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Antarctic krill and ecosystem monitoring survey off the South Orkney Islands in 2017

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Interior of a new state of the art experimental/equipment storage container designed for this project. Photo: B. Krafft

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Introduction and background

The fishing operations for Antarctic krill (*Euphausia superba*) are concentrated within CCAMLR (Commission on the Conservation of Antarctic Marine Living resources) subareas 48.1, 48.2 and 48.3 in the Southern Ocean. The total krill catch for 2016 was 260.168 tons. Regular monitoring of the krill during the last two decades has been carried out by US AMLR in the Bransfield Strait and Elephant Island (subarea 48.1), previously at austral summer time but presently at austral winter time, as well as the British Antarctic Survey off the South Georgia Islands (subarea 48.3) during austral summer time.

The two Norwegian fishing companies operating in the Antarctic krill fishery have in recent years contributed to more than half of the total krill harvest. Consequently, as a contribution to the resource monitoring requested for the fisheries management, the Norwegian fishing company Aker Biomarine ASA, offered to carry out an annual 5-day krill monitoring survey during the years 2011-2015 (Jensen et al. 2010). Through discussions in CCAMLR WG-EMM (Working Group on Ecosystem Monitoring and Management) in 2010 it was agreed that the survey could be carried out in the CCAMLR statistical Subarea 48.2 according to similar standards as the annual scientific surveys undertaken in 48.1 and 48.3. Together the three surveys could form an integrated monitoring effort extending across the Scotia Sea and linking three of the areas with highest concentrations of krill and highest fishing activity. In 2012, the other Norwegian operating company, Olympic ASA, adhered to the agreement, and the Norwegian Fisheries Directorate recommended that each company's monitoring effort should reflect the number of vessels active in the fishery. At present 2 vessels from Aker and 1 from Olympic are active in the fisheries and the circulation is therefore two successive years of monitoring on board an Aker vessel, and one year on board the Olympic vessel.

The first annual survey was carried out in January/February 2011 using the F/V 'Saga Sea' (Aker Biomarine ASA). The results and study design from this survey was presented at the CCAMLR WG-EMM in 2011. The original survey design, which was suggested during the WG-EMM meeting in 2010 consisted of six parallel north-south bound transects extending 100 nmi. During this first survey season it was recognized a need to extend the monitoring effort covering the waters over the shelf edge, north of the South Orkney archipelago, where the majority of krill in this region traditionally aggregate. During the WG-EMM meeting in 2011 it was agreed to extend the survey transects 20 nmi northwards and to omit the westernmost transect line from the 2011 survey. Before the survey in 2014, it was agreed to extend the transect lines further south in order to cover the Marine Protected Area south of the South Orkney Islands, and the design has since remained unchanged.

This report presents the results from the seventh of the annual survey seasons (2017) off the South Orkney Islands including results from continuous acoustic recordings, trawl station data and krill predator sighting data collected during daylight hours along the transects. In addition, on board experiments investigating the survival of krill which had escaped through the trawl meshes were conducted. These experiments were part of the ongoing project SILF (Understanding and predicting size selectivity and escape mortality in commercial Zooplankton fisheries: case study on Antarctic krill). Our scientific team consisted of scientists, engineers and students from the Institute of Marine Research (Norway), University of Bergen, Technical University of Denmark and Yellow Sea Fisheries and Research Institute. As monitoring platform the krill fishing vessel 'Saga Sea' was used, owned by the Norwegian company Aker Biomarine.

Material and methods

Survey design, area and vessel
The supply vessel "La Manche" (Aker Biomarine ASA) departed Montevideo, Uruguay on the 27 January. On the 4 February the vessel dropped anchor north of Coronation Island (South Orkney Islands), and survey equipment and -personnel were transferred to the commercial trawler "Saga Sea" (Aker Biomarine ASA). Next, echo sounder calibration was carried out under good conditions in 'Saga Bay' north of Coronation Island, and the hydrophone mooring deployed last year was recuperated east of the 'Little Canyon'. The transect-survey commenced on the 6 February at 08:43 UTC and ended on 11 February at 10:55 UTC.

The survey design around the South Orkney Islands included five parallel transects extending from the northernmost waypoints at 59.67°S and southernmost waypoint at 62.00°S. Longitudes for transects 1 through 5 are at 44°W, 45°W, 45.75°W, 46.5°W and 47.5° W, respectively. This season the coverage of the survey area was not affected by sea-ice as experienced in some previous years. Wind conditions were also advantageous for surveying and only 1 trawl station (A5) had to be skipped due to heavy seas (Figure 1). After the completion of the standard survey all scientist personnel were returned to "La Manche" on the 11 February on the south side of Coronation Island, and the survey ended on the 20 February when the vessel reached Montevideo, Uruguay.

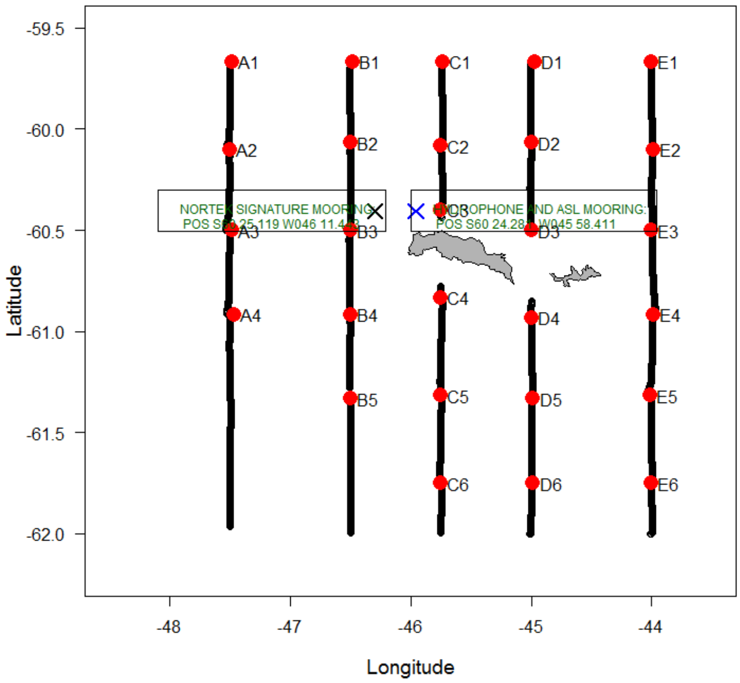

Figure 1. Summary of the 2017 krill monitoring survey. The black lines denote the transect lines. The red circles indicate the trawl stations.

