Overview of the IWC SOWER cruise circumpolar acoustic survey data and analyses of Antarctic blue whale calls within the dataset

Fannie W. Shabangu[1,2], Kathleen M. Stafford[3], Ken P. Findlay[2,4], Shannon Rankin[5], Don Ljungblad[6], Yasunari Tsuda[7], Laura Morse[8], Christopher W. Clark[9], Hidehiro Kato[10] and Paul Ensor[11]

Contact e-mails: FannieS@daff.gov.za or fannie.shabangu@yahoo.com

ABSTRACT

The International Whaling Commission (IWC) carried out blue whale research within its annual austral summer Southern Ocean Whale and Ecosystem Research (SOWER) cruises between 1996 and 2010. Over 700 sonobuoys were deployed to record blue whale vocalisations during 11 Antarctic and three low latitude blue whale cruises off Australia, Madagascar and Chile. The recorded acoustic files from these deployments were collated and reviewed to develop a database of both the digital acoustic files and the associated deployment station metadata of 7,486 acoustic files from 484 stations. Acoustic files were analysed using the automated detection template and visual verification method. We found a significant difference between the total number of acoustic recording hours (2,481) reported for these cruises (in the associated cruise reports) and the currently available number of acoustic recording hours (1,541). Antarctic blue whale vocalisations (9,315 D-calls and 24,902 Z-calls) were detected on 4,183 of the 7,486 acoustic files. December had the lowest call rates whilst January and February yielded high call rates. Although the majority (63%) of the sonobuoys were deployed between 1800hrs and 0600hrs the following day, most calls (62%) were detected during observation periods between 0600hrs and 1800hrs. The recently described southeastern Pacific 2 song of the Chilean pygmy blue whale was also found in Chilean blue whale cruise acoustic data. The difference between the available and reported data is of concern and a reconciliation of these and any future IWC acoustic data is strongly recommended.

KEYWORDS: ACOUSTICS; ANTARCTIC; BLUE WHALES; COMMUNICATION; DISTRIBUTION; HABITAT; MONITORING

INTRODUCTION

There are two recognised subspecies of Southern Hemisphere blue whale: the ‘Antarctic’ blue whale (*Balaenoptera musculus intermedia,* Burmeister, 1871) and the ‘pygmy’ blue whale (*B m brevicauda,* Ichihara, 1966). The Indian Ocean blue whale *B. m. indica* (Blyth, 1859) is considered an approximate synonym of *B. m. brevicauda* (Reeves *et al.,* 1998; Rice, 1998). Differentiation of the sub-species at sea is difficult and the IWC therefore initiated a programme of passive acoustic monitoring and recording in the presence of blue whales to determine whether the different subspecies might produce distinctly different sounds.

Blue whales were whaled to near extinction by modern whaling (1904–1973); with catches of some 360,000 individuals in the Southern Hemisphere. The 1996 estimate of population size 1,700 (860–2,900) remains at less than 1% of their pre-exploitation abundance of 239,000 despite protection in the Southern Hemisphere from 1964 (Branch *et al.,* 2004). The recovery and population status after protection from whaling has remained challenging to estimate from visual sighting surveys due to the current low abundance (Branch *et al.,* 2007) and wide winter dispersal of the species. However, the population is increasing at an average rate of 8.2% per annum (Branch *et al.,* 2004; Thomas *et al.,* 2015). The recovery status of pygmy blue whale populations is unknown. Population assessment must consider sub-species to allow for different rates in recovery; however, field identification of sub-species based on visual observation is considered unreliable (Kato *et al.,* 1996). Within the SOWER programme, the IWC considered alternative methodologies for blue whale sub-species identification, including surface expression of dive, relative body proportion, and blow-hole morphology (Ichihara, 1966; Donovan, 1984) and passive acoustic monitoring (Ljungblad *et al.,* 1998).

Some of the earliest acoustic studies of blue whales suggested that blue whale sounds, in particular their various songs as recorded in different regions and ocean basins, were distinctly different from each other (Cummings and Thompson, 1977; Thompson *et al.,* 1996; McDonald *et al.,* 2006). Acoustic monitoring of blue whale sounds might provide a means of determining sub-species in the field (Ljungblad *et al.,* 1997; Ljungblad *et al.,* 1998; Stafford *et al.,* 1999; 2001) in much the same way that humpback whale (*Megaptera novaeangliae*) songs can be used to identify and distinguish between populations (Payne and Guinee, 1983).

