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INTERNATIONAL WHALING COMMISSION

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ABSTRACT
The New Zealand-Australia Antarctic Ecosystems Voyage was a 42-day research expedition to the Ross Sea region between the 29 January and 11 March 2015. The focus of the voyage was multidisciplinary ecological studies of marine foodwebs of importance to top predators. This paper primarily describes the research related to the Antarctic Blue Whale Project of the IWC-Southern Ocean Research Partnership. Two phases of blue whale research occurred during the voyage (8-14 February and 24 February-2 March). During these periods the ship's position was guided by bearings to calling blue whales detected using DIFAR sonobuoys. Over the voyage 310 sonobuoys were deployed that detected over 40,000 individual blue whale calls over 520 hours of recordings. These calls indentified 4,000 triangulated positions of calling blue whales. There was a marked increase in the rate of blue whale calling after 8 February. Total visual sightings effort was 467 hours yielding a total of 480 sightings of approximately 1297 cetaceans, including 29 confirmed sightings of approximately 81 Antarctic blue whales. Photo-identification data were collected from 58 blue whales. The acoustic and visual data suggest the blue whales were very strongly aggregated in a region approximately centred around 69°S, 178°W. Photogrammetry was used to describe the behaviour of the blue whales and active acoustic surveys, meso-pelagic trawling and oceanographic data were collected to describe the prey field and habitat characteristics of the blue whale aggregation. Preliminary analyses of the active acoustic surveys suggest the blue whale aggregation was associated with an area populated by very dense but patchily distributed krill swarms at depths less than 100 m.

Introduction

The New Zealand-Australia Antarctic Ecosystems Voyage aimed to undertake multidisciplinary ecological studies of Ross Sea marine foodwebs of importance to top predators. The five main science objectives for the voyage were: 1) determine factors influencing the abundance and distribution of humpback whales around the Balleny Islands; 2) habitat characterisation of blue whale foraging 'hotspots'; 3) a demersal trawl survey of the Ross Sea slope to estimate abundance, and collect biological data for stock assessment of the demersal fish species, particularly grenadiers *Macrourus* spp.; 4) deployment of a moored echosounder to study Antarctic silverfish (*Pleuragramma antarctica*) spawning in Terra Nova Bay; 5) undertake oceanographic and atmospheric observations of the Southern Ocean to contribute to validating global ocean and atmosphere models. The voyage was funded through a collaboration of New Zealand's National Institute of Water and Atmospheric Research Limited (NIWA), Antarctica New Zealand (ANZ) and the Australian Antarctic Division (AAD).

The principal focus for the AAD contingent on the voyage was blue whale research (Objective 2) that could contribute to the IWC-Southern Ocean Research Partnership's (IWC-SORP) Antarctic Blue

Whale Project. This paper principally describes the activities directly related to this objective. For further details on all activities associated with this voyage see O'Driscoll & Double (2015).

From the late 19th through to the mid 20th century over one third of a million blue whales (*Balaenoptera musculus*), principally Antarctic blue whales (*B. m. intermedia*), were killed in the Southern Hemisphere (Clapham & Baker, 2002), first by shore-based operations and then by the pelagic catcher and factory ships. Close to extinction, in 1964 the International Whaling Commission banned the hunting of blue whales although they were still caught by illegal Soviet whaling operations until 1973 (Branch et al., 2004). Today, the blue whale is classified as critically endangered by the International Union for Conservation of Nature and is of global interest as one of the most at risk baleen whale species in the Southern Ocean.

Our understanding of the impact of the whaling era on the Antarctic blue whale (*Balaenoptera musculus intermedia*) is based predominantly on two sources of information: catch data derived from the logbooks of whaling vessels and from circumpolar cetacean sightings surveys. Circumpolar sighting surveys were initiated in 1978 as the International Decade of Cetacean Research (IDCR) and later Southern Ocean Whale Ecosystem Research (SOWER) initiatives (Branch & Butterworth, 2001). The IDCR/SOWER surveys usually involved two ships conducting line-transect surveys from the Antarctic ice-edge north to 60oS. These vessels conducted three circumpolar surveys (CPI, CPII and CPIII) that were completed in 2004, although further regional surveys went on until 2010. While the catch data can provide yearly catch distribution and magnitude as well as often detailed information on the animals caught (including size, sex, pregnancy status, stomach contents etc.), the data from sightings surveys can generate estimates of circumpolar abundance, trends and distribution.

The low sighting rates of Antarctic blue whales from the IDCR/SOWER surveys generated abundance estimates with low precision which in turn hampered early efforts to assess population trend (Branch & Butterworth, 2001; Gerrodette, 1995). Later, Branch et al. (2004) estimated trend using catch and sightings data in a Bayesian modeling framework which estimated that the circumpolar Antarctic blue whale population decreased from pre-exploitation abundance of 239 000 (95% Bayesian interval of 202,000 – 311,000) to a low of around 360 individuals (95% Bayesian interval of 150 – 840) in the early 1970s. This represents a population decline of greater than 99%. This study also determined that from the lowest abundance the population had increased at a mean rate of 7.3% per year (95% CI 1.4-11.6%) and the estimated abundance in 1996 was 1,700 individuals (CV = 0.51, 95% CI 860 – 2,900).

The long-term aim of the IWC-SORP Antarctic Blue Whale Project (ABWP) is to deliver a new, precise estimate of the abundance and trend for Antarctic blue whales; it also aims to describe their distribution, migratory behaviour and population structure. Through an extensive examination of possible survey methods based on the likely current abundance, recovery rate and future survey effort (Kelly et al., 2011; Kelly et al., 2012; Kelly et al., 2013; Kelly et al., 2014) mark-recapture, involving photographic and genetic identification of individuals assisted by passive acoustic tracking (Miller, 2012; Miller et al., 2013), was deemed to be most appropriate and efficient survey method (Peel et al., 2014; Peel et al., in press).

Since the inception of this ABWP several voyages have contributed directly to the project (e.g. Findlay et al., 2014; Reyes et al., 2014) and data have also been provided by ships of opportunity (for summary see Bell, 2015). In 2013 an IWC-SORP voyage to east Antarctica tested the efficacy of passive acoustic tracking methods (Double et al., 2013; Miller et al., 2015). The 52 groups of blue whales ‘targeted’ by acoustic tracking yielded 33 encounters of approximately 84 individual blue whales (Miller et al., 2015; Olson et al., 2013).

Initially only 10 of the 42 days of the New Zealand-Australia Antarctic Ecosystems Voyage were allocated to blue whale research (O'Driscoll & Double, 2015). This timeframe was likely to limit the opportunity to target many blue whale groups. However, the expertise and equipment on the *RV Tangaroa* provided an opportunity to examine the oceanographic and prey-field characteristics of areas in which blue whales feed; during planning this was designated the highest priority objective for the blue whale component of the voyage.