Acoustic data collection

Vessel mounted echo sounders

'Saga Sea' is equipped with Simrad ES60 echo sounders operating at 38 and 120 kHz. These are the fishery versions of the scientific Simrad EK60 used for research purposes. Scientific transceivers (GPTs) were available, but not used since experience has shown that there is less noise on the 120 kHz when using the vessel mounted GPTs. The ES60 GPTs can be calibrated and logged with only some limitations in software flexibility, and this was done for the present survey.

The echosounders were calibrated close to shore ('Saga Bay') north of Coronation Island using standard sphere calibration (Foote et al.1987). The echo sounder was operating continuously during the survey with a ping interval of 1.5 seconds. Nominal vessel speed during surveying is 10 knots, and could be kept during the entire survey. Acoustic data were sampled down to 500 m on both frequencies. Other transceiver settings are specified in Table 1.

Table 1. Specification of transceiver settings on 'Saga Sea' applied during the 2017 survey.

Echosounder specification	38 kHz	120 kHz
Transducer type	ES38-B	ES120
Transmitted power (W)	2000	300
Pulse duration (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	10.1	38.4
Sound speed (ms^{-1})	1452	1452
Sample distance (m)	0.186	0.186
Two-way beam angle (dB)	-20.5	-18.5
S_v transducer gain (dB)	25.52	23.94
S_A-correction	-0.70	-0.41

Sonar

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

Acoustic moorings

An Aural hydrophone deployed last year for passive recording of whale sounds was successfully retrieved east of the 'Little canyon' at position S 60° 24.297 and W 045° 57.548. It had been logging data from the deployment in February until August last year. The settings were slightly changed to attempt to increase the data collection period, and then deployed for a new year. The Aural was deployed together with the stationary ASL Acoustic Zooplankton Fish Profiler (see details in Appendix), which has previously been successfully deployed over two entire annual cycle periods east of the 'Little canyon' (Position S 60° 24.281 and W 045° 58.311). The ASL mooring was not deployed last year due to technical problems.

A NorTek Signature 55 combined echo sounder and Acoustic Doppler Current Profiler (ADCP; see details on deployment in Appendix) was deployed west of the ‘Little canyon’ at position S 60° 25.119 and W 046° 11.443.

Acoustic data analyses

Discrimination of targets

The method for target discrimination as described in the CCAMLR protocol requires data from the frequencies 38, 120 and 200 kHz and our data were collected at 38 and 120 kHz. However, we used the idea that different targets have predictable frequency dependent volume backscattering strength (S_v; dB re m^{-1}) within a specified range of body lengths. Following this idea, targets which fall within a specific range of ΔS_v-values ($S_{v,120} - S_{v,38}$) will be identified as *E. superba*. The method was applied on sample bins of 514 m horizontal*5 m vertical resolution. 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.

Target strength prediction

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

The predicted target strengths were used to calculate weighted conversion factors (CF) from NASC-values to biomass density

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

where *f* is the frequency of a specific length group (*i*) and W(TL) is weight at total length, which was calculated following Hewitt et al. (2004):

$$W(g) = 2.236 \cdot 10^{-3} \cdot TL^{3.314}$$

σ(TL) is the backscattering cross-section at a specific total length and was calculated using the full SDWBA model.

Estimation of biomass

Based on the average biomass density for each nautical mile, a weighted biomass density for each transect line could be calculated and the sampling variance from the averages of each transect line according to Jolly and Hampton (1990).

Biological sampling

Four to six trawl stations were conducted on each of the 5 transect lines (Fig. 1) using a “Macroplankton trawl”; a plankton trawl having a 6 x 6 m mouth opening and a mesh size of 7 mm from the mouth to the rear end (see Krafft et al. 2010). At each trawl station, the trawl was lowered from surface to 200 m depth and towed to surface at 2.5 knots speed. When a trawl was landed on deck, the catch was weighed and taxonomic composition was investigated. For *E. superba*, the length of individual krill was measured (± 1 mm) from the anterior margin of the eye to the tip of telson excluding the setae, according to the “Discovery method” used in Marr (1962). Sex and maturity stages of *E. superba* were determined on fresh material using the classification methods outlined by Makorov and Denys (1981). In brief; in contrast to all other stages the juveniles had no visible sexual characteristics, males were divided into three sub adult stages: MIIA1, MIIA2 and MIIA3 and two adult stages: MIIIA and MIIIB, females were divided into one sub adult stage: FIIA and five adult stages: FIIIA, FIIIB, FIIIC, FIIID and FIIIE (see Krafft et al.2015 for further details).

Hydrographical sampling
A Seabird CTD sensor was mounted in an open metal frame for protection and welded on the trawl beam to obtain profiles of temperature and salinity during the trawl hauls.

Marine predator observations
Sightings for seabirds and marine mammals were carried out by two dedicated observers. Observations were made during daylight hours (0600-2200 local time); in total approximately 43 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 10 knots, with observations made from the bridge approximately 10m above sea level.