Sounds recorded in the presence of blue whales are basically of two forms: calls and songs. Blue whale D-calls

[1] *Fisheries Management, Department of Agriculture, Forestry and Fisheries, Private Bag X2, Roggebaai, Cape Town, 8012, South Africa.*
[2] *Mammal Research Institute Whale Unit, University of Pretoria, c/o 16 Ebor Road, Wynberg, Cape Town, 7800, South Africa.*
[3] *Applied Physics Laboratory, University of Washington, Seattle, WA 98105, USA.*
[4] *Cape Peninsula University of Technology, P.O. Box 652, Cape Town 8000, South Africa.*
[5] *Southwest Fisheries Science Center, US National Marine Fisheries Service, NOAA, 8901 La Jolla Shores Drive, La Jolla, CA 92037, USA.*
[6] *Ljungblad Associates, P.O. Box 6, Elk Mountain, WY 82324, USA.*
[7] *Kyodo Senpaku Kaisya, Ltd, Toyomi Shinko Bldg, 4-5 Toyomi-cho, Chuo-ku, Tokyo 104-0055, Japan.*
[8] *P.O. Box 240434, Anchorage, Alaska 99524, USA.*
[9] *Bioacoustics Research Program, Cornell Laboratory of Ornithology, Cornell University, 159 Sapsucker Woods Rd, Ithaca, NY 14850, USA.*
[10] *Large Cetacean Section, National Research Institute of Far Seas Fisheries, 5-7-1 Orido, Shimizu, Japan.*
[11] *Australian Marine Mammal Centre, Australian Antarctic Division, Hobart, TAS, Australia.*

typically occur as single or short sequences of frequency-modulated (FM) sounds in the 22–106Hz frequency band, last *ca.* 2–6s, and are always downswept but sometimes start with an up-down frequency inflection (Thompson *et al.,* 1996; Mellinger and Clark, 2003; Rankin *et al.,* 2005; Ljungblad and Stafford, 2005; Oleson *et al.,* 2007). In contrast, songs are composed of *ca.* 1–4 stereotyped sounds (i.e. notes), that have been reported as 1–2s amplitude-modulated (AM), 1–2s pulses; or long-duration (5–25s), FMs, with and without harmonics. Song notes are organised into phrases that are repeated in a patterned sequence lasting *ca.* 10–20 mins (i.e. a song), which is sung repeatedly (i.e. song bout) over periods of hours to many days (Cummings and Thompson, 1971; Edds, 1982; Thompson and Friedl, 1982; Thompson *et al.,* 1996; Alling *et al.,* 1991; Stafford *et al.,* 1999; 2001; Clark and Gagnon, 2002; Mellinger and Clark, 2003; Rankin *et al.,* 2005; McDonald *et al.,* 2006). D-calls have been reported for both males and females, while to date all identified singers have been males (McDonald *et al.,* 2001; Oleson *et al.,* 2007).

Antarctic blue whales and pygmy blue whales in the Southern Hemisphere exhibit geographic variation in their songs (Ljungblad *et al.,* 1997; Clark and Fowler, 2001; McDonald *et al.,* 2006; Samaran *et al.,* 2010a; Stafford *et al.,* 2011). The songs recorded from Antarctic blue whales consist of patterned sequences of tonal sounds composed of three distinct parts; an 8–12s tone centred at 28Hz (28-Hz component), a 2s FM downsweep, and a 3–6s tone centred at 18Hz (Ljungblad *et al.,* 1998). Subsequent to IWC SOWER studies, there has been a documented decrease in the tonal frequency of the first part of the song to between 26 and 27Hz (Gavrilov *et al.,* 2012; Ward *et al.,* 2017). This contrasts with the song of Southern Hemisphere pygmy blue whales, for which at least six different songs have been described to date that consist of 2–4 units including frequency- and amplitude-modulated notes (Ljungblad *et al.,* 1998; Samaran *et al.,* 2010a; Stafford *et al.,* 1999; 2011; Buchan *et al.,* 2014; Miller *et al.,* 2014).

Dedicated research effort directed at Antarctic blue whales in the Southern Ocean was carried out by the IWC SOWER programme conducted from 1996 to 2010. IWC SOWER was preceded by the IWC's International Decade of Cetacean Research (IWC IDCR) programme that ran from 1978 to 1995. The IWC SOWER programme included a blue whale research component that centred on both the evaluation of acoustic techniques for their assessment and identifying criteria for distinguishing the Antarctic and pygmy blue whales in the field (Donovan *et al.,* 1996). Although IWC SOWER was conducted within all of the six IWC Management Areas in the Southern Ocean (Donovan, 1991): Area I (120°W–60°W), Area II (60°W–0°), Area III (0°–70°E), Area IV (70°E–130°E), Area V (130°E–170°W) and Area VI (170°W–120°W), much of the blue whale research centred on Area III.