Previous studies have reported a patchy distribution of Antarctic blue whales (Gedamke & Robinson, 2010; Peel et al., 2014) and the vocalisations detected on the 2013 voyage were similarly indicative of blue whale 'hotspots' with no blue whales sighted independently of the acoustic aggregations (Miller et al., 2015). Few studies have focused on the relationship between baleen whales and krill in the Antarctic and most to date have focused on humpback whales, minke whales, and fin whales over a variety of spatial scales (Friedlaender et al., 2014a; Friedlaender et al., 2014b; Nowacek et al., 2011; Santora et al., 2010; Santora et al., 2014). Only a single recent study, near the Western Antarctic Peninsula focused on the relationship between Antarctic blue whales and krill, (Širović & Hildebrand, 2011). Though no blue whales were visually encountered, this study found negative relationship between the detection of blue whale song calls and the mean krill biomass from 0-100 m. Despite the lack of empirical data, there have been several studies that have attempted to model the relationship between blue whales and krill, and it is believed that this relationship plays an important role in the Southern Ocean Ecosystem (e.g. Roman et al., 2014; Wiedenmann et al., 2011; Willis, 2014).

Methods

The methods employed on the voyage are presented in brief here; for further details refer to Double et al. (2013) and O'Driscoll & Double (2015); see Miller at al. (2015; 2013; 2014c) and Olson et al. (2013; Olson et al., 2015) for further information on acoustic tracking and photo-identification respectively.

The research was conducted from the *RV Tangaroa,* a purpose-built deep-water research vessel operated by NIWA. This vessel is capable of stern trawling and has a 1C ice classification (can operate in ice floes up to 0.4 metres thick). Due to the limited time allocated exclusively to blue whale research (10 of the 42 days) and a limit of 10 berths to AAD personnel, small boat operations were excluded early in the planning phase for this voyage.

The blue whale research was initially scheduled after the active acoustic and visual survey at the Balleny Islands (67°S, 164°E) and before a demersal trawl survey on the Mawson and Iselin Banks in the northern Ross Sea (71°S to 73°S, 173°E to 178°W; see Table 1). Therefore attempts to locate blue whales were initially focused on an area between 164°E and 178°W but otherwise directed by bearings to received calls.

During the voyage the whale research team operated under seven specific survey modes. All events occurring during daylight operations such as sightings, biopsy attempts and sonobuoy deployments were recorded in a customized data entry program Logger (Logger 2010, www.ifaw.org) along with weather and effort data.

The active and passive acoustics teams typically operated 24 hours a day for the duration of the voyage. The primary task of the passive acoustic team was to detect, track and target blue whales. DIFAR sonobuoys were deployed at 30 nm intervals, or more frequently when needed for tracking and targeting pods (Miller et al., 2015; Miller et al., 2014b; Miller et al., 2014c). All activities related to passive acoustic operations were recorded using the DIFAR module in the PAMGuard software (Calderan et al., 2015).

Active acoustic data were collected using a multifrequency (18, 38, 70, 120, and 200 kHz) suite of Simrad EK60 echosounders. A Simrad EK80 echosounder system was also installed on the *RV Tangaroa* before the voyage and an experiment was carried out on 6-7 February where 70, 120, and 200 kHz transducers were swapped between EK60 and EK80 systems while running a repeated line transect. This EK60/EK80 experiment was repeated on 23 February on a silverfish aggregation in the Ross Sea during the transit from Terra Nova Bay north, and on 26 and 28 February on aggregations of krill and myctophids (primarily *Electrona* spp.) during the second phase of the blue whale work (See Table 1 and Figure 1). The EK60 and EK80 echosounders were calibrated during the Balleny survey on 5 February 2015 using a 38.1 mm tungsten carbide sphere (for details see O'Driscoll & Double, 2015).

Trawls were carried out for acoustic target identification using the NIWA fine-mesh midwater trawl. This trawl has a circular mouth opening of about 12 m diameter, a codend mesh of 10 mm, and is rated to a maximum depth of 1200 m. It is similar to the IYGPT (International Young Gadoid Pelagic Trawl), which was recommended by Census of Antarctic Marine Life (CAML) for sampling pelagic fish layers. During tows for acoustic identification, the midwater trawl was targeted at the aggregation of interest and towed for 20–30 minutes at 3–4 knots. The profile and performance of each tow was monitored from net depth data obtained from a Furuno CN22 net monitor. Perliminary acoustic data analyses techniques followed those endorsed for krill by the CCAMLR Subgroup on Acoustic Survey and Analysis Methods (SG-ASAM). Acoustic data processing was undertaken using Echoview v6.1 (Myriax, Hobart, Australia) controlled using the R package EchoviewR (Harrison et al., 2015). Krill were identified using the validated dB-difference technique (see Cox et al., 2011; Madureira et al., 1993; Watkins & Brierley, 2002).

Visual surveys were conducted during daylight hours by observers on the open-air monkey island (flying bridge) or in the enclosed bridge depending on weather conditions. Observers on the flying bridge were stationed in one of two viewing boxes that provided seating, a wind break, and a small shelf with a radial angle board that was used to determine the angle to whale sightings. Observers alternated between searching with and without 7x binoculars. For each cetacean sighted the distance and angle relative the ship’s course were estimated using reticle binoculars and angle boards mounted on the viewing boxes or on the bridge.

Upon sighting suspected blue whales, the vessel was guided towards the whale for species confirmation, focal follows, photo-identification and biopsy. The location, track and behaviour of whales were described using a photogrammetric measurement system described by Leaper & Gordon (2001). These positional data can also be used to assess source levels of calls and the calling behaviour of individual blue whales. When possible both sides of each whale were photographed using high resolution digital SLR cameras with image-stabilized zoom lenses. Photographs and associated records were archived at the end of each day for later quality control and reconciliation (Olson et al., 2013; Olson et al., 2015).

Biopsy collection from humpback and blue whales was attempted from the bow of the ship using Larsen rifles (Larsen, 1998). Biopsy samples were split between All Protect (Qiagen), 70% ethanol, and freezing at -20^{o}C.

A suite of underway oceanographic and atmospheric measurements were made throughout the voyage including CTD casts, tows of the continuous plankton recorder, water sampling, measures of nutrient uptake by phytoplankton and rates of primary production. Twelve Argo floats and 10 surface drifters were also deployed during the voyage (see O'Driscoll & Double, 2015).

