	Exclude samples below 10m above second bottom echo
MaskNoise	☐	Exclude samples below noise threshold
MaskRegion	none	Exclude samples in connection with regions
MaskTrack	none	Exclude samples in connection with tracks
MinPing	0	[#] Number of pings used ≥ 2*MinPing + 1
MaxPing	10	[#] Number of pings used ≤ 2*MaxPing + 1
HorizontalKernelType	gaussian	Convolution kernel type horizontally
VerticalKernelType	gaussian	Convolution kernel type vertically
HorizontalWidth	16	[m] Convolution kernel width
VerticalWidth	0.5	[m] Convolution kernel height
LogarithmicValues	☐	If checked use log(sv), otherwise use (linear) sv

7) Bottom detection



Bottom depth detection module

Active	[x]		If the module is not active then all datagrams pass unaltered through it
Algorithm	EK500		The algorithm to be used in the bottom calculation
MinDepthLimit	10	[m]	The maximal distance above bottom accepted as the minimal bottom distance
MinDepthValueFraction = "Backstep"	1E-5	[–]	A fraction of the maximal bottom echo strength. Used in the minimal bottom calculation
SignalStrengthThreshold	-35	[dB]	The detected bottom must have signal strength larger than this value
Minimum depth threshold factor	0.99	[–]	Shallowest acceptable depth relative to max depth
MaxRangeFactor	1.5	[–]	Factor to multiply with given transducer ranges for ranges used in depth detection
Always detect bottom	[ ]		Always try to detect bottom even if echosounder has zero bottom at all frequencies
Minimum bottom depth	40	[m]	The detected bottom must be minimum this value
Maximum bottom depth	1000	[m]	The detected bottom must be maximum this value
Minimum kHz	0	[kHz]	Only use channels with at least this frequency
Maximum kHz	40	[kHz]	Only use channels with at most this frequency

8) Temporary computations end

IV) Information on the deployment of the moorings

Data sheets on outgoing moorings

Institute of Marine Research

Data record book for self registrating instruments detail

Ship/Platform: Cabo de Hornos
Location:
Latitude: S 60° 24.2625
Longitude: W 045° 57.9522

Instruments / Sensors					
#	Brand	Type	Serial No.	Depth	Comments
1	ASL	Acoustic Zooplankton Fish Profiler	55062	292	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Bottom depth: 497 m
Outgoing date: 2019.02.07
Outgoing time (UTC): 00:53
Incoming date: Click here to enter a date.
Incoming time (UTC): xx:xx

Comments:

Responsible: Ronald Pedersen

~~ARGOS~~
~~PTTID: 00000~~

Acoustic release: IXSEA ARX61
Serial no: 0698
Range code: 4B13
Release code: 4B14

Station name: Krill 2019 ASL AZFP	
Color code:	
Sum weight (incl. anchor): [kg]	
Sum weight (excl. anchor): [kg]	
Sum volume: [l]	
Buoyancy (anchor on): [kg]	
Buoyancy (anchor off): [kg]	

Shackle Stainless Steel S
Shackle Galvanized Steel G
Thimble Stainless Steel
Thimble Galvanized Steel
Thimble Nylon Stainless Steel Bolt

Description	Spec	No.
Shackle Stainless Steel		0
Shackle Stainless Steel	2.50	0
Shackle Galvanized Steel	0.50	0
Shackle Galvanized Steel	2.00	1
Shackle Galvanized Steel	3.25	6
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
ThimblesStainless Steel		0
Thimble Galvanized Steel		2
Thimble Galvanized Steel		0
Thimble Nylon		2
Bolt Stainless Steel (RCM-7)		0
		0
		0