The blue whale component of the IWC SOWER cruises included video recording, behavioural notes, photographs, biopsy samples, and acoustic recordings of blue whales that can be integrated to learn more about the behavioural ecology of blue whales. This included, but was not limited to, determining the sex of vocal whales (by combining biopsy results with recordings of localised whales), estimating the proportion of calling whales in a region (by comparing the number of whales seen with the number heard) and comparing the types of sounds recorded in association with observed behaviour. Finally, although blue whales were the primary targets of acoustic monitoring, the data collected included acoustic detections from other species, including other baleen whales, killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*) and crabeater (*Lobodon carcinophaga*) and leopard (*Hydrurga leptonyx*) seals.

The South African Blue Whale Project (SABWP) was aimed at estimating the relative abundance, distribution and seasonal movements of Antarctic blue whales within the South Eastern Atlantic Ocean including through investigation of seasonal call rates (Findlay *et al.,* 2012; Shabangu and Findlay, 2014). The SABWP applied for and received permission to analyse the IWC SOWER Antarctic and low latitude blue whale cruise acoustic data from 1996/1997 through 2008/2009 in 2013. This paper summarises the acoustic data collected during the circumpolar IWC SOWER Antarctic cruises and the compilation of a database of the resultant data from these cruises.

MATERIALS AND METHODS

Field recordings

Acoustic data were collected on board the research vessels *Shonan Maru* (SM) and *Shonan Maru* No. 2 (SM2), during nine IWC SOWER cruises in the austral summer between 1996 and 2009, with opportunistic recordings obtained during an additional three cruises in the Southern Ocean in 1996/1997, 1997/1998 and 2000/2001 (Fig. 1, Table 1). These cruises in both the Antarctic and in low latitude regions have been fully described by Branch *et al.* (2007) and Kelly *et al.* (2012) whilst detailed descriptions of survey methodology are provided in the annual cruise reports (Ensor *et al.,* 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008; 2009; Kato *et al.,* 1996; Ljungblad *et al.,* 1998; Findlay *et al.,* 1998; Sekiguchi *et al.,* 2010). Sonobuoys were deployed on acoustic stations in close proximity to sighted blue whales and fin whales (*Balaenoptera physalus*) during directed research on these species, but were otherwise deployed while drifting at night.

The primary acoustic recording method used expendable DiFAR (Direction Finding and Ranging) sonobuoys (Spartan Electronics Model AN/SSQ53D DIFAR). A modified reusable AN/SSQ 57A Sonobuoy (fixed 27.4m [90ft] hydrophone cable) and a fixed hydrophone with a preamp and 305m (1,000ft) of cable were also available for recordings while the ship was drifting. These 'Donobuoys' could be retrieved and recharged for redeployment. No calibrations were conducted between different listening systems used nor were individual units calibrated before surveys.

The sonobuoy radio signal was received via the ship antenna, which was coupled to an ICOM IC-R100 single channel receiver that had been modified to extend its audio bandwidth. This output was connected to a Sony DAT TCD-D7 recorder (flat frequency response from 5Hz to 24kHz) or a Sony mini-disk MZ-R700 recorder (frequency response 20Hz–20kHz±3dB). Recordings were later digitised to a