Results and Discussion

The voyage timetable is presented in Table 1 and voyage route in Figure 1. The voyage departed from Wellington, New Zealand on the 29 January and returned to the same port on 11 March 2013 (42 days). The total distance covered during the voyage was nearly 15,000 km and ultimately13.5 days were fully or largely dedicated to blue whale research. The weather conditions during the voyage were generally very good with wind speeds seldom greater than 30 knots (O'Driscoll & Double, 2015). Ice conditions frequently presented difficulties with no full clearing of the Ross Sea and accumulation of wind-driven ice around the Balleny Island and the entrance to Terra Nova Bay. Many of the acoustically targeted blue whales were located within non-navigable ice during the second phase of the blue whale research (see Table 1).

A total of 310 sonobuoys were deployed over the entire voyage. During the dedicated blue whale phases of the voyage (8-14 February; 24 February to 2 March) the course of the ship was diverted to follow bearings to calling Antarctic blue whales. Over 520 hours of individual recordings were made and more than 40,000 individual blue whale calls detected. The spatial distribution of calling locations of Antarctic blue whales was highly concentrated into vocal aggregations that could be heard from hundreds of kilometres away (Figures 2 & 3).

Of the 40,000 bearings to calls of Antarctic blue whales, 8,000 could be paired as calls that were received simultaneously on two widely spaced sonobuoys. These were used to obtain 4,000 triangulated positions of calling whales. Within a vocal aggregation, passive acoustics was used both to precisely locate calling individuals for close approach, as well as to design active acoustic transects through areas where Antarctic blue whales were either seen or acoustically localised (Figures 3 & 4).

Both tonal and frequency modulated calls of Antarctic blue whales were detected within and around vocal aggregations and the 26 Hz tones were detected heard at great distances from the vocal aggregations, while frequency modulated (FM) and Z calls are only detected much closer to and from within vocal aggregations respectively (Figure 5).

There was a marked increase in the number of detections of both FM and tonal calls starting on 8 February (Figure 6). Since acoustic monitoring effort and conditions were largely comparable before and after 8 February, a possible explanation for the observed increase in detections after 8 February is a widespread change in the vocal behaviour of Antarctic blue whales commencing on this date. Alternatively background noise may have varied through the voyage affecting our ability to detect blue whale calls. Both explanations will be explored further using additional data from moored acoustic loggers (Opzeeland et al., 2014).

Total visual sightings effort was 467 hours yielding a total of 480 sightings of approximately 1297 cetaceans (Table 2). Sightings of humpback whales were most common around the Balleny Islands and close to the ice bridge in the northern Ross Sea (Figure 7). Sightings of Antarctic blue whales were limited to two individuals near the Balleny Islands and a large, concentrated but mobile aggregation of probably over 80 blue whales (~48 photo-identified) close to the 180^{o} meridian and at the northern edge of the Ross Sea ice bridge (Figures 2 & 3). On 13 February a formal line transect survey was conducted to estimate the total number of blue whales within this aggregation. Although ice restricted the spatial extent of the survey, a total of 24 sightings of approximately 58 blue, like blue or large baleen whales were observed and were clearly aggregated even at a relatively small spatial scale (Figure 7b).

More than 80 confirmed Antarctic blue whales were sighted during the voyage; of these photographs of sufficient quality for individual identification were obtained from 58 Antarctic blue whales (Table 3, Olson et al., 2015). Photo-identification data collected on this voyage will be contributed to the circumpolar Antarctic Blue Whale Catalogue managed by Paula Olson (NOAA) while subsamples of biopsies will be submitted to the IWC-recognised genetic repository for Antarctic blue whale at NOAA Southwest Fisheries, La Jolla. Further examination of the photographs will determine the total number of photo-identified individual blue whales, the number of individuals re-sighted within the voyage and the number of new and known individuals contributed to the Antarctic Blue Whale Catalogue (Olson et al., 2015). Photo-identification data was also collected from a single pygmy (Tasman-Pacific) blue whale late in the voyage (Table 3, Miller et al., 2014a; Olson et al., in press). During the voyage photo-identification data were also collected for 22 humpback whales and on 18 February, a group of killer whales was sighted and approached, resulting in nine individual photo-identifications (for further details see O'Driscoll & Double, 2015). One blue whale (Table 3) and ten humpback whales were biopsied successfully during the voyage. Biopsying blue whales from the bow of the *RV Tangaroa* proved challenging due to the ship's manoeuvrability and the limited capacity to change speed rapidly.

Approximately 15 hours of focal follow data were recorded on video of which 8 hours were classified as good quality of a single animal or in one case a pair of animals that stayed close together. Focal follows were aborted when it was no longer possible to follow the focal animal due to ice or when the presence of other animals meant it was no longer possible to be sure which was the focal animal. This resulted in seven tracks of longer than 45 minutes with the longest around 2 hours. These data will be analyses further to characterise the behaviour of tracked whales (Figure 8).

Eleven acoustic grid surveys were conducted in close association with blue whale sightings and acoustic triangulations (e.g. Figure 4). During the first phase of blue whale research the acoustic surveys within the blue whale aggregation revealed very dense, but very patchy swarms of Antarctic krill at depths less than 100 m (e.g. Figure 9). More substantial krill marks were observed during the second phase of blue whale research from the 26 February to 2 March (Figure 3b) and consisted of surface swarms and layers at depths of about 50 m. There were also layers of myctophid fish (mainly *Electrona* spp.) at a depth of 250 m, below the krill. These surveys were less closely linked to foraging blue whales as sightings were few and acoustic triangulations indicted that most whales were located within the surrounding pack ice but inaccessible to the *RV Tangaroa* (Figure 3b).

Nine midwater trawls were carried out to verify composition of acoustic feed layers and to provide samples length frequency distribution data for estimates of krill density and total biomass. Preliminary estimates, based on school dimensions and estimated density suggest that the krill swarms associated with the blue whale aggregations contained in excess of 100 tonnes of krill. Further preliminary analyses of the active acoustic data are presented in Cox *et al.* (2015) together with a short commentary on the challenges of analysing and interpreting these acoustic data in the context of describing whale habitat, distribution and behaviour.

This voyage again highlighted the utility of passive acoustics for detecting and tracking Antarctic blue whales (Miller et al., 2015). This technique is clearly reliable and efficient and will facilitate future studies of Antarctic blue whales. Even though relatively few days were allocated specifically to blue whale research on this voyage we were able to locate large numbers of blue whales and to collect novel data on their distribution, behaviour, habitat and prey field. These passive acoustic techniques will become more widely available as the techniques are disseminated and the associated software is refined (Calderan et al., 2015). This in turn will provide greater capacity for research vessels, tourist ships and other ships of opportunity to contribute valuable data to the Antarctic Blue Whale Project of IWC's Southern Ocean Research Partnership.

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Table 1. Timetable of activities on the New Zealand-Australia Antarctic Ecosystems Voyage 2015.