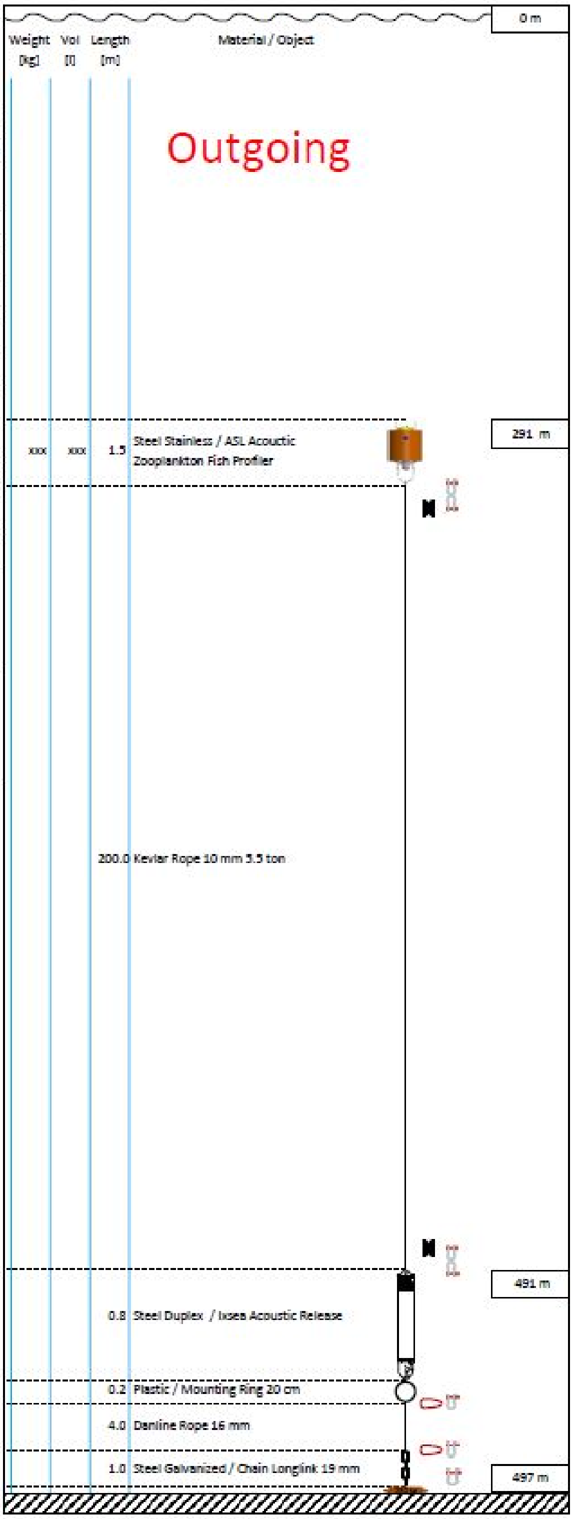


Fig. AIV_1) Data sheet for deployment of ASL acoustic profiler.

Institute of Marine Research

Mooring record book for self registrating instruments detail

Ship/Platform: Cabo de Hornos
Location:
Latitude: S 60° 12.3399
Longitude: W 046° 31.8146

Instruments / Sensors					
#	Brand	Type	Serial No.	Depth	Comments
1	Nortek	Signature 100	101122	234	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

Bottom depth: 1094 m
Outgoing date: 2019.02.06
Outgoing time (UTC): 16:24
Incoming date: Click here to enter a date.
Incoming time (UTC): XX:XX

Comments:

Responsible: Ronald Pedersen

~~ARGOS~~
~~PTTID: 00000~~

Acoustic release: IXSEA ARX61
Serial no: 2418
Range code: 1BD7
Release code: 1B55

Station name: Krill 2019 Nortek SIG 100	
Color code:	
Sum weight (incl. anchor): [kg]	
Sum weight (excl. anchor): [kg]	
Sum volume: [l]	
Buoyancy (anchor on): [kg]	
Buoyancy (anchor off): [kg]	
Stainless Steel Shackle	S
Galvanized Steel Shackle	G
Stainless Steel Thimble	
Galvanized Steel Thimble	

Description	Spec	No.
Shackle Stainless Steel		0
Shackle Stainless Steel	2.50	0
Shackle Galvanized Steel	0.50	0
Shackle Galvanized Steel	2.00	1
Shackle Galvanized Steel	3.25	12
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
Thimble Stainless Steel		0
Thimble Galvanized Steel		2
Thimble Galvanized Steel		0
Thimble Nylon		8
		0
		0
		0

