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Cruise participants:
Institute of Marine Research: Bjørn A. Krafft, Ronald Pedersen and Georg Skaret
British Antarctic Survey: Phil Trathan and Catrin Thomas
Yellow Sea Fisheries Research Institute: Xinliang Wang

Project leader: Svein A. Iversen

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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. Krill are abundant in this region, but available data sources for use in scientific advisory to the fisheries management are scarce.

During the last two decades the US AMLR Program and the British Antarctic Survey have carried out small-scale surveys in the Bransfield Strait area and around the South Georgia Islands, in subarea 48.1 and 48.3, respectively. Norwegian fishing companies have in recent years contributed to more than half of the total catch of Antarctic krill, and as a contribution to the collection of scientific data needed for fisheries management, the Norwegian fishing company Aker Biomarine ASA, offered to carry out an annual 5-day 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 using similar standards to 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. Such an integrated effort could also make an important contribution to the Southern Ocean Observing System (SOOS) and provide valuable information for use within analysis of the international ICED Program (Integrated Climate and Ecosystem Dynamics- ww.iced.ac.uk).

The first annual survey was carried out in January/February 2011 using the fishing vessel Saga Sea (Aker Biomarine ASA) (Krafft et al. 2011). 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. The new survey design will be maintained until the last survey season.
This report presents data from the second of the annual survey seasons (2012) around the South Orkney Islands including continuously recorded acoustic data, krill predator sighting data collected at daylight hours along the transects and trawl station data. Our scientific team consisted of scientists and engineers from the Institute of Marine Research (Norway), British Antarctic Survey (UK) and the Yellow Sea Fisheries Research Institute (China). As research platform the krill fishing vessel ‘Juvel’ owned by the Norwegian group of companies Olympic was offered to our disposal.

Material and methods

Survey design, area and vessel

The commercial krill trawler 'Juvel' (Olympic) departed from Montevideo, Uruguay on 19 January 2012 and started the survey along the predefined transect grid off the South Orkney Islands, CCAMLR subarea 48.2 at 0200 (UTC) on 26 January. Starting point was the southernmost point of the easternmost transect. The survey included five parallel transects extending from the northernmost waypoints at 59.67°S and southernmost waypoint at 61.75°S. Longitudes for transects 1 through 5 were, respectively, at 44°W, 45°W, 45.75°W, 46.5°W and 47.5°W. The survey ended at 1900 (UTC) on the 29 January and the vessel reached Port Stanley, Falkland Islands, on the 8 February.

Acoustic sampling procedure

For the collection of acoustic data, a Simrad echo sounder system logged data continuously at three frequencies, 38, 70 and 120 kHz. From the original vessel set-up Simrad ES60 were replaced with Simrad EK60 General Purpose Transceivers connected to ES60 transducers mounted in the vessel hull. An attempt to calibrate the system prior to the survey was carried out in the waters off the South Orkneys using standard sphere calibration with a 38.1 mm tungsten carbide sphere (Foote et al., 1987). However, due to difficult current conditions, the calibration was only partly successful and merely the results for the 120 kHz echo sounder could be used. A post-calibration was therefore carried out in Scotia Bay on Laurie Island. This bay is probably the most sheltered and suitable spot for calibration at the South Orkneys. During post-calibration it was discovered that the 38 kHz transducer was not working properly, so only data from the 70 kHz and 120 kHz were used for the biomass estimation. The echo sounder was operating with a ping repetition rate of 1 second^{-1}. Occasionally ping interval requirements could not be met due to the system settings and a higher interval was then chosen (between 1 and 1.5 second^{-1}). Nominal vessel speed was 10 knots. The transceiver settings are specified in Tab. 1. Acoustic data were sampled down to 750 m on all three frequencies.

'Juvel' is also equipped with a high frequency (116 kHz in single CW/FM) Simrad SH 80 sonar and a low frequency (26 kHz in single CW/FM) Simrad SP70 sonar. The sonar pulse transmission was synchronized with echo sounder transmission and raw data were logged continuously on both sonars. The SH80 sonar was applied in the 'Bow up/180 degrees' mode. In this mode a 180 degree horizontal section and a vertical 60 degree section is obtained as output. The sonar was fixed at 90 degrees pointing to starboard side. SP70 data were logged in the 'North up' mode providing a 360 degree horizontal section.

Analyses of the acoustic data

The acoustic data were pre-processed in the software Large Scale Survey System (LSSS; Korneliussen et al. 2006). Signals interpreted as noise were removed, as were periods with trawling and steaming between transect lines.

Discrimination of targets

The method for target discrimination described in the CCAMLR protocol was applied with some modifications. This method takes advantage of the predictable frequency dependent volume backscattering strength (S_v; dB re m^{-1}) for krill within a specified range of body lengths. The range of ΔS_v-values ($S_{v,120}$ - $S_{v,38}$) is used to discriminate krill from other targets. However, due to the problems with the 38 kHz echo sounder, we applied the range of ΔS_v-values ($S_{v,120}$ - $S_{v,70}$) to discriminate krill. We used the krill length distribution found during the survey to calculate the values of ΔS_v (SC-CAMLR, 2005; Reiss et al. 2008; SC-CAMLR, 2010). The method was applied on sample bins of 50 pings horizontal*5 m vertical resolution, and if ΔS_v fell within the range estimated for krill targets it was included as krill.

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

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

where L_0 is the reference length 38.35 mm (McGehee et al. 1998), k is denoting acoustic wave numbers (k=2πf/c) used to transform the model to different frequencies (f) at a given sound speed (c). A to J are coefficients extracted from the full SDWBA model run parameterized according to the description in the beginning of this section (coefficients are given in Table 2).