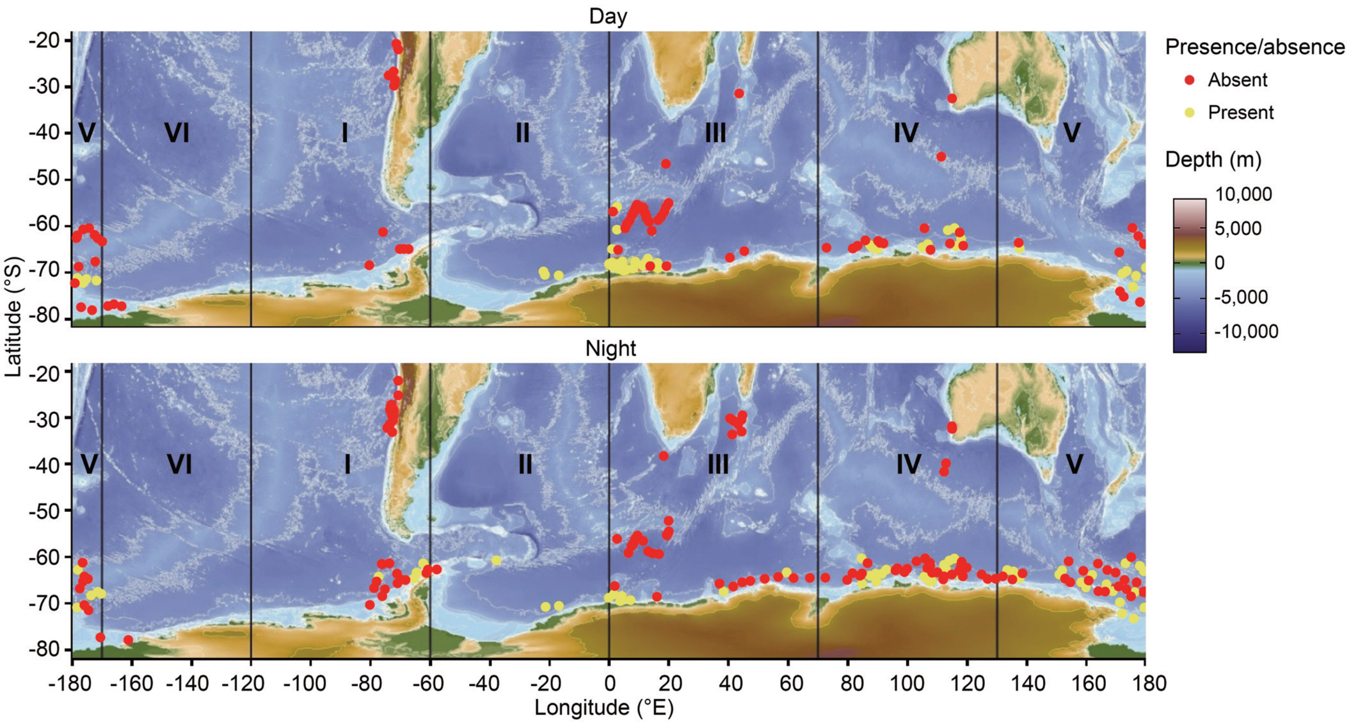

Fig. 1. Distribution of IWC SOWER sonobuoy deployments showing the presence/absence of Antarctic blue whale calls over various depths of the Antarctic Peninsula and the low latitudes. The six 'outlying' sonobuoys in Area VI are from three stations of the 2003/2004 *SM*2 cruise supposedly deployed in Area V.

Table 1

Summary and comparison of available and reported acoustic data associated with Antarctic blue whale vocalisation from the IWC SOWER cruises. Values in brackets refer to those reported in the cruise reports. RVs used: *Shonan Maru* (SM), *Shonan Maru No. 2* (SM2) and *Kaiko Maru* (KM). Only the acoustic recording data are presented here. The species detected include BL = blue whales (*Balaenoptera musculus*), PBL = pygmy blue whales (*Balaenoptera musculus brevicauda*), FW = fin whales (*Balaenoptera physalus*), RW = southern right whale (*Eubalaena australis*), HW = humpback whales (*Megaptera novaeangliae*), KW = killer whale (*Orcinus orca*), SW = sperm whale (*Physeter macrocephalus*) and SE = seals (Pinniped). There was no acoustic component during the 2000/01, 2004/05 and the 2009/10 cruises.