Observations were made forward and to one side covering targets out towards the horizon, usually from the Forward Port Quarter, but sometimes from the Forward Starboard Quarter, depending upon weather conditions. Each recorded observation included the species and the number of individuals observed, the time (in UTC), the ship's position, the distance to the target at first sighting, and the relative angle from the vessel. For whales, seals and penguins the swim direction relative to the vessel was also recorded. Records were made using an in-house voice recording system which contains a microphone and a GPS connected to a laptop. The system records vessel position and time continuously at regular intervals, and a .wav sound-file is generated each time a sighting is read into an activated microphone.

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

Validation of a method for ageing Antarctic krill
A newly developed method identifies growth zones in the Antarctic krill eye stalks (Krafft et al. 2016). To validate the method, the increment deposit rate requires validation. Krill were chemically stained with calcein over a 24h period, then kept in holding tanks with rich supply of sea surface water for monitoring of growth. Every second week, during this fishing season, krill we be sampled and fixated for later on-shore analysis.

Krill mesh escapement
The size selection process of krill was studied as part of the ongoing SILF project, for establishing detailed understanding of the influence of different sections of a trawl during a harvesting process. Selectivity analysis are length based. Krill display a considerable morphological variation during the spawning season, which may introduce a variability into length based selection estimates. Individuals representing the different stages of krill were collected to perfectionate size selectivity models for krill. Controlled penetration experiments were executed with relevant meshes used commercially, including codend and trawlbody nets, using underwater video recordings of krill escaping custom designed net-frames.

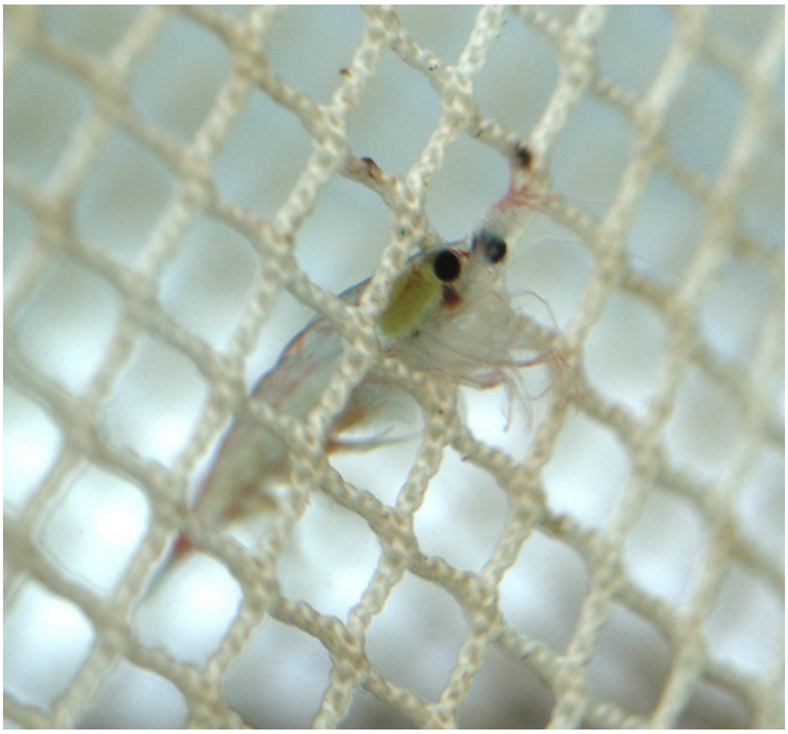

Figure 2. Example of image of krill in contact mode with trawl meshes.