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

Each of the five transects extended 120 nmi (nautical miles) and a trawl haul was conducted every 20 nmi, using a 'Macroplankton trawl' (see Krafft et al. 2010) with trawl doors of 7.5 m height. This trawl has a mouth-opening of 38m^2 and a mesh size of 3 mm from the trawl-opening to the rear end. At each trawl station the trawl was lowered from surface to 200 m depth (or ~ 20 m above bottom if the water was shallower than 200 m) and then hauled at 2.5-3 knots.

The catch from each trawl station was weighed using a DeLaval spring scale (250 ± 1kg). A sub-sample was sorted, identified to the nearest taxonomic group and weighed using a Marel M2200 bench scale (300 ± 0.1g) to determine their relative proportion in the sample. A sub-sample was also preserved from each trawl station, on borax-buffered formalin (4%) on a 100ml plastic container. Body length was measured (± 1 mm) for *E. superba* from the anterior margin of the eye to the tip of telson excluding the setae, according to the "Discovery method" used in Marr (1962). Sex and maturity stages of *E. superba* were determined on fresh material using the classification methods outlined by Makorov and Denys (1981). Measurements of body length and sex and maturity were determined for a total of 1865 animals from the 'Macroplankton trawl'.

Hydrographical sampling

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

Marine predator observations

Sightings for seabirds and marine mammals were carried out by 2 dedicated observers who rotated between observing and recording at frequent intervals, usually every 30 minutes. Observations were made during all daylight hours (0600-2200 local time); in total approximately 55 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 at 10m 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. 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 diving predators (penguins, seals and whales), the swim direction relative to the vessel was also recorded. All sightings also included details of the meteorological conditions (i.e. wind, seastate, visibility, glare). Records were entered directly into Excel, where they were processed for later analysis in Arc GIS.

Observations were carried out using both the naked eye and through binoculars. A range of texts were used to identify unknown species and documentations were made with film and photo.

Results

Acoustics

The krill abundance and distribution based on the acoustic recordings from the 120 kHz echosounder is shown in Figure 1. Apart from the recordings along the westernmost transect line, the krill concentrations were generally high compared to last years' survey. The highest concentrations were found to the north-west of the Coronation Island.

The average krill concentrations and biomass estimates are found in Tab. 4. Corresponding to a biomass density of 520 g/m^2, the total biomass for the area was estimated at 21.2 million tons based on the 120 kHz echosounder data, and slightly less when including the night-time data. The biomass density at 70 kHz was less than a third of the one at 120 kHz, and given the difficult calibration conditions, the 70 kHz data should be revisited in the light of a more appropriate calibration in the future.

Biological sampling

From a total of 31 trawl stations, four stations did not contain any zooplankton, in one occasion this was likely caused by net failure. The composition of taxa from the total sample was dominated by the order Euphausiacea (83%), Phylum Cnidaria (6%), Order Mysida (4%), Order Amphipoda (4%), Class Actinopterygii (2%) and Phylum Chaetognatha (1%) (Figure 1). The total sample of Order Euphausiacea was dominated by *E. superba* (84%) and only one other species belonging to this order was found in the catch this season, namely *Thysanoessa macrura* (16%), (Figure 2). A total of 26 stations contained specimens of *E. superba*. The average body length was 32.3 ± 9.2 mm (SD), ranging between 13 – 59 mm (Figure 3, Table 2). The sample comprised 43.7% juveniles, 36.5% sub adults, and 19.9% adults, with a male versus female sex ratio of 1:1 (Figures 4 and 5, Table 2).

Hydrography

The hydrographical profiles are shown in Figure 6, and fluorescence profiles in figure 7.

Marine predator observations

A total of 1793 observations were made covering 20 species of marine predator. Notable species included 70 fin whales (*Balaenoptera physalus*) observed along the cruise tracks, 884 (excluding one observation with approximately 900 individuals hauled out on an iceberg) chinstrap penguins (*Pygoscelis antarcticus*) and 75 Antarctic fur seals (*Arctocephalus gazella*) (Figures 8, 9 and 10).

Acknowledgements

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Tables and figures

Table 1. Specification of transceiver settings applied during the survey. Note that the 38 kHz transducer had problems with sensitivity so the specifications are not shown.

Echo sounder specification	70 kHz	120 kHz
Transducer type	ES70-C	ES120-7C
Transducer depth (m)	0	0
Transmitted power (W)	700	250
Pulse length (ms)	1.024	1.024
Absorption coefficient (dB km^{-1})	23.4	38.4
Sound speed (ms^{-1})	1450	1450
Sample distance (m)	0.186	0.186
Two-way beam angle (dB)	-21	-21
S_v transducer gain (dB)	26.05	25.9
Angle sensitivity alongship	23.0	23.0
Angle sensitivity athwartship	23.0	23.0
3 dB beamwidth alongship (deg)	7.07	6.84
3 dB beamwidth athwartship (deg)	6.88	6.94

Table 2. Parameter settings applied for the prediction of *E. superba* target strength using the full SDWBA model (Demer and Conti, 2006) as implemented in the SDWBApackage2010 (Calise and Skaret, 2011).

Parameter	Symbol	Value applied	Unit	Reference
Krill length	L	$38.35 \cdot 10^{-3}$	m	1
Density contrast	g	1.0357		2
Sound speed contrast	h	1.0279		3
Seawater sound speed	c	1456	$m\ s^{-1}$	
Fatness		1.2		4
Standard deviation of stochastic phase	$sd_{\phi 0}$	sqrt(2)/2	radians	5
Distribution of orientations	θ_0	N[-20,28]	degrees	6
Stochastic realisations		100		4

1 - McGehee et al. 1990; 2 - Foote et al. 1990; 3 - Foote, 1990; 4 - Calise and Skaret, 2011; 5 – Demer and Conti, 2006; 6 - SG-ASAM, 2010

Table 3. Coefficients of the Simplified SDWBA model parameterised with N[-20,28] distribution of orientation angles, krill length of 38.35 mm and fatness coefficient of 20 %.