Activity	Dates
Mobilisation & training:	22–28 January (7 days)
Depart Wellington:	29 January
Transit to Ross Sea:	29 January – 3 February (6 days)
Balleny Islands survey & acoustic calibration:	4–7 February (4 days)
Blue whale survey (part 1):	**8–14 February (7 days)**
Transit to shelf:	15 February (1 day)
Shelf demersal survey:	16–20 February (4.5 days)
Transit to Terra Nova:	20-21 February (1.5 days)
Mooring deployment:	21-Feb
Transit from Terra Nova:	22-23 February (2 days)
Blue whale survey (part 2):	**24 February –2 March (6.5 days)**
Transit to Wellington:	2–10 March (8.5 days)
Arrive Wellington and demobilisation:	11–12 March (2 days)

Table 2. Summary of cetacean sightings data on the New Zealand-Australia Antarctic Ecosystems Voyage 2015.

Species	Sightings	Individuals
Antarctic blue whale	29	81
Pygmy blue whale	1	1
Fin whale	4	11
Humpback whale	252	466
Antarctic minke whale	20	51
Sei whale	3	5
Pilot whale	2	45
Southern bottlenose whale	1	3
Sperm whale	3	3
Ziphiidae	3	5
Killer whale	2	7
Killer whale type A	1	10
Common dolphin	2	360
Like Antarctic blue	5	15
Like Antarctic minke	3	3
Like blue whale	6	14
Like fin whale	2	3
Like humpback whale	40	72
Like minke	8	8
Like sperm whale	4	5
Undetermined minke	32	57
Unid large baleen	40	54
Unid large whale	6	6
Unid small whale	3	3
Unid whale	8	9
Total	**480**	**1297**

Table 3. Summary of photo-identified and biopsied blue whales collected during the New Zealand-Australia Antarctic Ecosystems Voyage 2015.

Species	UTC Date	Sighting No.	Latitude (decimal)	Longitude (decimal)	No. photo-ID	Biopsy samples
Antarctic Blue	6-Feb	086	-67.16	163.98	2	-
Antarctic Blue	9-Feb	149	-69.16	178.22	3	-
Antarctic Blue	9-Feb	157	-69.34	179.07	1	-
Antarctic Blue	10-Feb	163	-69.02	179.69	1	-
Antarctic Blue	10-Feb	170	-69.15	-177.92	1	-
Antarctic Blue	11-Feb	172	-69.30	-178.08	2	-
Antarctic Blue	11-Feb	177	-69.28	-178.30	1	-
Antarctic Blue	11-Feb	181	-69.26	-178.08	5	-
Antarctic Blue	12-Feb	182	-69.28	-178.14	2	-
Antarctic Blue	12-Feb	183	-69.35	-178.10	2	-
Antarctic Blue	12-Feb	198	-69.30	-178.07	1	-
Antarctic Blue	13-Feb	208	-69.44	-177.79	2	-
Antarctic Blue	13-Feb	209	-69.36	-178.14	11	15BW008
Antarctic Blue	14-Feb	210	-69.09	-178.20	2	-
Antarctic Blue	14-Feb	211	-69.37	-178.13	3	-
Antarctic Blue	14-Feb	212	-69.38	-178.17	2	-
Antarctic Blue	14-Feb	217	-69.33	-177.96	8	-
Antarctic Blue	25-Feb	352	-69.71	-175.91	3	-
Antarctic Blue	26-Feb	361	-69.77	-175.75	4	-
Antarctic Blue	28-Feb	407	-70.00	-175.01	1	-
Antarctic Blue	1-Mar	420	-69.90	-174.65	1	-
Pygmy Blue	10-Mar	485	-41.87	174.43		

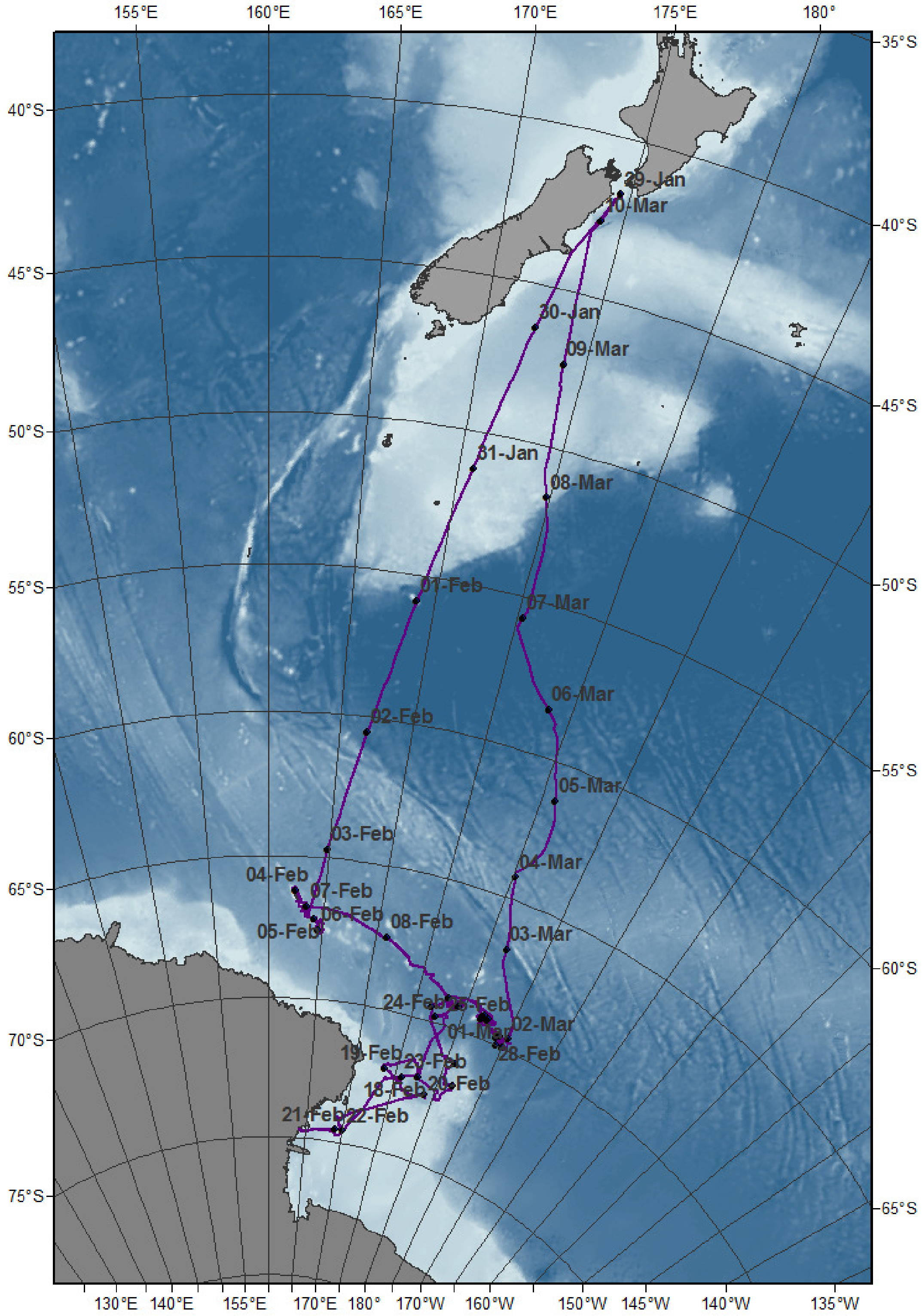

Figure 1. Voyage track of the New Zealand-Australia Antarctic Ecosystems Voyage 2015. Labeled points indicate positions at 00:00 hours (UTC).