Cruise year	RV	Recording dates	Total hours recorded	Number of sonobuoys	Hydro-phones	IWC Area	Species reported	Reference
1996/97	SM	15 Jan.–04 Feb. 1997	42.85 (59.73)	3 (6)	9 (10)	II	BL, PBL	Ensor *et al.* (1997)
	SM2	08–12 Feb. 1997	12.42 (12.00)	4 (3)	0 (0)	II		
1997/98	SM	–	0 (17.32)	0 (2)	0 (13)	II	BL	Ensor *et al.* (1998)
	SM2	29 Jan. 1998	5.00 (26.40)	2 (12)	0 (1)	II		
1998/99	SM	08 Jan.–23 Feb. 1999	190.10 (241.96)	98 (50)	0 (7)	III and IV	BL, SP, KW, FW, HW,	Ensor *et al.* (1999)
	SM2	13 Jan.–21 Feb. 1999	30.53 (235.84)	11 (35)	0 (11)	III and IV	SE, BN, HG	
1999/00	SM	14 Jan.–12 Feb. 2000	33.62 (151.5)	10 (30)	0 (0)	I and II	BL, SP, KW, FW, HW,	Ensor *et al.* (2000)
	SM2	14 Jan.–13 Feb. 2000	164.70 (177.8)	50 (51)	0 (0)	I and II	SE, UN	
2000/01	SM	12 Jan. 2001	0 (2.63)	0 (0)	0 (1)	V, VI and I	None	Ensor *et al.* (2001)
	SM2	–	0 (0)	0 (0)	0 (0)	V, VI and I		
2001/02	SM	31 Dec. 2001–23 Jan. 2002	64.30 (117)	17 (26)	3 (8)	V	BL, SP, KW, HW, SE	Ensor *et al.* (2002)
	SM2	–	0 (118.5)	0 (7)	0 (20)	V		
2002/03	SM	23 Dec. 2002–24 Feb. 2003	120.17 (271.1)	26 (39)	7 (16)	V	BL, SP, KW, FW, HW,	Ensor *et al.* (2003)
	SM2	22 Dec. 2002–24 Feb. 2003	44.95 (162.25)	23 (42)	0 (2)	V	SE, UN	
2003/04	SM	26 Dec. 2003–26 Feb. 2004	68.00 (106)	18 (26)	5 (18)	V	BL, SP, KW, HW, SE	Ensor *et al.* (2004)
	SM2	26 Dec. 2003–28 Feb. 2004	142.23 (136)	28 (28)	12 (12)	V		
2004/05	SM and SM2	–	0 (0)	0 (0)	0 (0)	III	None	Ensor *et al.* (2005)
2005/06	SM2	23 Dec.–15 Feb. 2006	231.40 (264)	127 (127)	0 (0)	III	BL, SP, KW, FW, SE, UN	Ensor *et al.* (2006)
2006/07	SM2	29 Dec. 2006–08 Feb. 2007	76.32 (87)	51 (55)	0 (0)	III	BL, SP, FW, SE	Ensor *et al.* (2007)
2007/08	SM2	26 Dec. 2007–13 Feb. 2008	251.77 (251)	59 (71)	0 (0)	IV	BL, SP, FW, RW, KW, SE, UN	Ensor *et al.* (2008)
2008/09	SM2	21 Jan.–09 Feb. 2009	40.00 (43.38)	23 (25)	0 (0)	IV	BL, SP, FW	Ensor *et al.* (2009)
2009/10	KM	–	0 (0)	0 (0)	0 (0)	IV	None	Sekiguchi *et al.* (2010)
Total			1,518 (2,481)	550 (635)	36 (119)			

Sony PCG-FX120 computer (sample rate 48kHz) using the software program Ishmael (Mellinger, 2001). As opportunity allowed, recordings were monitored visually using a scrolling spectrographic display in Ishmael or Raven (Bioacoustics Research Program, 2013) and often aurally using headphones. The spectrographic display characteristics varied by user, but in general were selected to allow for detection of very low frequency sounds associated with blue or fin whales (< 200Hz). Not all recordings were monitored to detect sounds from other species (e.g. sounds > 200Hz). There may therefore be additional acoustic recordings of other species in the existing, but unreviewed, data.

When possible, DiFAR processing provided bearings to sounds. DiFAR signal processing was performed using an automatic Matlab function within Ishmael that executes a series of commands for de-multiplexing the DiFAR signal (software developed by Greeneridge Sciences, Inc, McDonald, 2004) and determines the bearing to a sound source. DiFAR was not always available in real time for surveys although on occasion it was used to obtain bearings to animals in real time, and extensive post-cruise analysis was performed on a subset of these DiFAR data (see Rankin *et al.*, 2005). During the 2001/2002 cruise, the paucity of recording media necessitated recording at the lowest possible sampling rate to maximise the recording time (with a sample rate of 32kHz, the frequency response of the Sony TCD-D7 was 20–14,500Hz±1dB). This eliminated the multiplexed DiFAR signal, so bearings could not be obtained for these data.

Acoustic monitoring and recording durations at stations ranged between 5mins and 17hrs. For the purposes here, acoustic monitoring is defined as when the underwater environment was acoustically monitored, i.e. listened to using headphones or viewed on a spectrogram without recording in Ishmael (Mellinger, 2002) or Raven (Bioacoustics Research Program, 2013). Acoustic recording, on the other hand, is defined here as when encountered blue whale sounds were recorded and archived for future use.

All acoustic stations were described by an acoustic record form which included the monitoring and/or recording times. Acoustic recordings were made over short intervals although animal calls were monitored for a longer time period (Ensor *et al.*, 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008; 2009; Kato *et al.*, 1996; Findlay *et al.*, 1998; Ljungblad *et al.,* 1998). In a few cases, marine mammal vocalisations were recorded but not documented on the acoustic record form. Prior to 2005, recorded acoustic files were logged at hourly intervals and were saved in an Audio Interchange File Format (AIFF) at a 16-bit encoding with the majority of the files having two channels. From 2005 onwards, the sampling interval was decreased to 10mins and sound file type was changed from AIFF to Waveform Audio File format (WAV) at a 16-bit signed encoding.