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

Table 4. Biomass density (BM density) with variance and total biomass (BM) with CV based on acoustic recordings from the 120 kHz and 70 kHz echosounders. Biomass is calculated according to a modified CCAMLR protocol (see text for details).

	Freq (kHz)	Average BM density (g/m^2)	Var	Total biomass (mill. tons)	CV (%)
Night-time excluded	120	520	37117	21.3	37
	70	159	2654	6.5	32
Night-time included	120	468	24987	19.2	34
	70	146	1918	6.0	30

Table 5. Number and proportions (%) of different sexual maturity stages of juvenile, male and female Antarctickrill caught in the South Orkney Islands area, during 26-29 January 2012.

Krill maturity stages	No. in sample	Proportion (%)	Total length (Mean±SD)
Juvenile stage 1	815	43.7	24.8 ± 3.1
Male subadult MIIA1	197	10.6	32.2 ±3.3
Male subadult MIIA2	113	6.1	36.5 ± 4.0
Male subadult MIIA3	58	3.1	44.0 ± 3.1
Male adult MIIIA	33	1.8	47.1 ± 2.3
Male adult MIIIB	169	9.1	48.7 ± 3.3
Female subadult FIIB	312	16.7	31.3 ± 4.0
Female adult FIIIA	49	2.6	39.1 ± 3.9
Female adult FIIIB	39	2.1	44.4 ± 2.6
Female adult FIIIC	24	1.3	45.2 ± 3.4
Female adult FIIID	38	2.0	48.6 ± 3.5
Female adult FIIIE	18	1.0	47.9 ± 5.0
Total	1865		

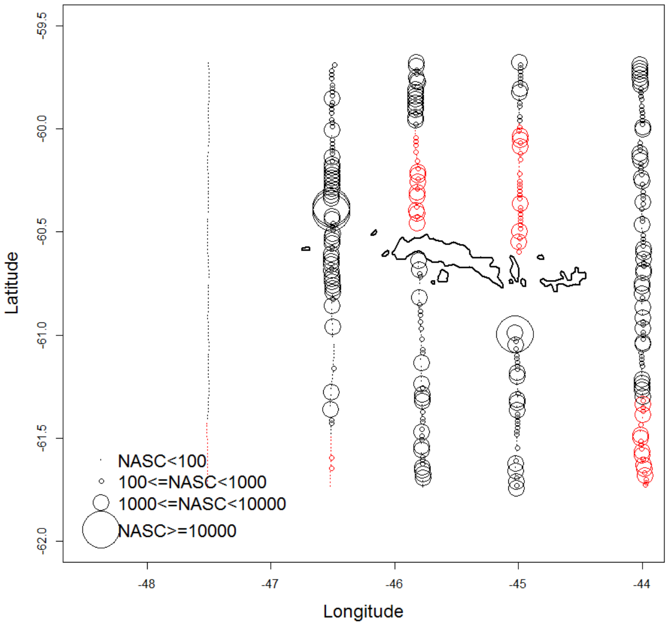

Figure 1. Distribution of Nautical Area Scattering Coefficients (NASC (m^2/nmi^2) allocated to krill. Black circles denote daytime hours, and red circles night-time hours. The data were collected during 26-29 January 2012 in the South Orkney Island waters.

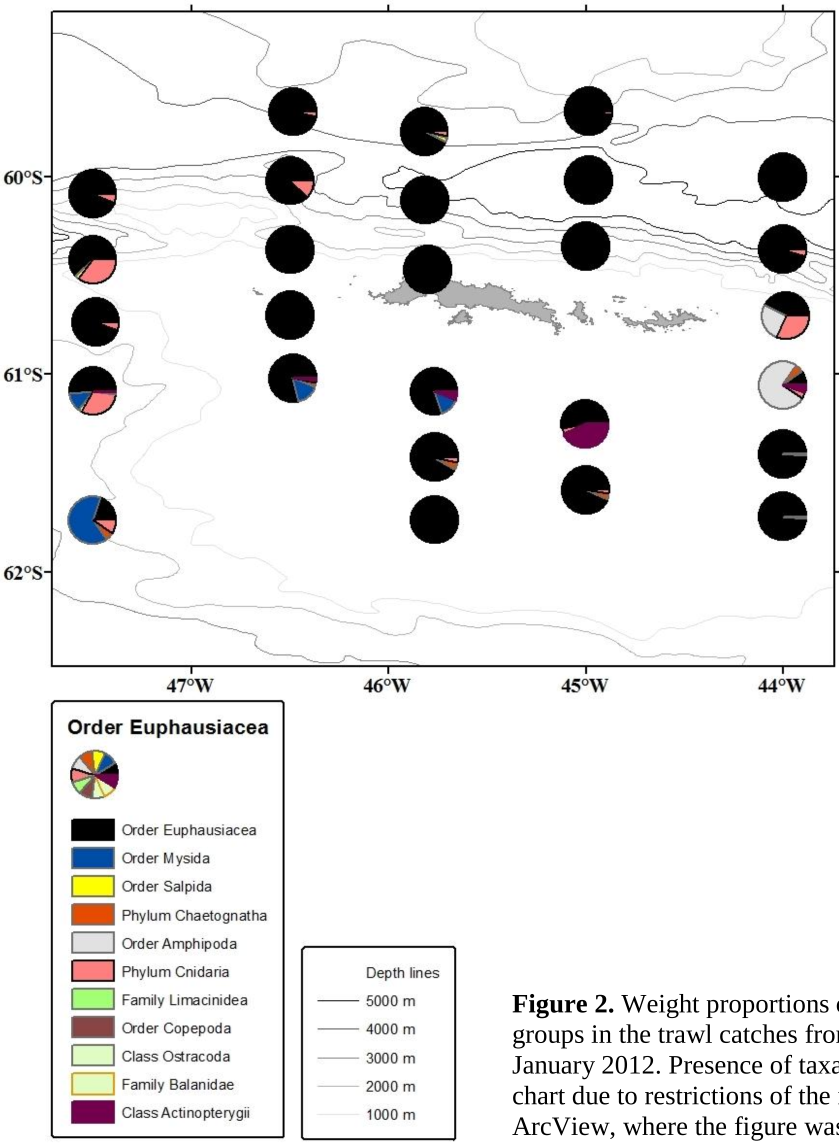

Figure 2. Weight proportions of different macrozooplankton groups in the trawl catches from South Orkney Islands waters in January 2012. Presence of taxa <1% is not visible in the pie chart due to restrictions of the resolution in the software ArcView, where the figure was generated.