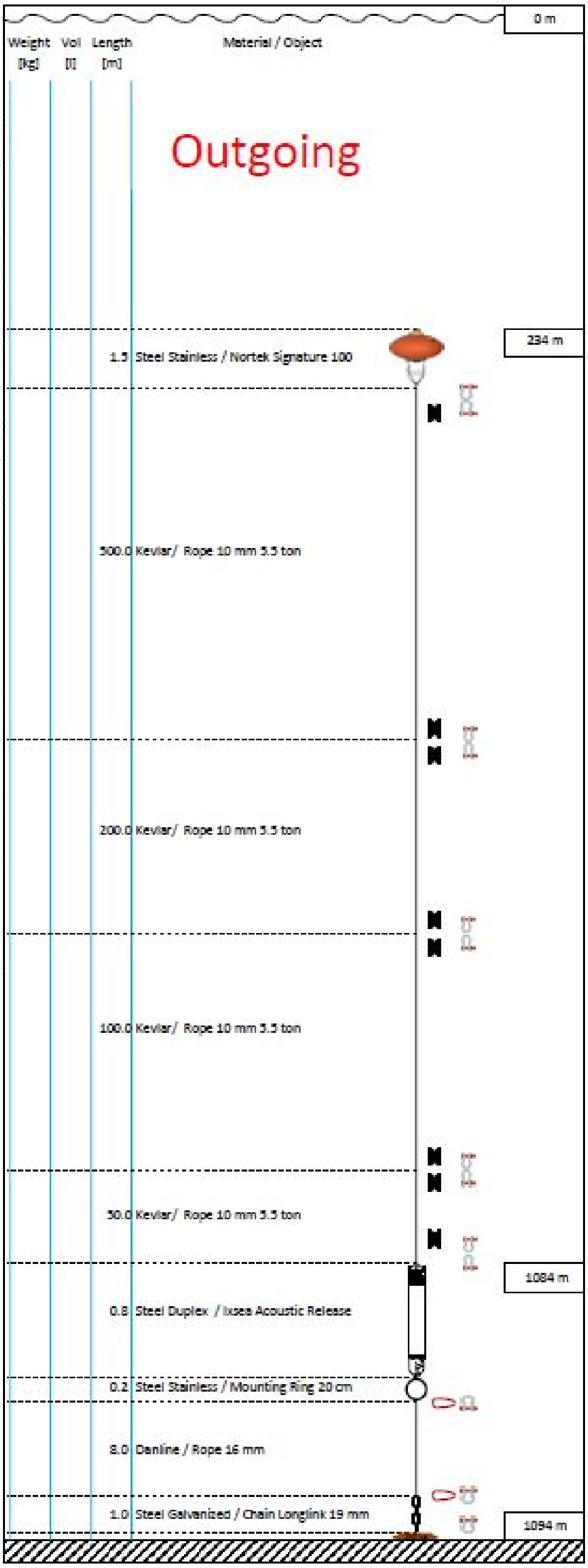


Fig. AIV_2) Data sheet for deployment of Nortek Signature 100 echosounder and current profiler.

Institute of Marine Research

Mooring record book for self registrating instruments detail

Ship/Platform: Cabo de Hornos
Location:
Latitude: S 60° 25.2993
Longitude: W 046° 38.0601

Instruments / Sensors					
#	Brand	Type	Serial No.	Depth	Comments
1	Nortek	Signature 100	101135	270	
2	Sea Bird	SBE 37	03716352	272	
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

Bottom depth: 480 m
Outgoing date: 2019.02.06
Outgoing time (UTC): 21:06
Incoming date: Click here to enter a date.
Incoming time (UTC): XX:XX

Comments:

Responsible: Ronald Pedersen

~~ARGOS~~
~~PTTID: 00000~~

Acoustic release: IXSEA ARX61
Serial no: 2417
Range code: 1BD6
Release code: 1B55

Station name: Krill 2019 Nortek SIG 100	
Color code:	
Sum weight (incl. anchor): [kg]	
Sum weight (excl. anchor): [kg]	
Sum volume: [l]	
Buoyancy (anchor on): [kg]	
Buoyancy (anchor off): [kg]	

Stainless Steel Shackle S
Galvanized Steel Shackle G
Stainless Steel Thimble
Galvanized Steel Thimble
Nylon Thimble w/Stainless Steel Bolt