Database compilation

All the currently available IWC SOWER acoustic recording files (including duplicates) amounting to 286GB were sourced from archives held by the Cornell University Laboratory of Ornithology or from individual cruise participants. The acoustic recording files from low latitudes; i.e. the Australia, Madagascar and Chile blue whale cruises, amounted to only 3.31GB, whilst the remainder were largely from South of 40°S. Spatial and temporal metadata of the observed stations were extracted from the cruise reports (Ensor *et al.,* 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008; 2009; Kato *et al.,* 1996; Findlay *et al.,* 1998; Ljungblad *et al.,* 1998; Sekiguchi *et al.,* 2010). Acoustic data forms and the associated sightings forms were sourced from the IWC Secretariat. The reconciled acoustic database and all metadata are currently held at the Mammal Research Institute Whale Unit of the University of Pretoria.

Received acoustic data files were archived in the following file and folder format. Folder (Cruise Year and Region), sub-folder (Vessel), sub-folder (Tape or Hard-drive) and File (acoustic file). A corresponding Microsoft Excel database was designed to include these fields for each acoustic file. For example, the database entries for these fields for an acoustic file from the 2000 Antarctic *Shonan Maru* cruise included: 2000 Antarctic (Cruise Year and Region), SM1 (Vessel), Tape 01 (Tape or Hard Drive number), and SM1_000114-000000.aif (acoustic file). Once these data had been captured, duplicates and empty folders were identified and deleted from the working database. Thereafter the date, time and location (latitude and longitude) data of each station were derived from the cruise reports and the acoustic record forms and were merged with the acoustic file database to complete the properties of each acoustic station. File duration, the visual presence or absence of blue whales, and the determined total recording time (which comprised a number of files at each station) were thereafter entered into the database.

Records were categorised to daytime/night-time based on their recording times depicted on the file names with daytime designated as 06h00–18h00 and night-time designated as 18h00–06h00 (although not daylight schedules, in the Antarctic this means that this in reality reflects whether the vessel was engaged in sighting survey operations between 06h00 and 18h00 rather than natural light regimes). The visual survey operations during daylight hours (06h00 to 18h00) meant that acoustic stations were biased towards the night period, and daytime acoustic stations were biased towards deployments in association with whale groups. Acoustic data were further grouped by IWC Management Area. Data fields were later added to the dataset to include numbers and rates of D- and Z-calls detected at each station once the data analyses had been completed. The final spreadsheet dataset contained: cruise year; IWC Management Area; research vessel; date (year, month and day); tape/sonobuoy number; station number; file name; acoustic file type; time of the day; file duration; blue whale presence/absence; station total recording duration; station position (latitude, longitude); and a comments field (Table 2).

Database analyses

Acoustic data were investigated and characterised using the Raven Pro software (Bioacoustics Research Program, 2013). Antarctic blue whale call detection templates (Fig. 2) were created and applied to all acoustic files in eXtensible

Table 2

Example of the final database content.

Field	Example
Cruise (year and region)	2007/08 Antarctic cruise
Research vessel	SM2
Date	12 February 2008
Tape/sonobuoy number	SB 59
IWC Management Area	IV
Station number	46
File name	SOWERD-080212-000000
Acoustic file type	WAV
Time of the day	Night
File duration (hr)	8.08
Blue whale presence/absence	Present
Station total recording duration (hr)	8.08
Station position (latitude, longitude)	–64.27, 105.59
Comments	Faint calls