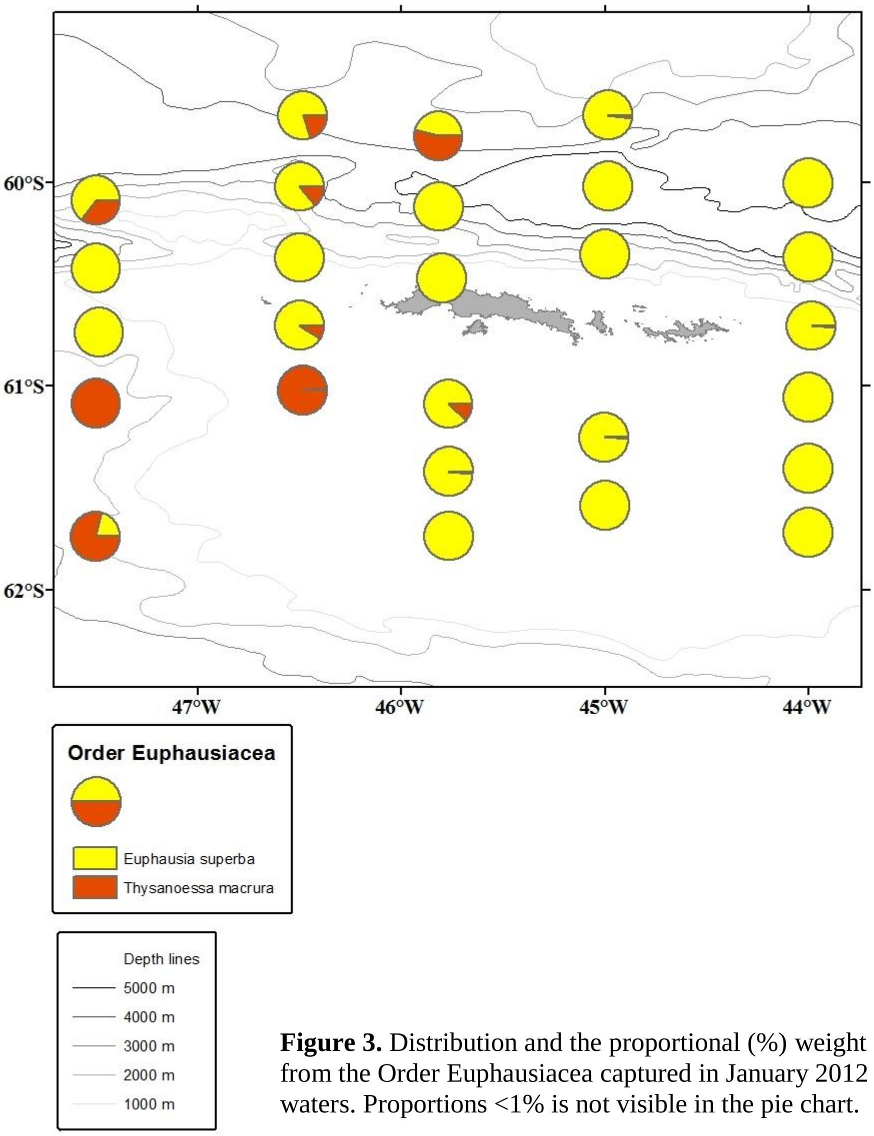

Figure 3. Distribution and the proportional (%) weight composition of the two species from the Order Euphausiacea captured in January 2012 in the South Orkney Island waters. Proportions <1% is not visible in the pie chart.

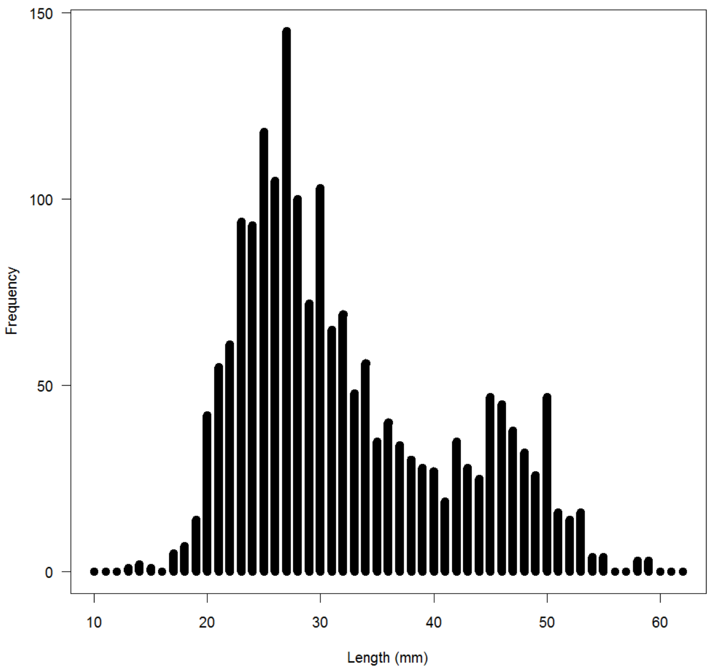

Figure 4. Krill length histograms based on all samples combined.