Results

Acoustics

Acoustic survey estimates of krill distribution and biomass

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

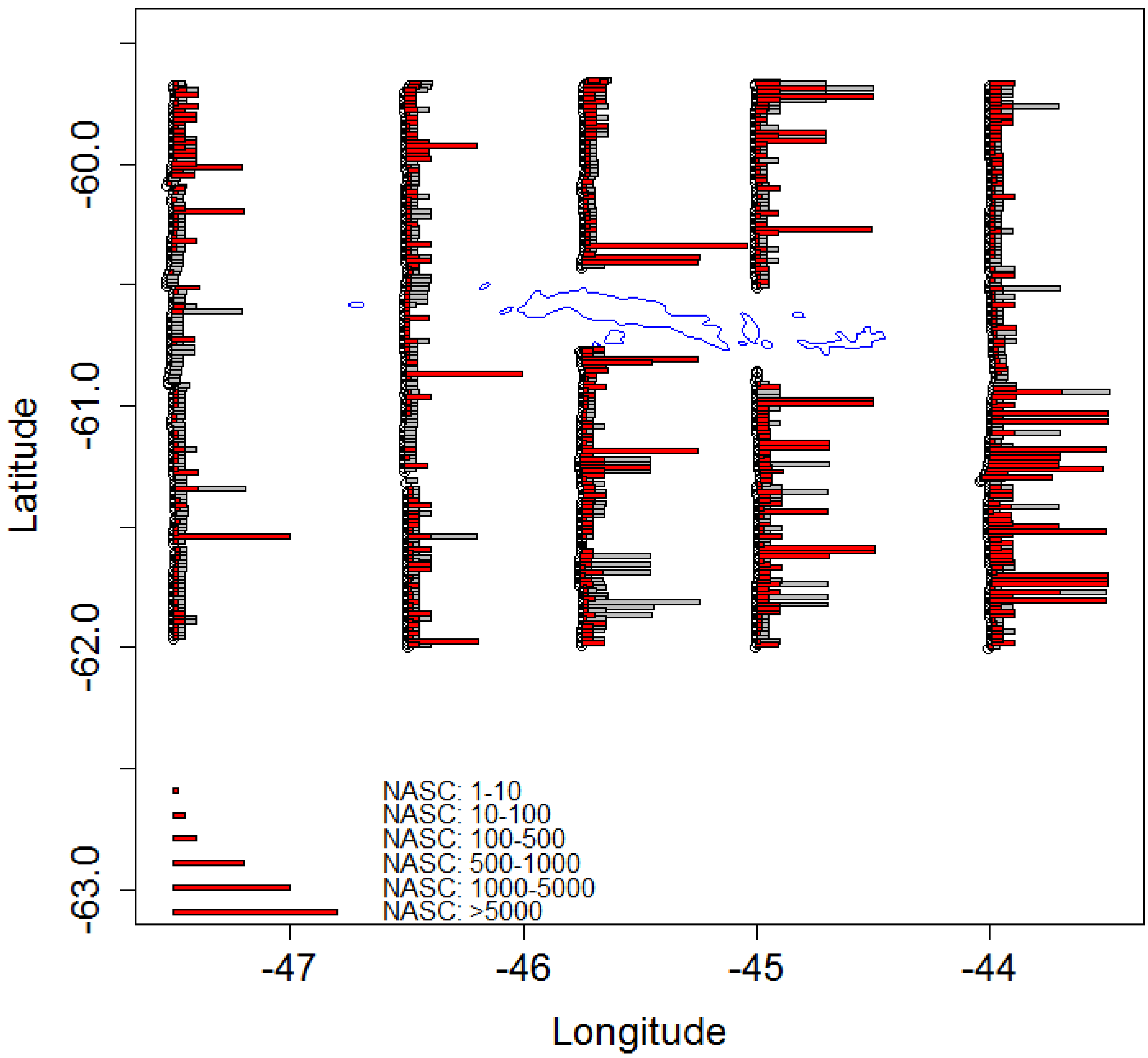

Figure 3. Distribution of Nautical Area Scattering Coefficients (NASC; m^2/nmi^2) allocated to *E. superba* (red) and other targets (grey) from the 120 kHz recordings.

Table 2. Summary table of krill biomass estimation from all surveys, including the 2017 survey. The ‘Subarea’ refers to an area north of the islands which was defined in order to make comparisons between years despite incomplete survey coverage in some years. The years with full or near-full coverage were 2012, 2014, 2016 and 2017.

	Entire covered area						Subarea							
Year	Freq	Density (g/m^2)	CV	**Freq**	**Density (g/m^2)**	**CV**	Freq	Density (g/m^2)	BM (mill. t)	CV	**Freq**	**Density (g/m^2)**	**BM (mill. t)**	**CV**
2011	38	69.31	12	**120**	**108.69**	**18**	38	121.79	3.29	17	**120**	**212.75**	**5.74**	**28**
2012	70	41.49	30	**120**	**86.93**	**32**	70	41.15	1.11	56	**120**	**94.79**	**2.56**	**66**
2013	38	118.19	26	**120**	**120.28**	**32**								
2014	38	73.69	38	**120**	**148.29**	**41**	38	143.02	3.86	42	**120**	**301.39**	**8.14**	**46**
2015	38	5.26	51	**70**	**7.10**	**49**	38	7.83	0.21	54	**70**	**10.42**	**0.28**	**51**
2016	38	57.10	53	**120**	**57.19**	**45**	38	9.4	0.25	33	**120**	**10.12**	**0.27**	**26**
2017	38	32.91	20	**120**	**42.23**	**26**	38	25.22	0.68	34	**120**	**30.71**	**0.83**	**51**

Biological sampling

A total of 28 trawl stations was successfully completed during the survey, 1 station was decided not to carry out due to harsh weather conditions (Figure 1). The five largest trawl catches were either located in the northern part of the study area (stations B1, C1, D1 and E1), these were dominated by *Salpa thompsoni,* or south of the Signy island (C4) dominated by *Euphausia superba. Salpa thompsoni* was present at 27 stations, *Euphausia superba* was present at 21 stations, fish was present at 24 stations, Gammaridea at 24 stations, jelly fish at 21 stations and other taxa at 22 stations (Figure 4).