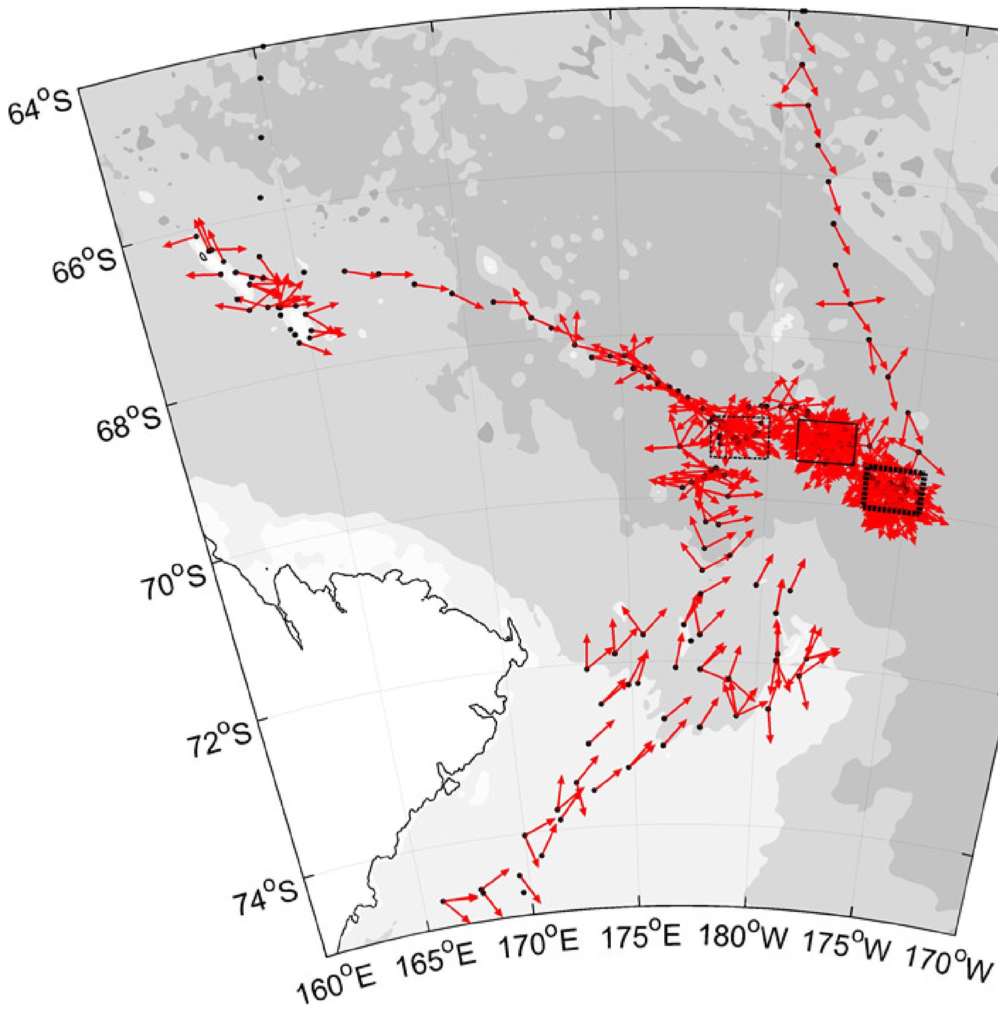

Figure 2. Sonobuoy deployments and best bearings towards Antarctic blue whale locations. Most bearings (red arrows) point towards the three areas where further research on blue whales was conducted. The dashed black box shows the location of blue whale research from 9-10 Feb. The solid black box shows the location of blue whale research from 11-14 Feb, and the bold dashed box shows the location of blue whale research from 25 Feb – 1 Mar. Bathymetry contours are shown as grayscale from white to dark grey at depths of 0, 200, 1000, 3000, and 6000 m.