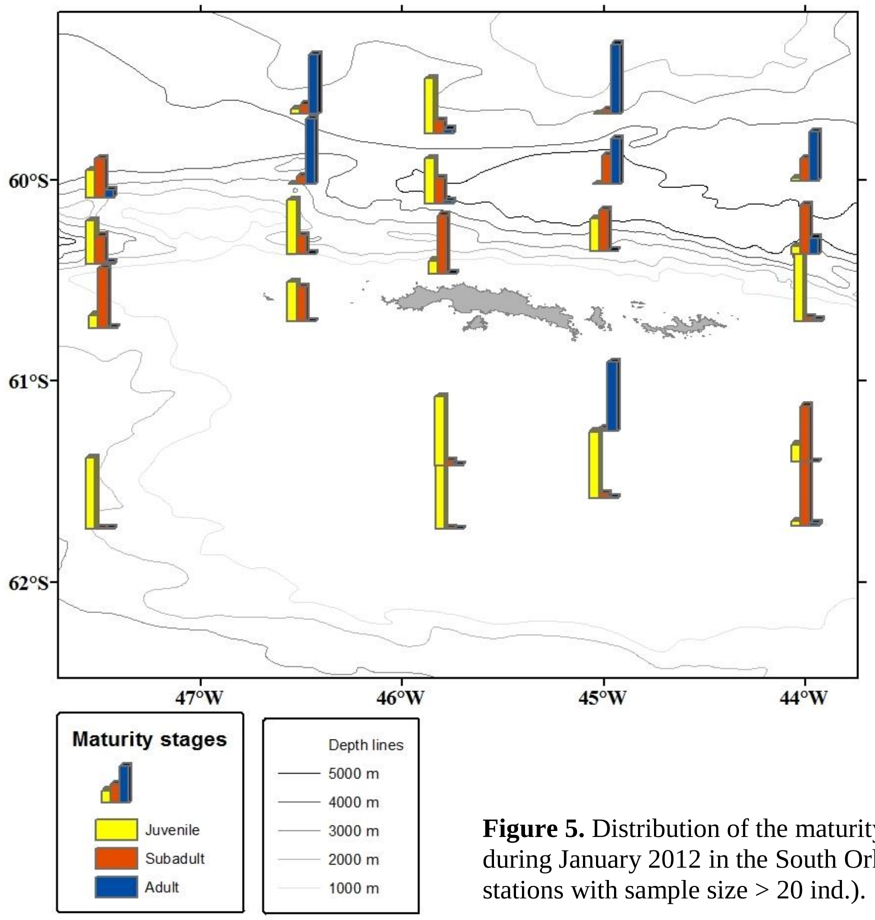

Figure 5. Distribution of the maturity stages of *E. superba* captured during January 2012 in the South Orkney Island waters (included stations with sample size > 20 ind.).

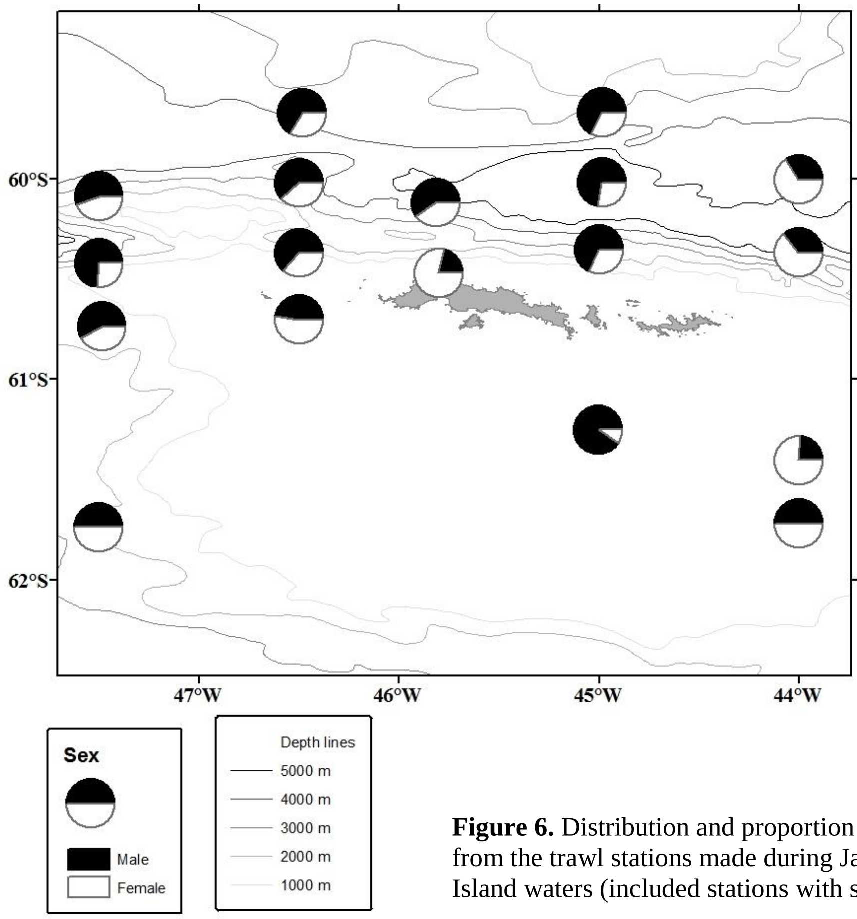

Figure 6. Distribution and proportion of *E. superba* males and females from the trawl stations made during January 2012 in the South Orkney Island waters (included stations with sample size > 20 ind.).