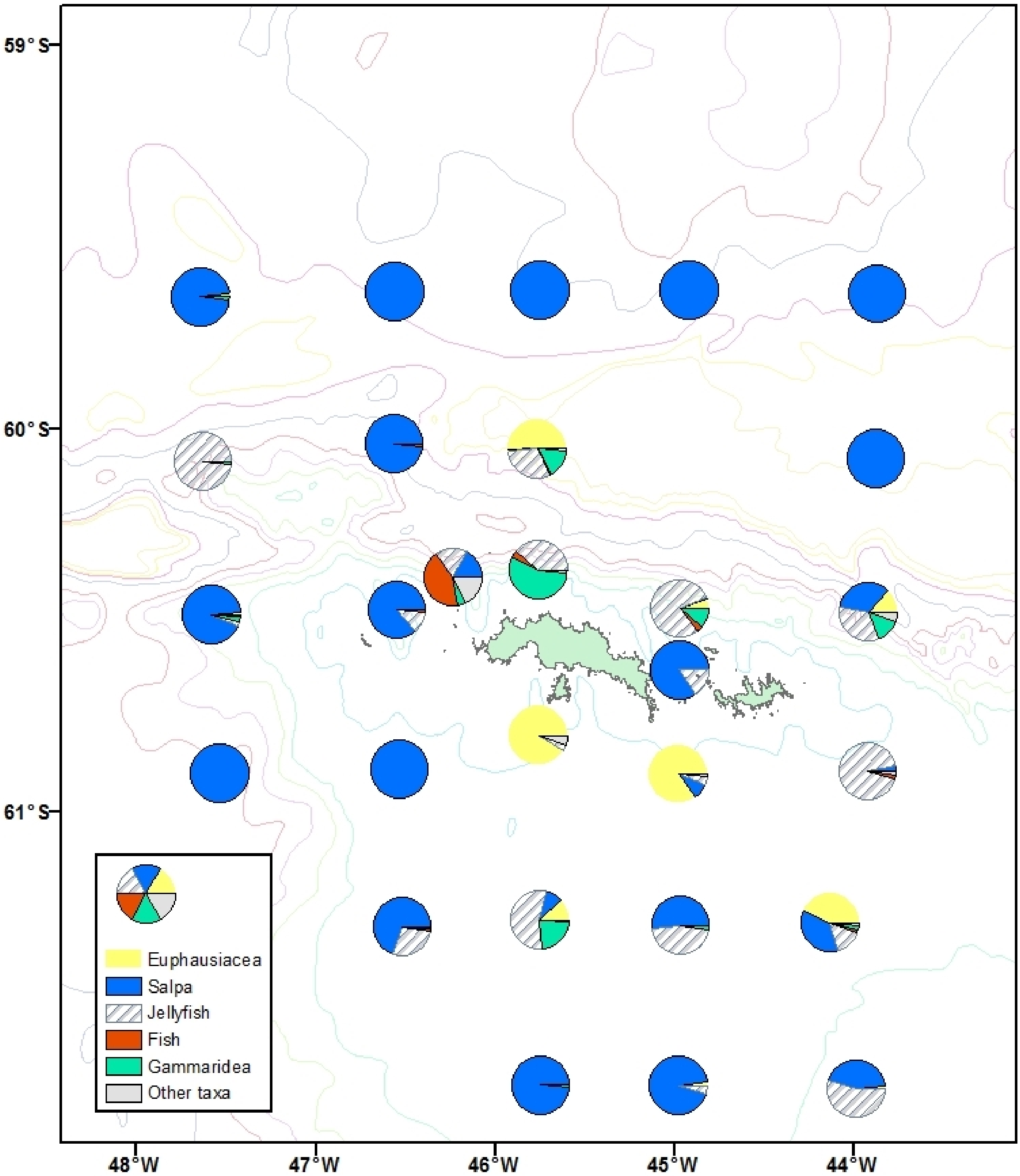

Figure 4. The most common taxa in terms of proportional catch weight.

The demographic composition of the *E. superba* caught in the trawl was dominated by juveniles and young males (Table 3). Among adults, males with completely developed spermatophores (MIIB) dominated in the catch, and females with spermathophores attached to their thelycum (FIIIB).

Table 3. Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctic krill caught in the South Orkney Islands area in the 2017 season.

Stage	N	Proportion	Total length (mm)
Juvenile	46	10.2	27.8 ± 2.1
MIIA1	114	25.2	33.2 ± 2.7
MIIA2	141	31.2	37.5 ± 3.2
MIIA3	22	4.9	43.3 ± 4.6
MIIIA	22	4.9	50.9 ± 3.3
MIIB	39	8.6	51.2 ± 3.7
FIIB	13	2.9	34.7 ± 2.1
FIIIA	12	2.7	47.8 ± 3.2
FIIIB	20	4.4	48.5 ± 4.2
FIIIC	12	2.7	51.9 ± 3.9
FIIID	8	1.8	50.8 ± 7.6
FIIIE	3	0.7	45.0 ± 3.5
Total	**452**		

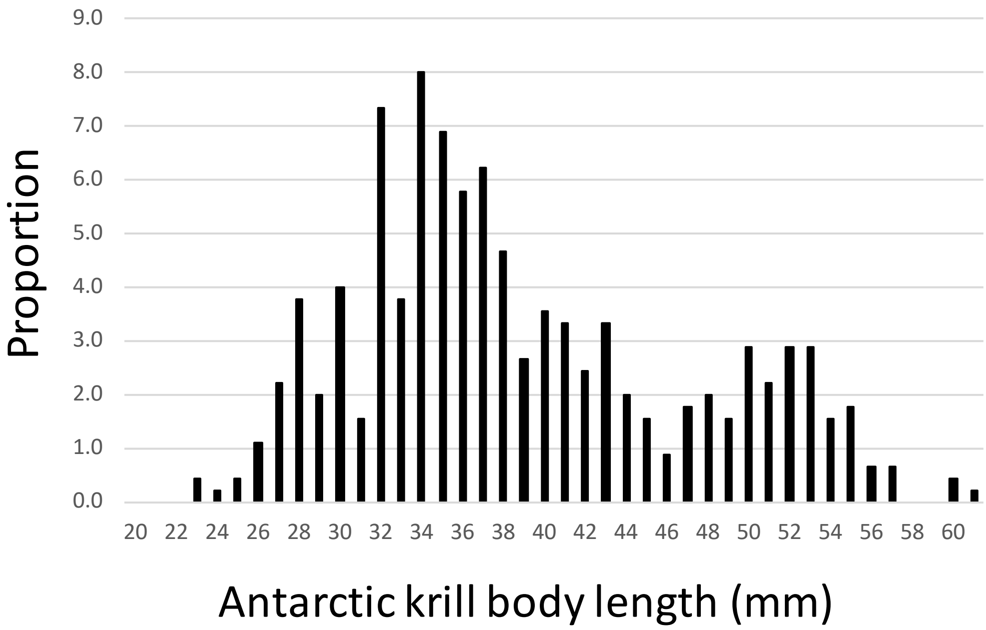

Figure 5. Antarctic krill length histogram based on all samples from the 2017 survey combined.

Hydrography

The hydrographical profiles from the survey area based on the trawl mounted ctd are shown in figure 6. There was a marked thermocline in all casts around 50 m depth. There was also a halocline around the same depth recorded in some casts, but less pronounced in the casts close to land.