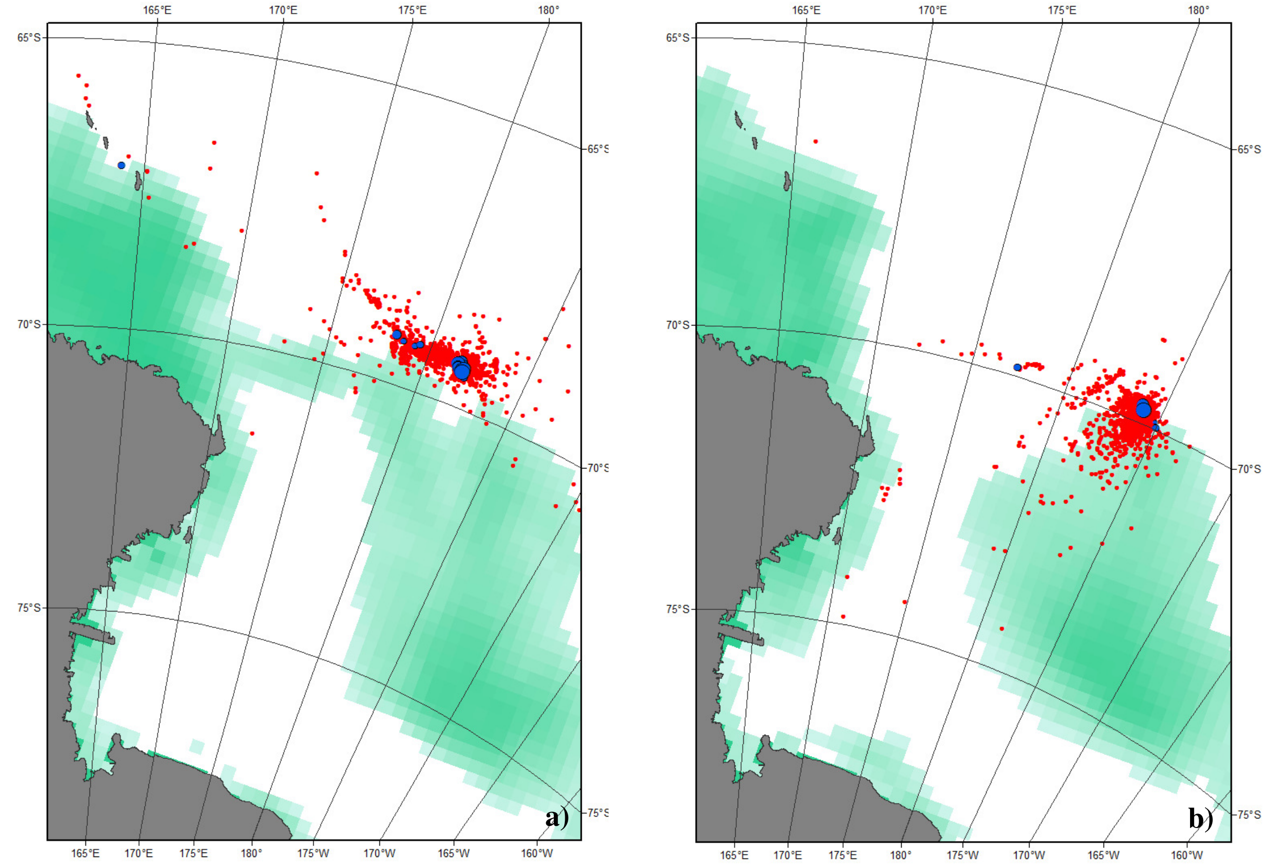

Figure 3. Locations of Antarctic blue whales through direct sightings (blue circles) and passive acoustic triangulation (red circles) during a) 29 January to 14 February, and b) 15 February to 10 March 2015. These temporal windows reflect the two phases of blue whale research during the voyage (Table 1). Indicative ice distribution and concentration is shown for a) 10 February and b) 28 February. Ice data were sourced from the National Snow and Ice Data Center (http://www. nsidc.org/).

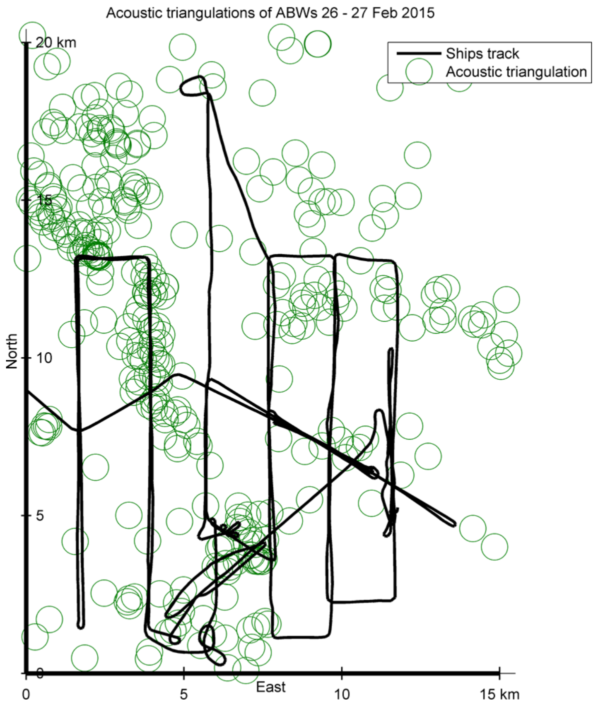

Figure 4. Passive acoustic triangulation of Antarctic blue whale calls.Green circles show calls over a 24 hour period starting at 0400 UTC on 26 February. The black line shows the ships track during active acoustic survey, mark identification trawling, and close approach. The cluster of acoustic locations in the northwest of the map were not accessible due to ice.