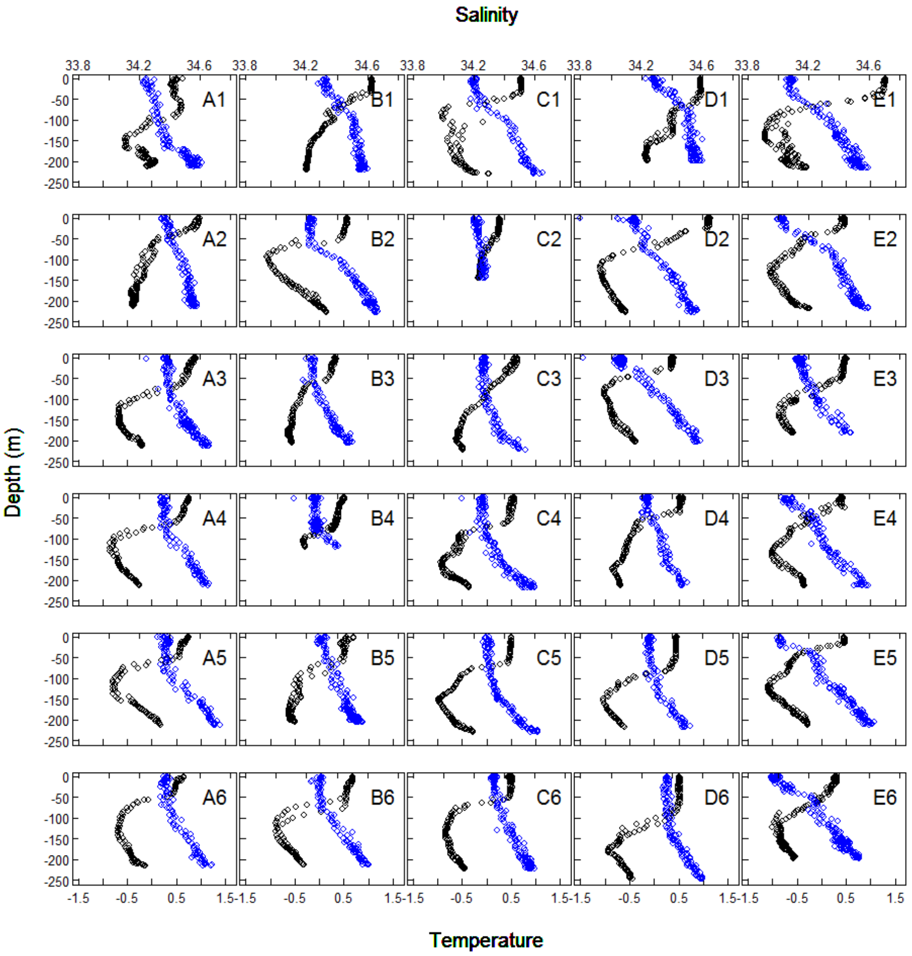

Figure 7. Temperature (black) and salinity (blue) profiles at the survey stations.

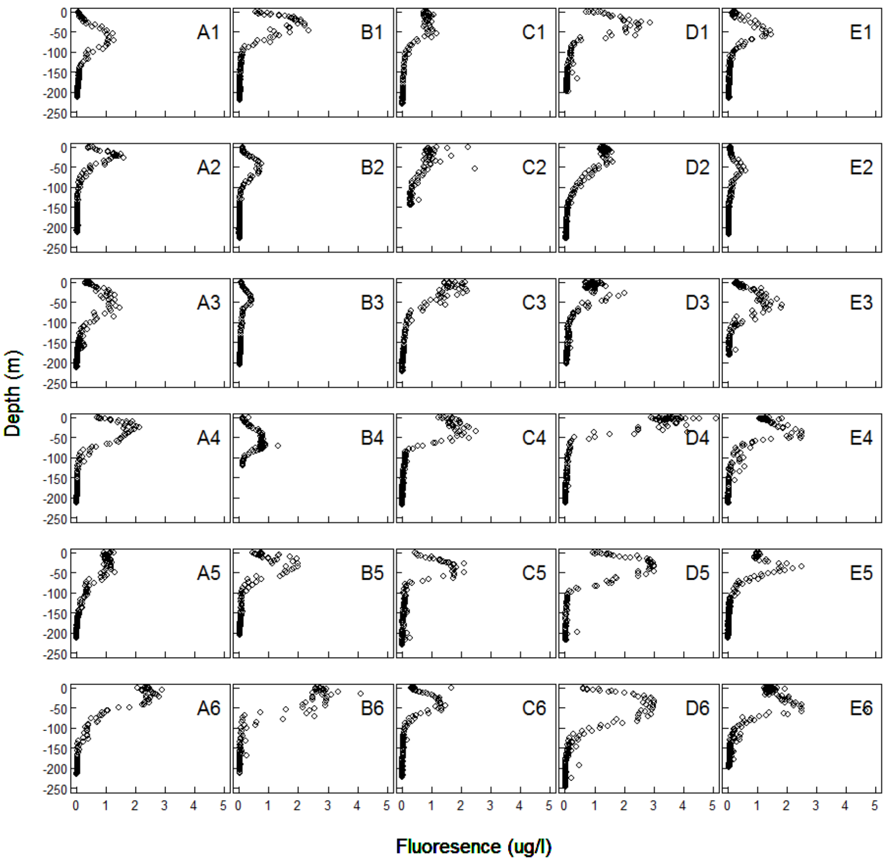

Figure 8. Fluorescence profiles at the survey stations.