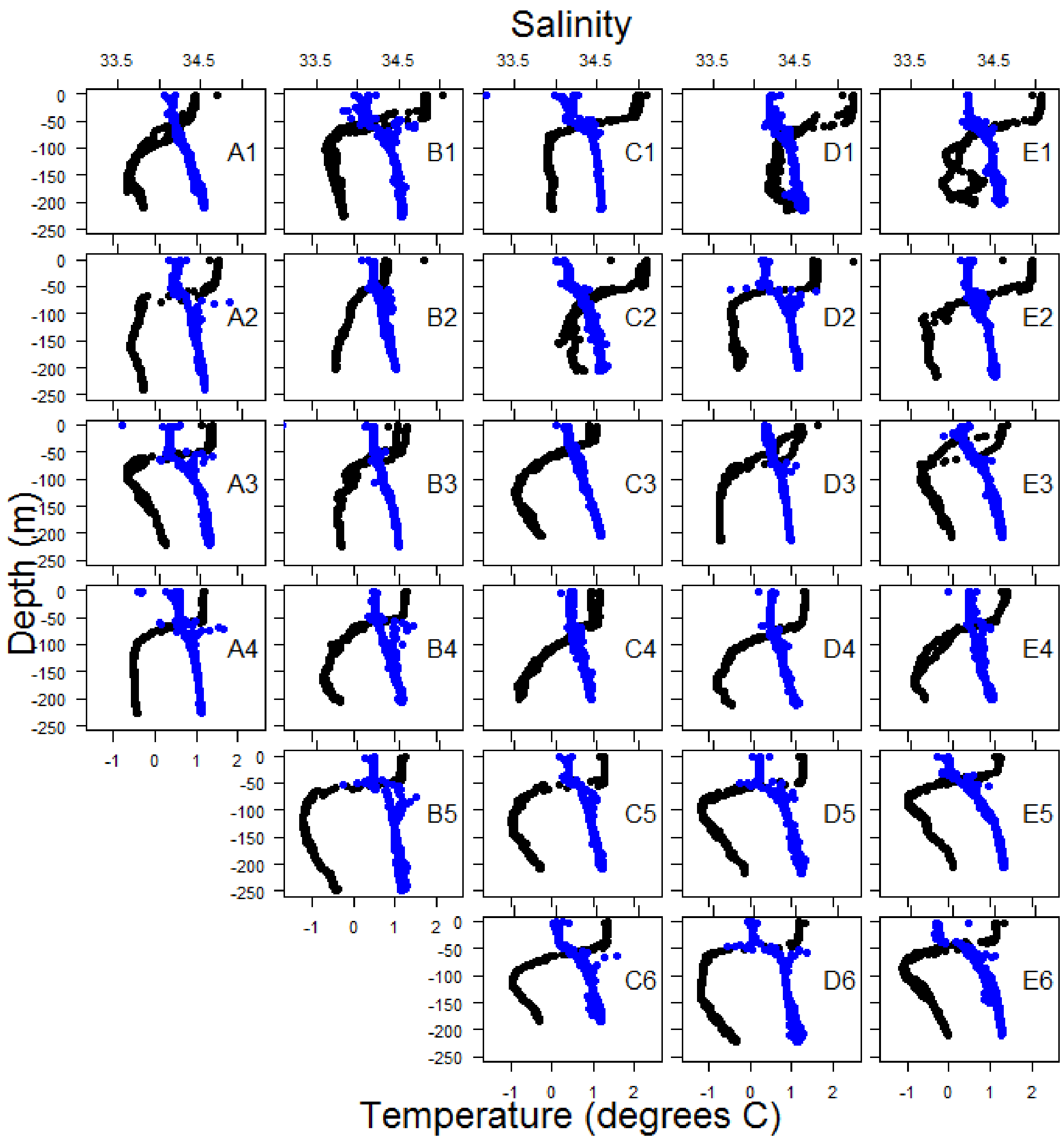

Figure 6. Hydrographical profiles from the ctd-casts with temperature in black and salinity in blue.

Marine predator observations

The conditions for predator observing were very good during most of the survey. In general there was good visibility and relatively calm sea, interrupted by short periods of fog. A total of 1670 sightings of 2556 individuals covering 20 species of marine predators were done. Notable observations were 84 whales, 475 chinstrap penguins (*Pygoscelis antarcticus*) and 47 Antarctic fur seals (*Arctocephalus gazella*) (Figure 7).