Description	Spec	No.
Shackle Stainless Steel		0
Shackle Stainless Steel	2.50	0
Shackle Galvanized Steel	0.50	0
Shackle Galvanized Steel	2.00	1
Shackle Galvanized Steel	3.25	6
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
Thimble Stainless Steel		0
Thimble Galvanized Steel		2
Thimble Galvanized Steel		0
Thimble Nylon		2
Bolt Stainless Steel (RCM-7)		0
		0
		0

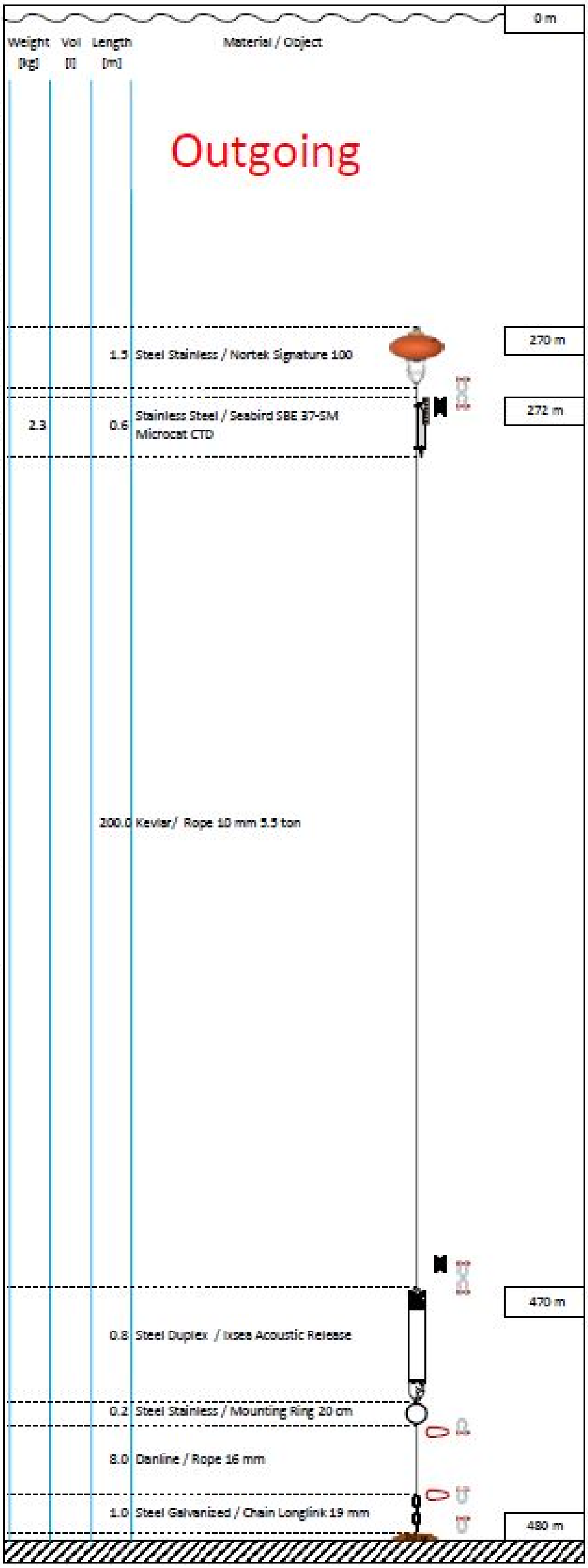


Fig. AIV_3) Data sheet for deployment of Nortek Signature 100 echosounder and current profiler mounted together with Seabird CTD.

Institute of Marine Research

Mooring record book for self registrating instruments detail

Ship/Platform: Cabo de Hornos
Location:
Latitude: S 60° 35.2487
Longitude: W 044° 10.4422

Instruments / Sensors					
#	Brand	Type	Serial No.	Depth	Comments
1	Multi-Electroniq.	Aural M2 Sound Rec.	MTEAU00289LF	365	
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

Bottom depth: 685 m
Outgoing date: 2019.02.17
Outgoing time (UTC): 18:08
Incoming date: Click here to enter a date.
Incoming time (UTC): XX:XX

Comments:

Responsible: Ronald Pedersen

~~ARGOS~~
~~PTTID: 00000~~

Acoustic release: IXSEA ARX61
Serial no: 0750
Range code: 16C1
Release code: 1655