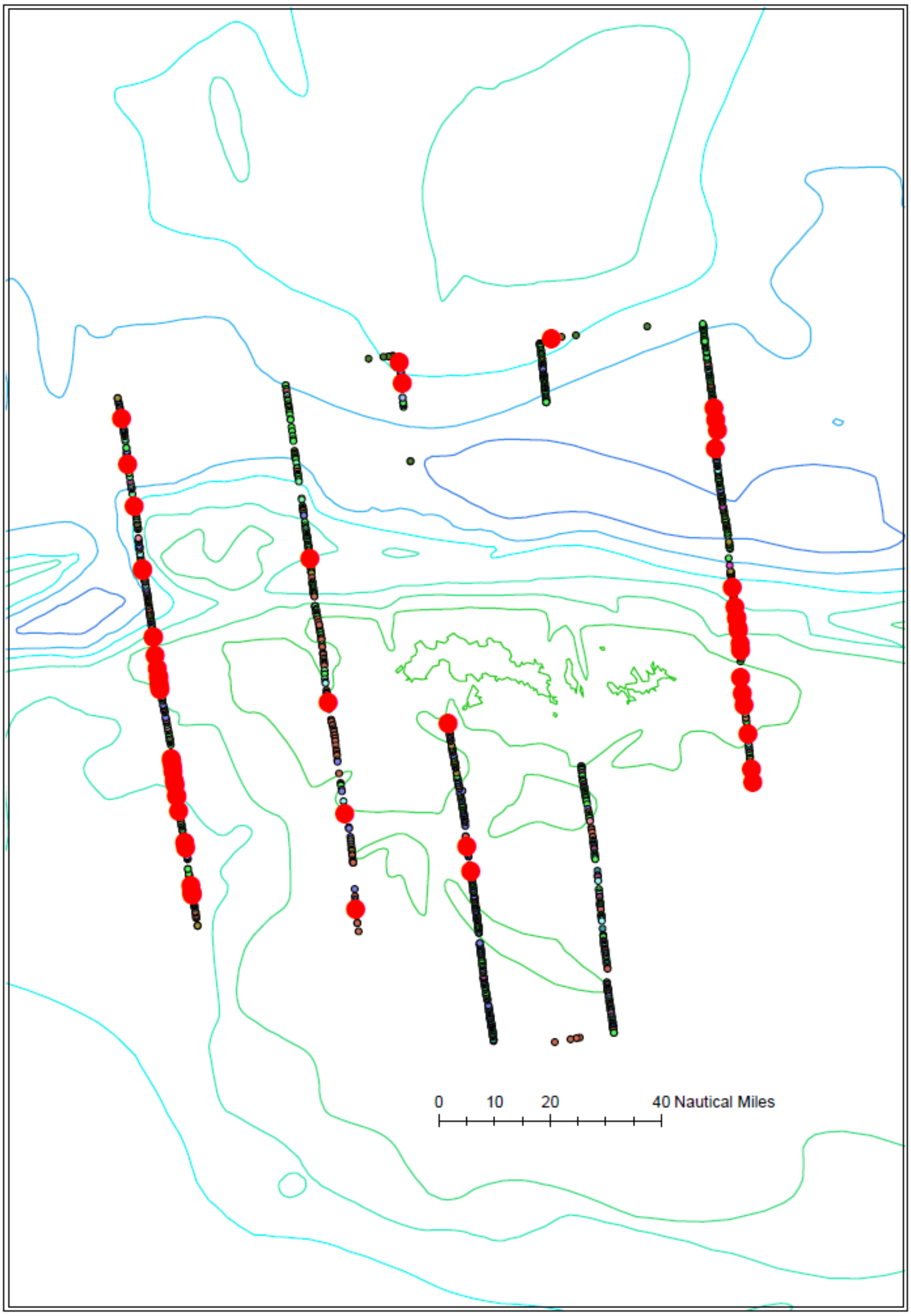

Figure 9. Observations of Antarctic fur seals (*Arctocephalus gazella*). Black circles indicate an observation of any kind including flying seabirds and red circles observations of Antarctic fur seals.