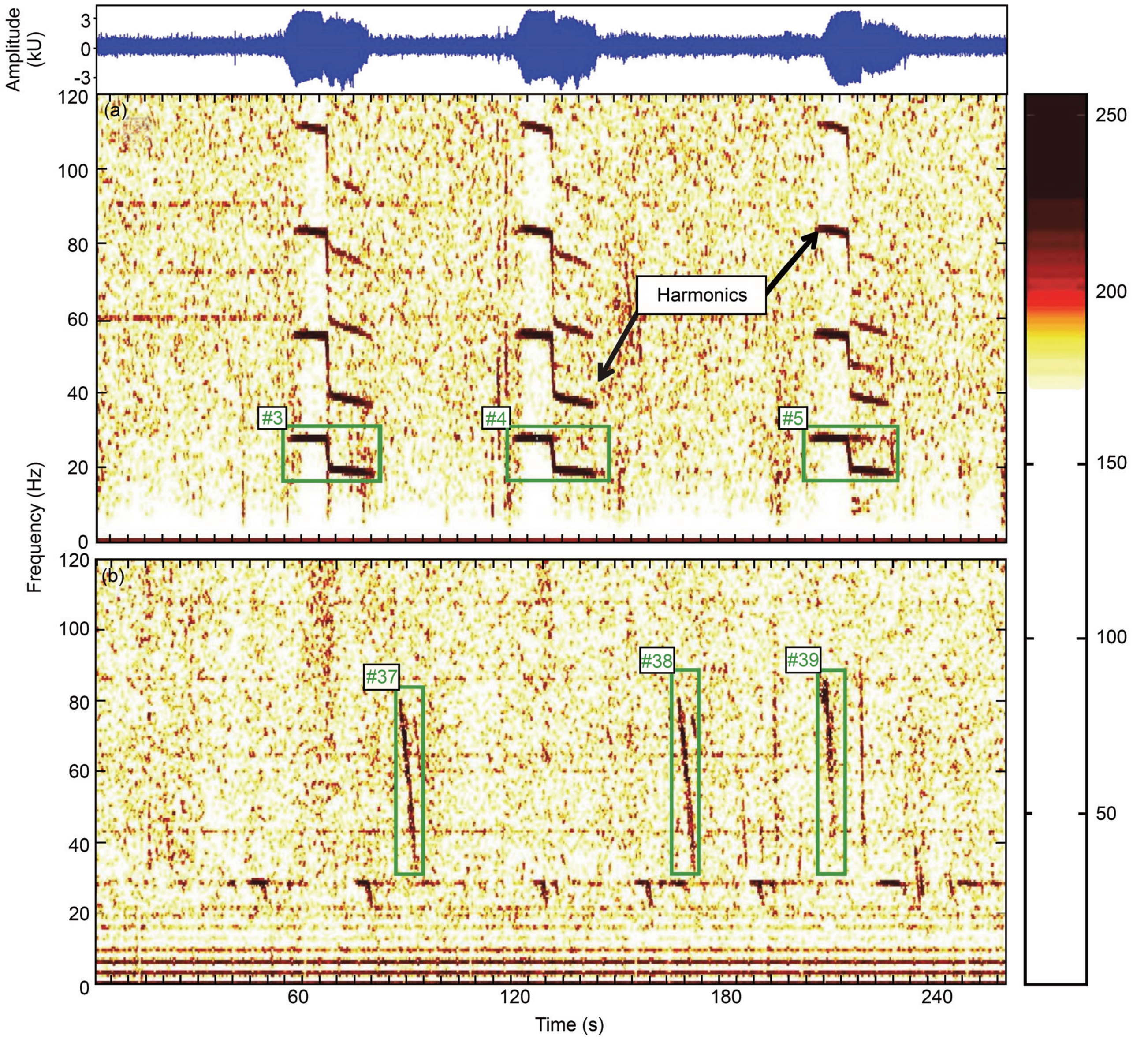

Fig. 2. Spectrograms of three auto-detected Antarctic blue whale (a) Z-calls and (b) D-calls (in green boxes). Z-calls and their amplitudes (top panel, kU is kilo unit) were recorded during the 2001/02 IWC SOWER cruise at –64.57°S and 137.68°E, and D-calls were recorded during the 1996/97 IWC SOWER cruise at 68°48'S and 00°06'E. The hash (#) number on the top left corner of each box refers to the call-type auto count number for that particular acoustic file. Spectrogram parameters: frame size 1.28s, 50% overlap, FFT size 1650 points, Hanning window.

Bio-Acoustic Tool (XBAT) software (Figueroa, 2006) operated on the MATLAB R2014a platform (MathWorks Inc, 2014). The non-decimated acoustic files from 2003/2004 through 2008/2009 sampled at 48,000Hz were decimated to 1,000Hz using custom-written MATLAB script to improve the frequency resolution and the Fast Fourier Transform (FFT) length. All call detections were verified by a manual visual verification method (more details about the detector performance are given in Shabangu *et al.,* 2017), and visually scrutinised for pygmy blue whale calls (Fig. 3). Sonobuoy deployments from Australia, Chile and Madagascar are not considered in our analyses as they do not contain Antarctic blue whale calls.

Statistical data analyses and plotting of the call data were performed in the R statistical software package (R Development Core Team, 2015), using script editor RStudio version 0.99.473 (RStudio Team, 2015). The call data were standardised by survey effort (recording duration) to calls per hour, which defines call rates. Pearson's correlation coefficients (r) were estimated to measure the linear correlation (dependence) between variables, while a two-sample Kolmogorov-Smirnov test (KS test) was used to determine if datasets differed significantly.