Station name: Krill 2019 ME Aural M2	
Color code:	
Sum weight (incl. anchor): [kg]	
Sum weight (excl. anchor): [kg]	
Sum volume: [l]	
Buoyancy (anchor on): [kg]	
Buoyancy (anchor off): [kg]	

Stainless Steel Shackle S
Galvanized Steel Shackle G
Stainless Steel Thimble
Galvanized Steel Thimble
Nylon Thimble w/Stainless Steel Bolt

Description	Spec	No.
Shackle Stainless Steel		0
Shackle Stainless Steel	2.50	0
Shackle Galvanized Steel	0.50	0
Shackle Galvanized Steel	2.00	1
Shackle Galvanized Steel	3.25	0
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
Thimble Stainless Steel		0
Thimble Galvanized Steel		2
Thimble Galvanized Steel		0
Thimble Nylon		4
Bolt Stainless Steel (ROM-7)		0
		0
		0

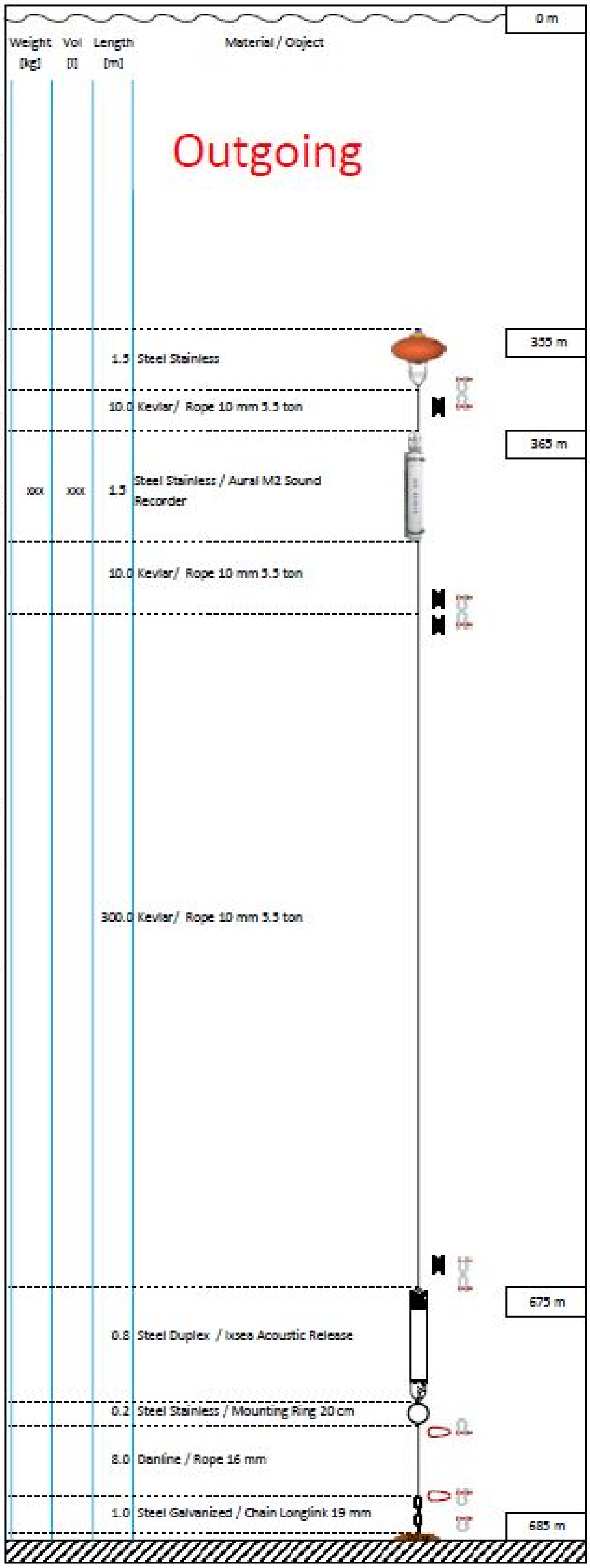


Fig. AIV_4) Data sheet for deployment of Aural sound recorder.