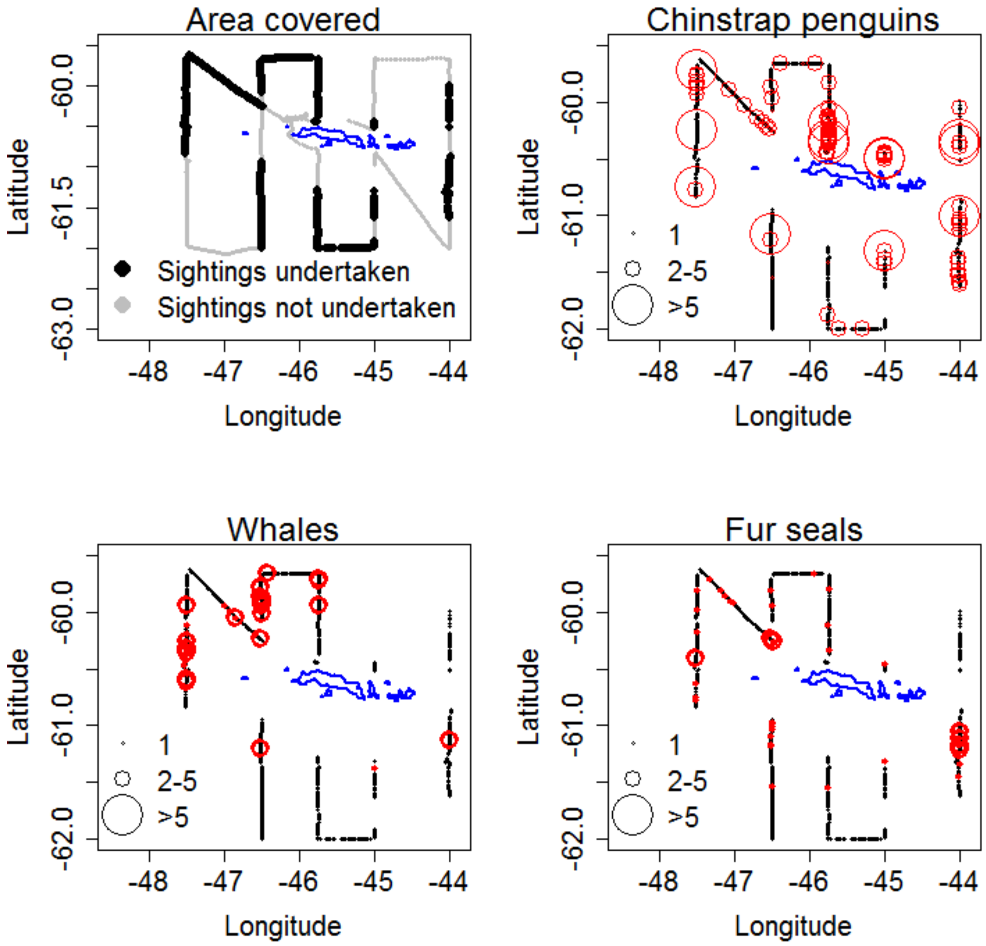

Figure 7. Overview of recorded sightings of chinstrap penguins (*Pygoscelis antarcticus*), whales (fin whales; *Balaenoptera physalus* and humpback whales; *Megaptera novaeangliae*) and fur seals (*Arctocephalus gazella*) during the survey.

Acknowledgements
We extend our gratitude to the Aker Biomarine AS for providing 'Saga Sea' and its crew to disposal for this research survey free of charge. We are most grateful to the captain, officers and crew on board 'Saga Sea' for all the help provided during the cruise. We greatly thank observer on board Jane Lelec for excellent help with the predator observation work.

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Appendix

Institute of Marine Research

Data record book for self registrating instruments detail

Ship/Platform:	Juvel
Location:	Little Canyon
Latitude:	S 60° 24.281
Longitude:	W 045° 58.311

Instruments / Sensors

#	Brand	Type	Serial No.	Depth	Comments
1	ASL	Acoustic Zooplankton Fish Profiler	55062	xxx	
2	Aural	M2			
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Bottom depth:	479 m
Outgoing date:	2017.02.18
Outgoing time (UTC):	15:22
Incoming date:	Click here to enter a date.
Incoming time (UTC):	xx:xx

Comments:

~~ARGOS~~

~~PTTID: 00000~~

Acoustic release: IXSEA ARX61

Serial no: 0301

Range code: 1421

Release code: 1455

Station name: Krill 2015 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	0
Shackle Galvanized Steel	3.25	0
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
ThimblesStainless Steel		0
Thimble Galvanized Steel		0
Thimble Galvanized Steel		0
Thimble Nylon		0
Bolt Stainless Steel (RCM-7)		0
		0
		0