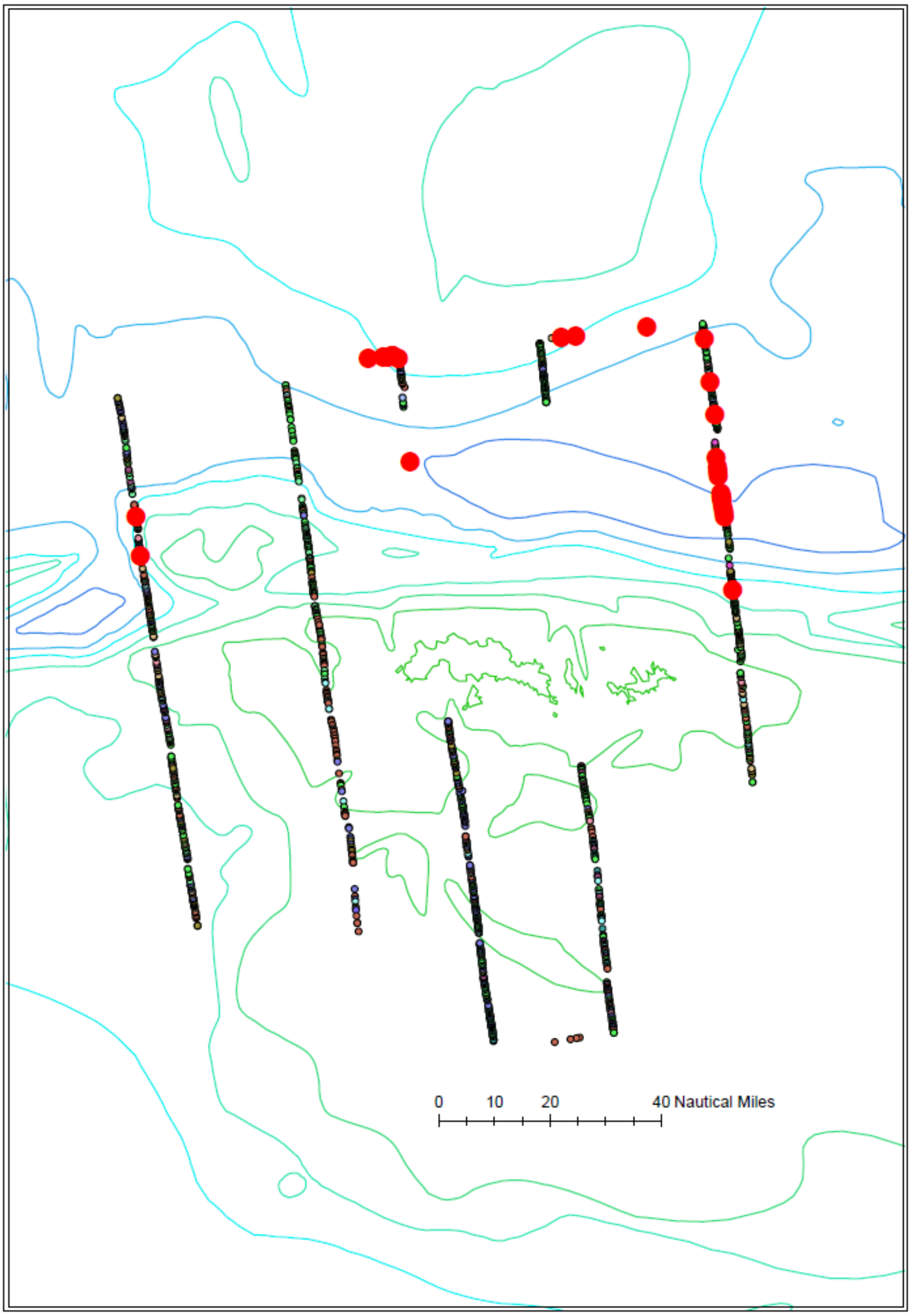

Figure 10. Observations of fin whales (*Balaenoptera physalus*). Black circles indicate an observation of any kind including flying seabirds and red circles observations of fin whales.

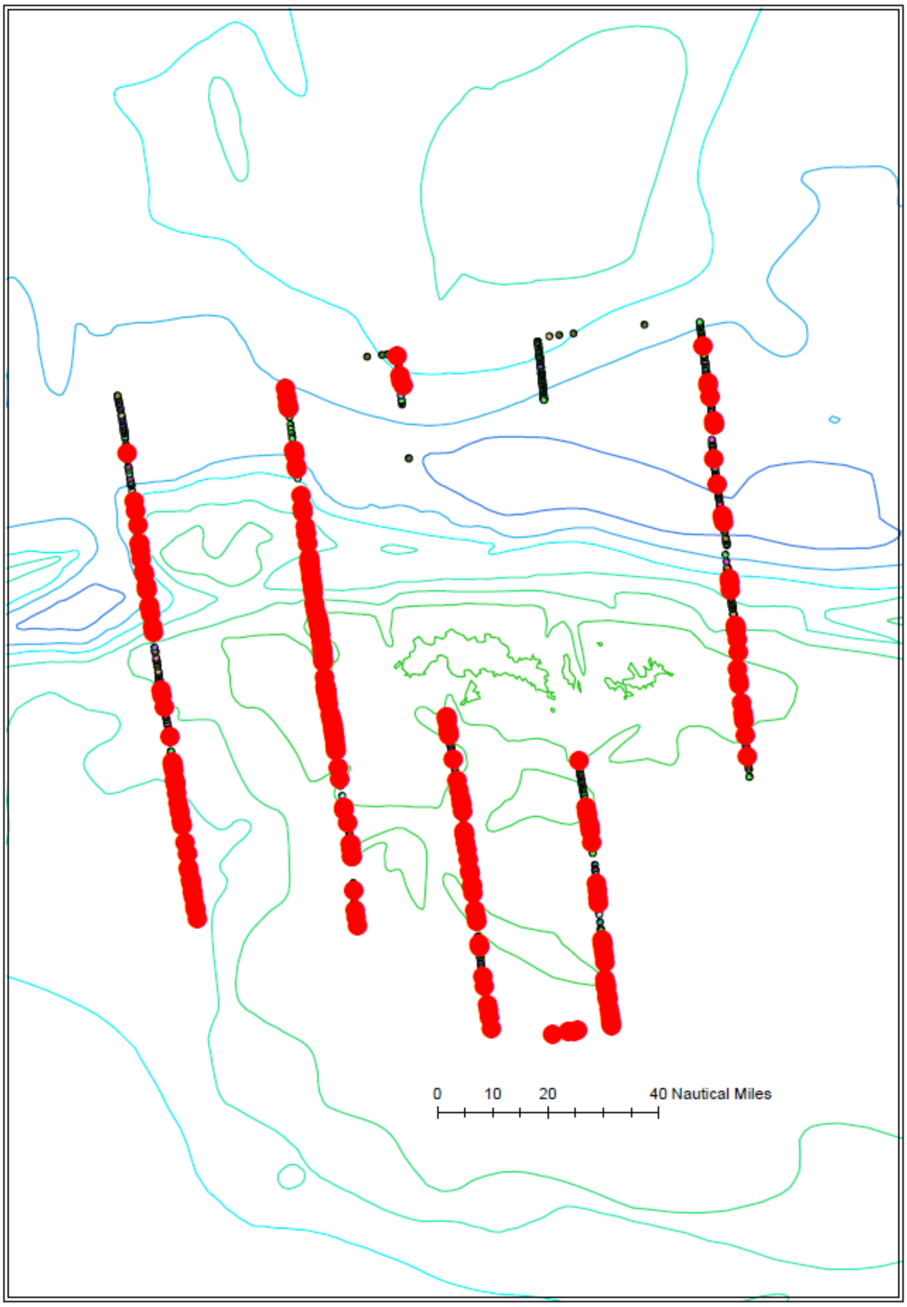

Figure 11. Observations of chinstrap penguins (*Pygoscelis antarcticus*). Black circles indicate an observation of any kind including flying seabirds and red circles observations of chinstrap penguins.