V) Depth profiles of the trawl hauls

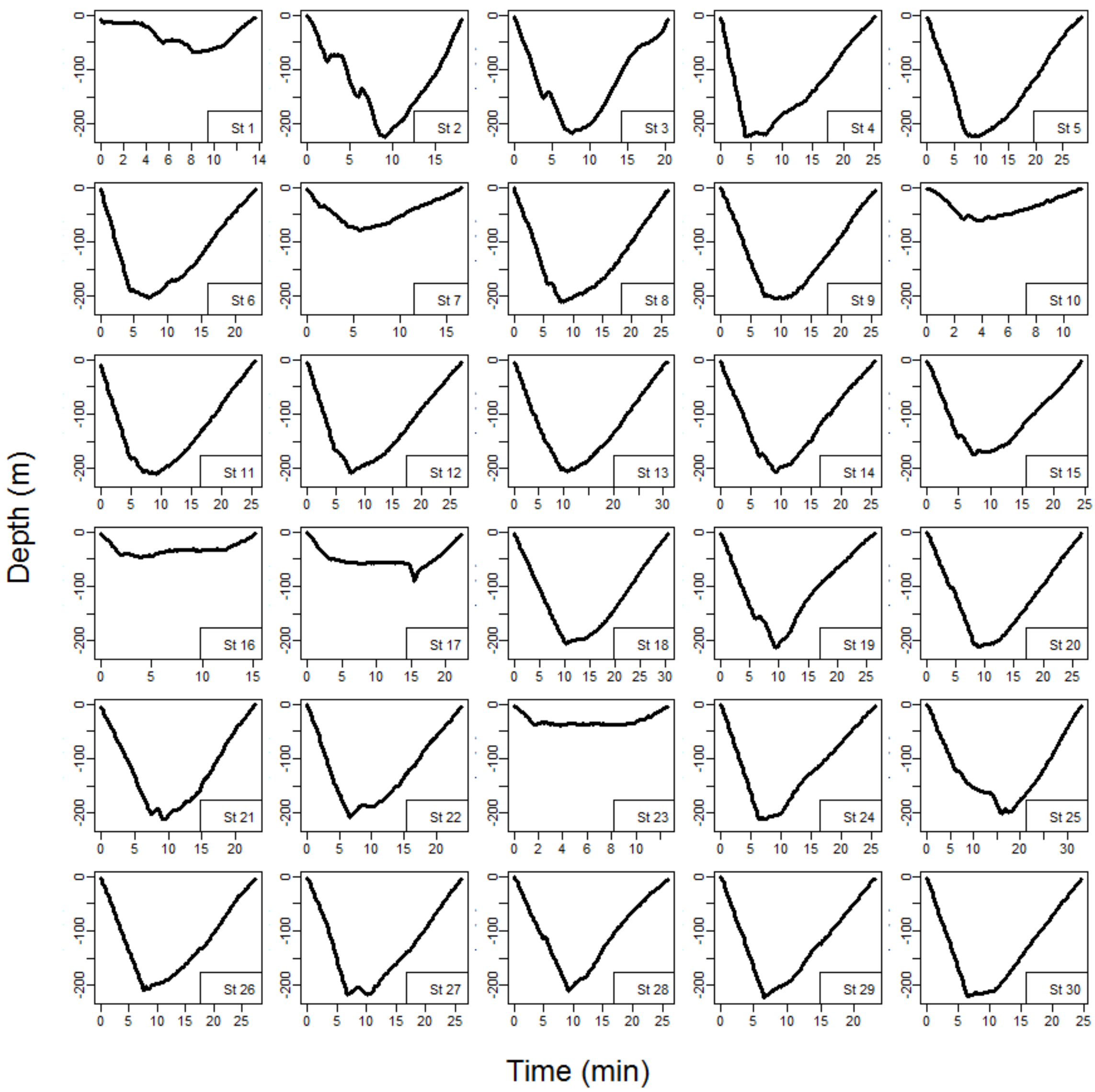


Fig. AV_a) Depth profiles of the trawl hauls stations 1-30.