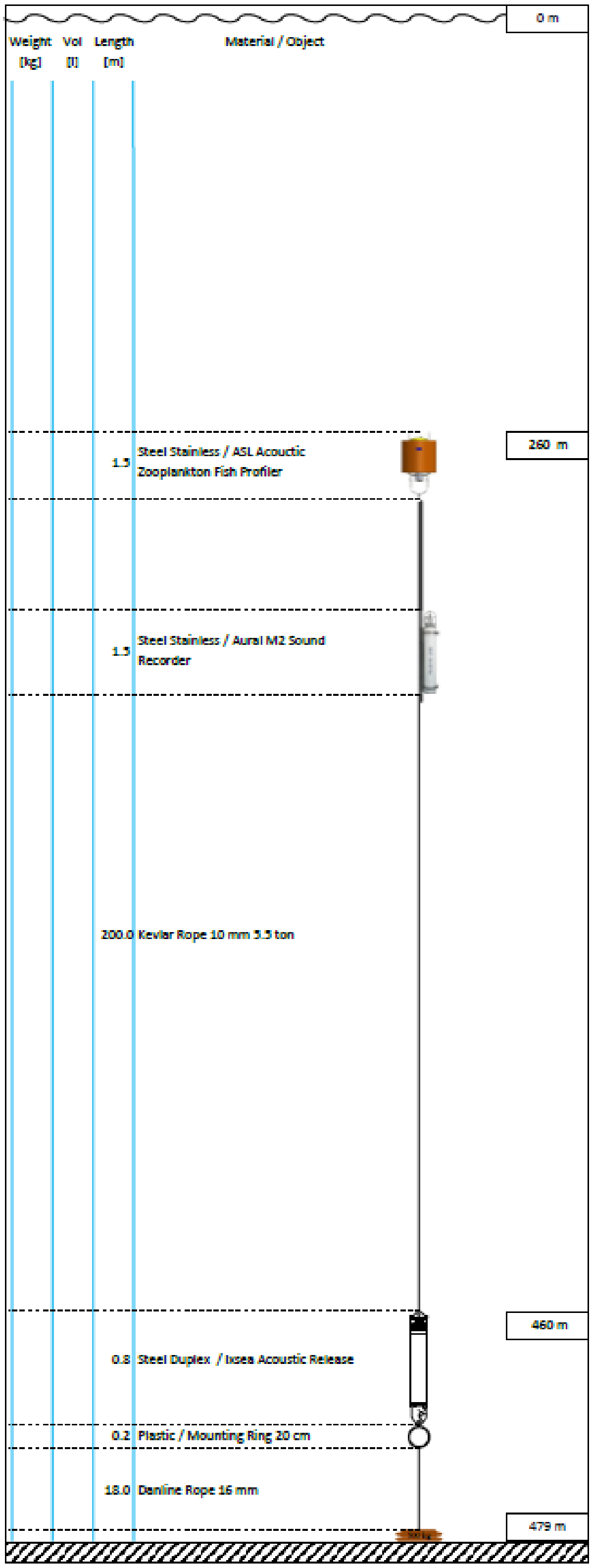
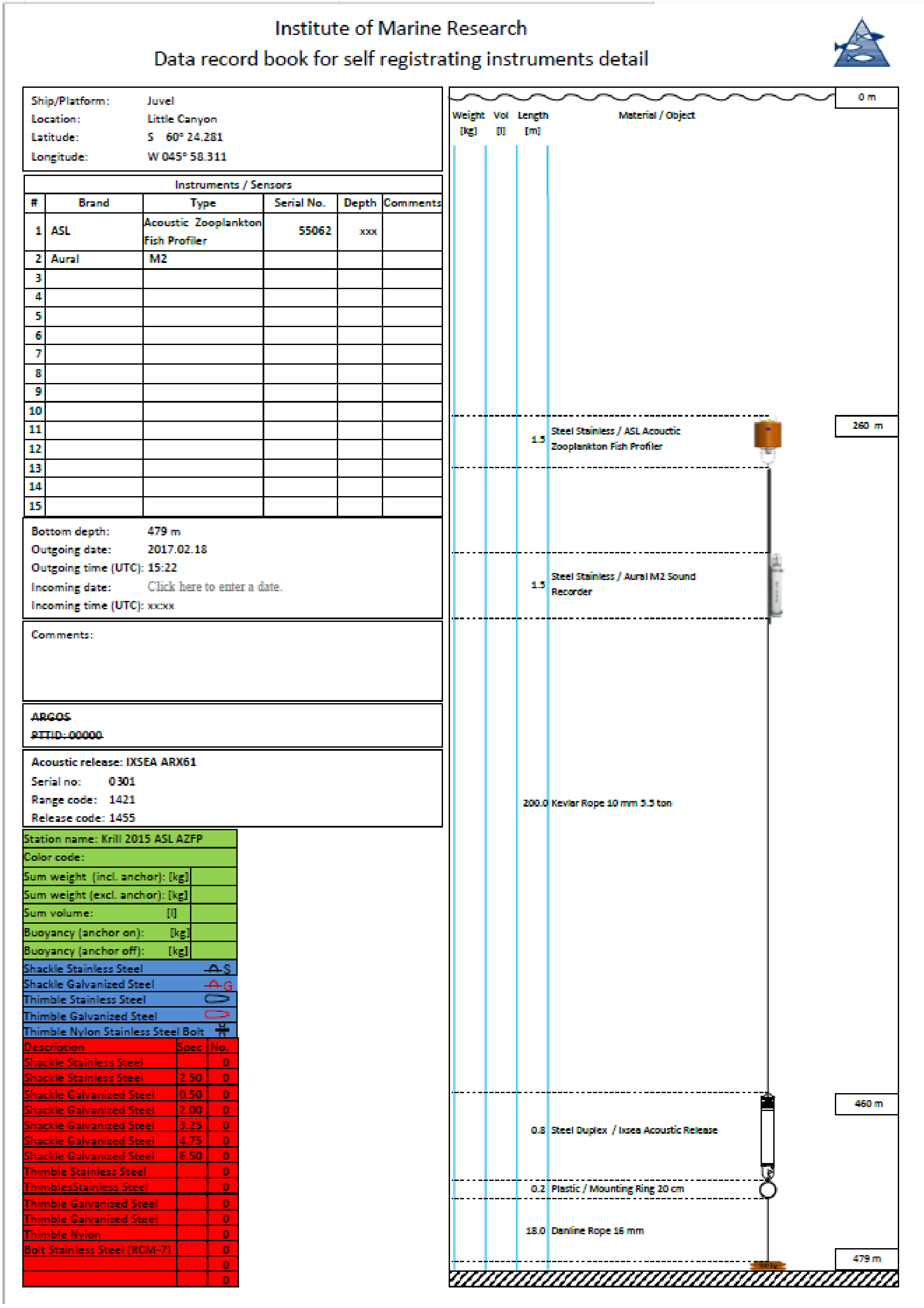


Figure A1. Details on the 2017 deployment of the ASL acoustic and AURAL sound recording moorings.



Institute of Marine Research

Data record book for self registrating instruments detail

Ship/Platform: Juvel
Location: Little Canyon
Latitude: S 60° 24.281
Longitude: W 045° 58.311

Instruments / Sensors					
#	Brand	Type	Serial No.	Depth	Comments
1	ASL	Acoustic Zooplankton Fish Profiler	55062	xxx	
2	Aural	M2			
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Bottom depth: 479 m
Outgoing date: 2017.02.18
Outgoing time (UTC): 15:22
Incoming date: Click here to enter a date.
Incoming time (UTC): xx:xx

Comments:

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

Acoustic release: IXSEA ARX61
Serial no: 0301
Range code: 1421
Release code: 1455

Station name: Krill 2015 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	0
Shackle Galvanized Steel	3.25	0
Shackle Galvanized Steel	4.75	0
Shackle Galvanized Steel	6.50	0
Thimble Stainless Steel		0
ThimblesStainless Steel		0
Thimble Galvanized Steel		0
Thimble Galvanized Steel		0
Thimble Nylon		0
Bolt Stainless Steel (RCM-7)		0
		0
		0

Figure A2. Details on the 2017 deployment of the NorTek echo sounder and current velocity profiler mooring.