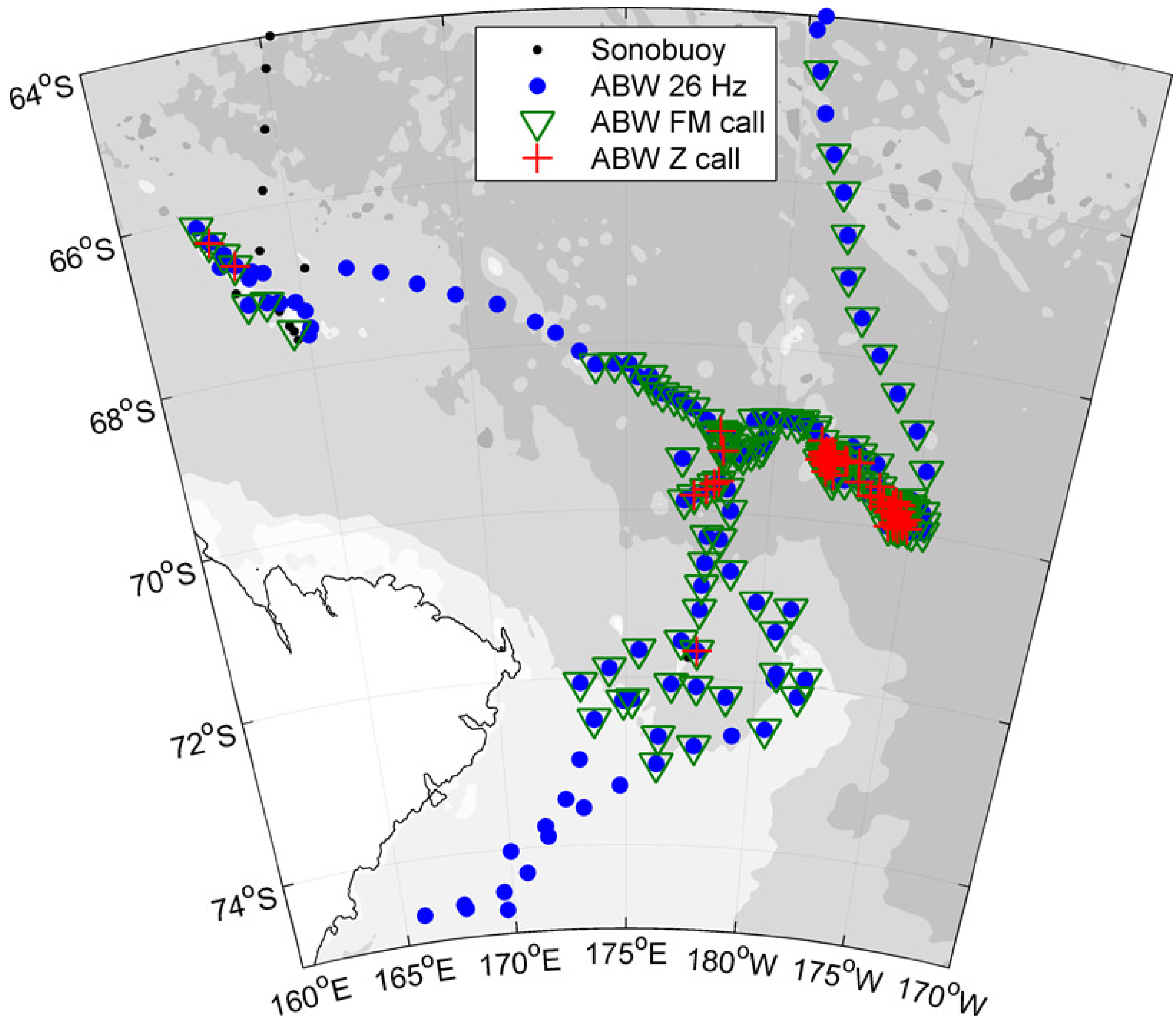

Figure 5. Location of detected calls of Antarctic blue whales.Deployments of sonobuoys (black dots), 26 Hz tonal calls from blue whales (blue dots), FM calls from blue whales (green triangles), and Z-calls from blue whales (red crosses). Bathymetry contours are shown as grayscale from white to dark grey at depths of 0, 200, 1000, 3000, and 6000 m.

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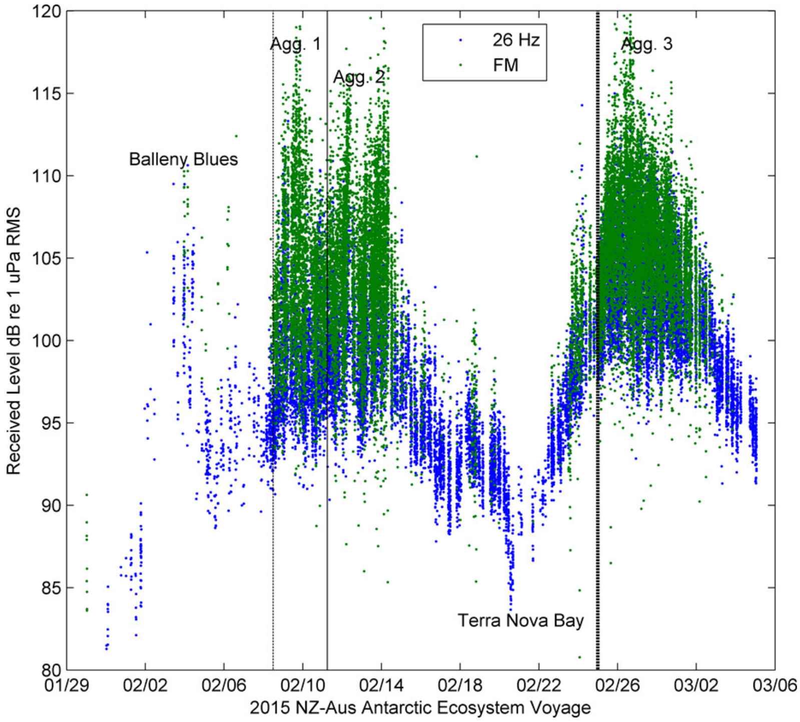

Figure 6. Time-series of received level of detected Antarctic blue whale calls.Received levels are of the 26 Hz tonal calls (blue dots) and frequency modulated calls (green dots). As in 2013, whales were typically within visual detection range when received levels were above 110 dB re 1 µPa RMS. There was a marked increase in the number of detections of both types of calls starting on 8 Feb.

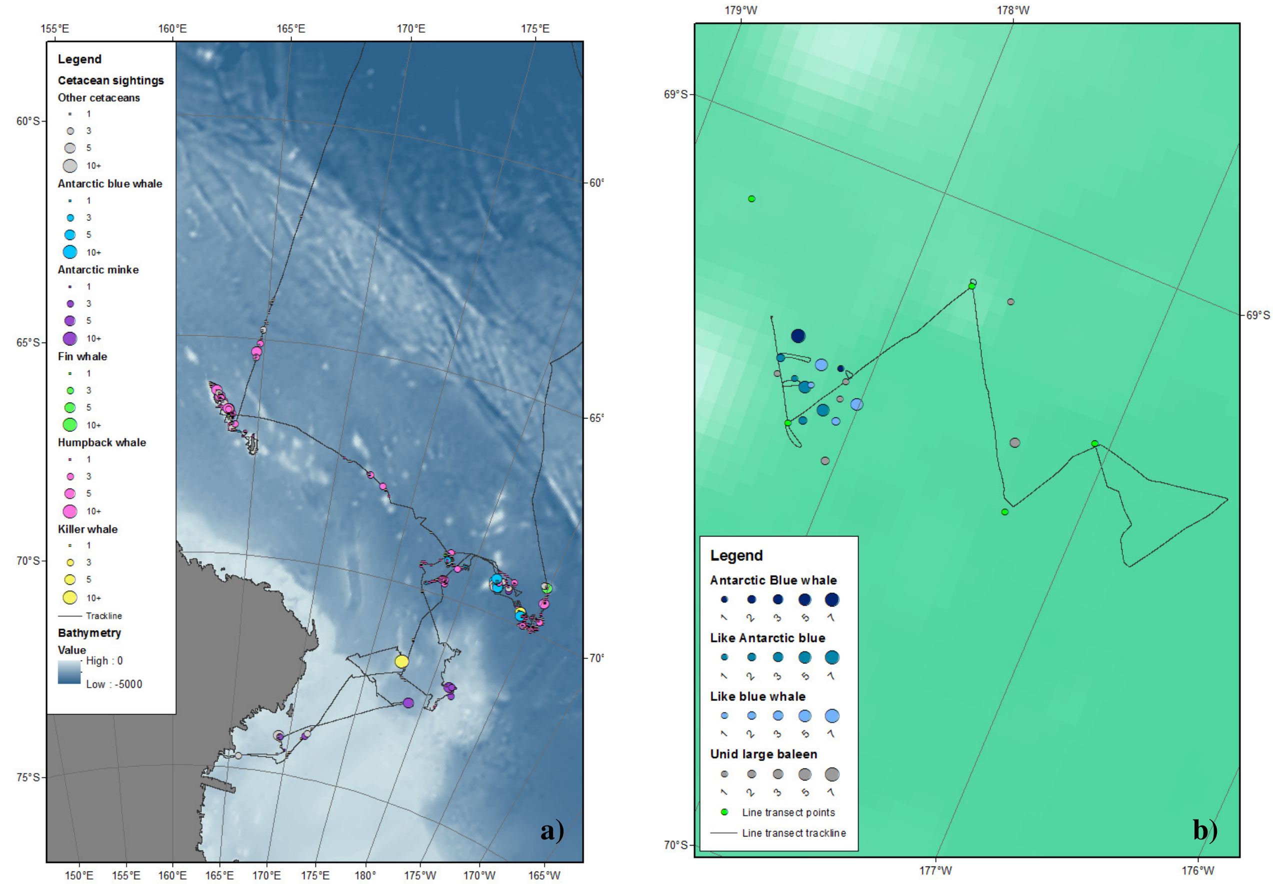

Figure 7. a) Location of visual sightings south of 60° S. Sightings of Antarctic blue, Antarctic minke, humpback, fin and killer whales are shown separately. All other sightings including sightings where the species identification was not determined are shown in grey. Symbol size indicates the number of individuals observed during each sighting record. b) Location of blue whale sightings during line transect survey on 13 February. The ship's track is shown as a black line. When possible the ship left the predefined track line to confirm the identity of sighted whales. The ship could not complete the full survey due to ice.