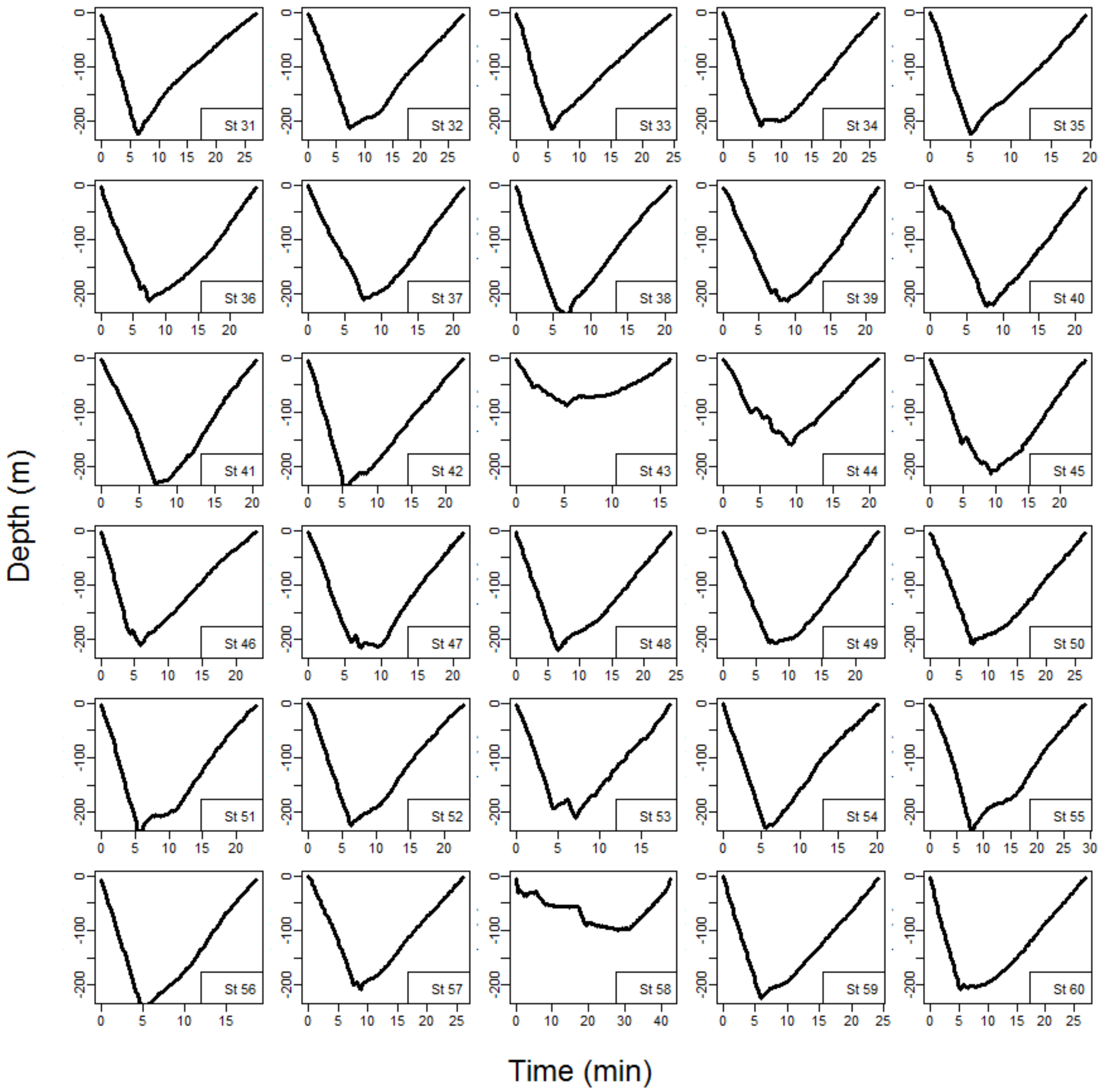


Fig. AV_b) Depth profiles of the trawl hauls stations 31-60.

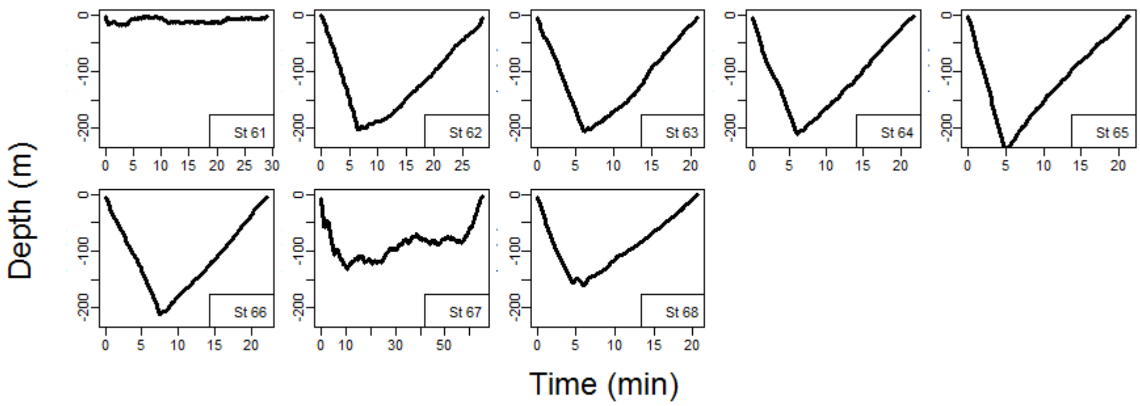


Fig. AV_c) Depth profiles of the trawl hauls stations 61-68.

VI) Measurements of acoustic density and sound speed contrasts in krill

Equipment

Density meter

We used an Anton Paar DMA 4500 density meter with an of accuracy: 3 x 10^{-5} g cm^{-3} to measure density of liquids. This instrument measures the densities of fluids injected using syringes. To ensure the accuracy of the measurements, we used different syringes for different fluids, i.e. the natural seawater that *E. superba* resides in, the 2nd fluid (freshwater), mixed solution (seawater and freshwater). The density meter is motion independent, so even at sea, the density measurements are believed to be accurate.

Balance scales

We applied two KERN motion compensated electric balance scales (120 g with 0.1 mg accuracy) for the weight measurements. The two electric balance scales were mounted on the same platform (experiencing the same acceleration). One scale has a calibration weight (50g) on it all the time and the other has the testing object. The readings from both scales were read from a laptop via RS232 ports (using a USB to 4 RS232 DB9 adapter). The motion compensated weight is determined by

$$\langle W_{mc} \rangle = \frac{\langle R_{nmc} \rangle}{\langle R_{cw} \rangle} W_{cal}$$

where W_{mc} and W_{cal} are the motion-compensated weight and calibration weight, respectively. R_{nmc} and R_{cw} are non-motion-compensated weight reading of the object and the weight reading of the calibration weight. Symbol "< >" stands for averaging. A minimum of 30000 weight samples were obtained for each series of measurements.

Oscilloscope

A PicoScope 3000D oscilloscope was used to transmit and receive signals in the animal chamber.

Measurement procedure

a. Measure the density of the seawater where the krill resided (ρ_1).
b. Measure density of the freshwater (ρ_2).
c. Measure the weight of empty animal container (W_0), with the weight readings determined from the compensated electric balance scales that are controlled by a computer.
d. Record acoustic waveform (>300 ping average) without krill in the animal compartment with plunger all the way in.
e. Record acoustic waveform (>300 ping average) without krill in the animal compartment with plunger all the way in. Care was taken to remove all bubbles from compartment.
f. Measure the weight of the animal container filled with zooplankton and a certain amount of seawater (W_1). Seawater was addded to about 2/3 full.
g. Calculate the net weights of the animals with the seawater in the animal container ($\Delta W_1 = W_1 - W_0$).

h. Add the freshwater into the animal container and fill it up to a pre-determined mark, which corresponded to a certain volume (V_{tot}) with an accuracy of 0.01 ml.

i. Put the small stopper on and measure the weight of the animal container when filled up (W_2).

j. Calculate the net weights of the animals/seawater/freshwater mix ($\Delta W_2 = W_2 - W_0$). The added volume of the freshwater is V_2 and can be determined accurately by $V_2 = \frac{\Delta W_2 - \Delta W_1}{\rho_2}$.

k. Measure the density of the mix-solution in the animal container using the density meter (ρ_m). The animal container was shaken gently first to mix the contents. Ideally, the mixed solution should be poured into a container through a fine-mesh sieve before measuring. This part of the instructions was overlooked.