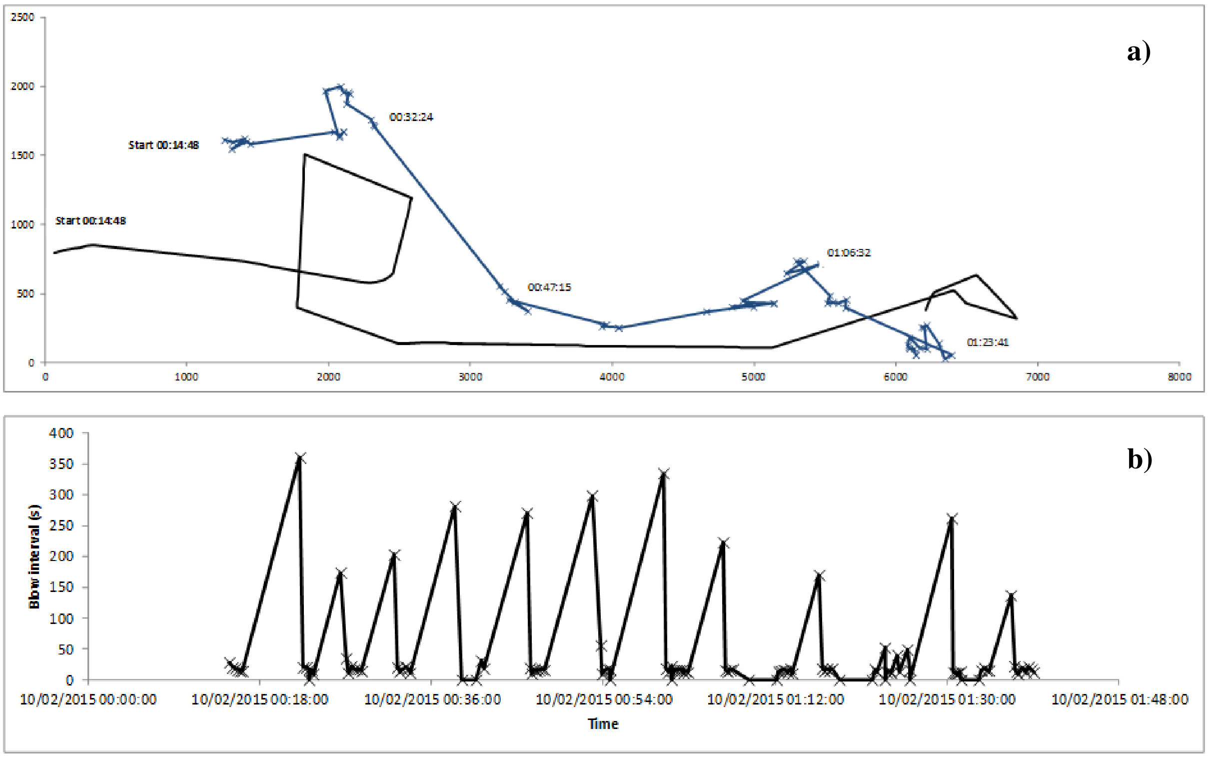

Figure 8. a) An example of Antarctic blue whale tracked using photogrammetry on 10 February. Track is from 00:14:48 to 01:39:02 UTC. Blue crosses indicate surfacing locations of the whale joined by blue lines. Black line indicates track of *Tangaroa*. Straight line swimming speeds measured between locations at least 120 s apart varied between 0.7 and 2.9 ms^{-1} (mean = 1.5 ms^{-1}). b) Blow intervals for tracked Antarctic blue whale. Blow intervals during the same period as Figure 22 showing 11 'long' dives of mean 245 s duration (standard deviation = 72). Between these 'long' dives there was a mean of 9.3 blows (standard deviation = 3.5).

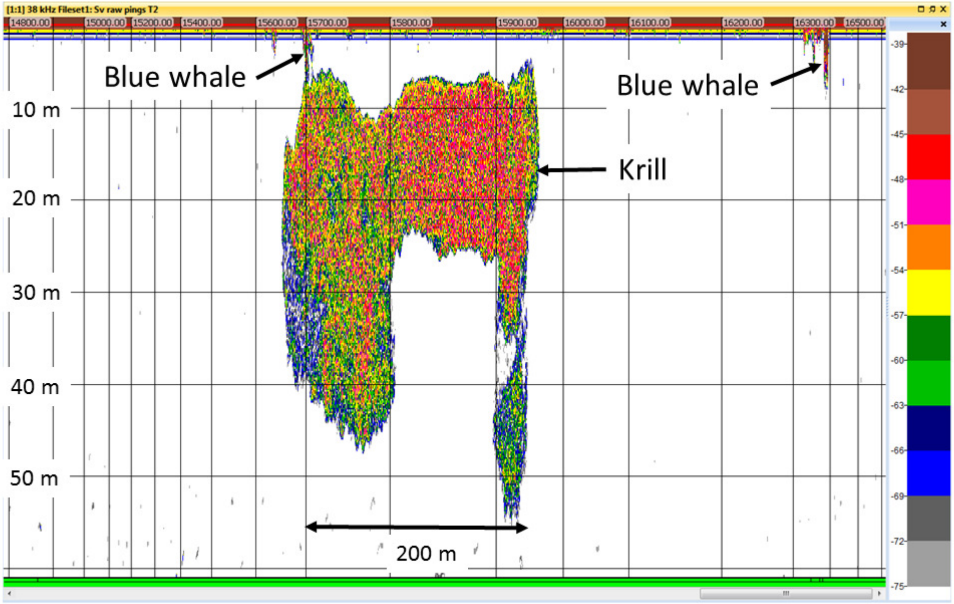

Figure 9. Acoustic echogram showing dense school of krill.Echogram recorded at 120 kHz during close approach of a blue whale on 10 February. The whale itself is also visible twice during the recording.