RESULTS

Based on the information extracted from the cruise reports, acoustic data were collected at a total of 716 acoustic stations during the IWC SOWER cruises between the 1996/1997 and the 2009/2010 seasons (Fig. 1). Sampling at acoustic stations was conducted in all IWC Areas except Area VI, and most effort occurred in Areas III, IV, and V. A total of 525 sonobuoys were deployed during 11 cruises (Table 1). Not all sonobuoys were functional; the overall failure rate of sonobuoys ranged from 0 to 40% per cruise. Overall, over 2,794hrs of acoustic monitoring were conducted in real time during the cruises where acousticians listened to sounds and monitored spectrograms in real time (Table 1). Recording acoustic data to media occurred for 24hrs of the day.

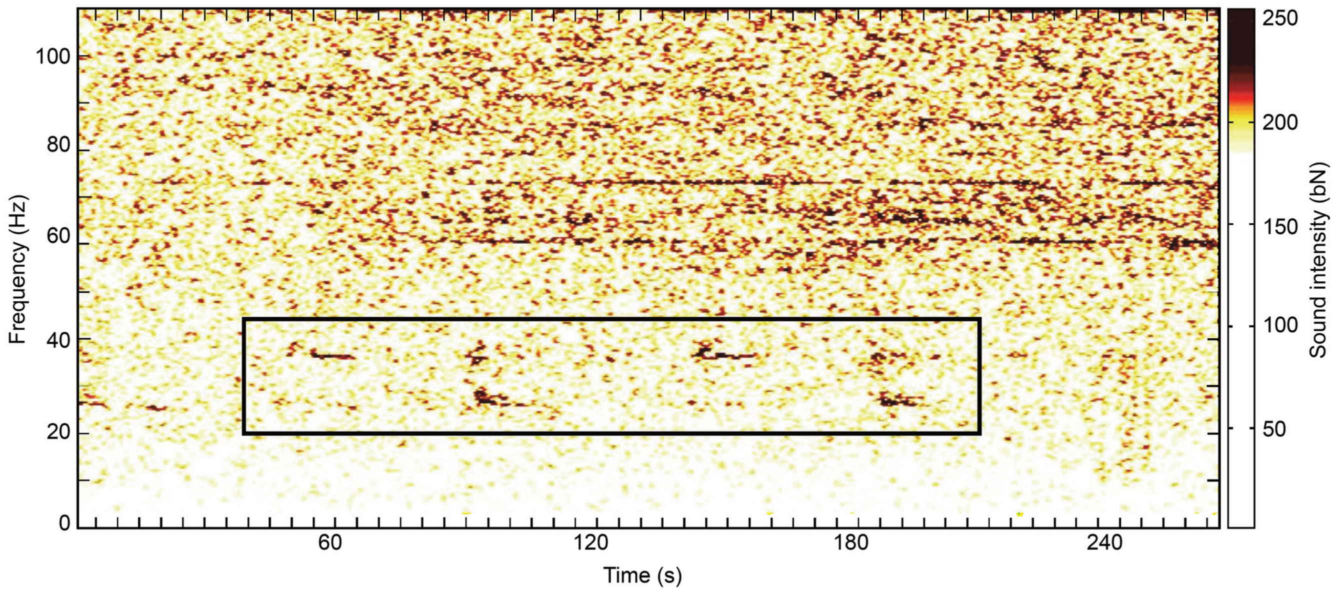

Fig. 3. Spectrogram showing calls of pygmy blue whales (rectangle) recorded in Madagascar during the 1996/1997 IWC SOWER cruise. Spectrogram parameters: frame size 1.28s, 50% overlap, FFT size 1650 points, Hanning window.

Detections included Antarctic blue whales (Fig. 2), Madagascan pygmy blue whales (Fig. 3), fin whales, humpback whales, killer whales, southern right whales (*Eubalaena australis*), sperm whales, small odontocetes and seals (Table 1, Figs 4–8). Assignment of a species to recorded call types was based on a combination of: (1) acoustician experience with visual spectrogram and real-time listening; (2) comparison of signals with the literature; and (3) post-processing attribution (as was the case for leopard seal sounds previously attributed to humpback whales based on presence of humpback whales and humpback whale–like low-frequency vocalisations reported in the literature).

Distinct Antarctic blue whale sounds were detected at 179 stations (Table 1, Fig. 1). With the exception of the 1996/1997 cruise, all blue whale songs detected were D-calls or 28Hz tonals attributed to Antarctic blue whales (Fig. 2), while songs associated with other Southern Hemisphere blue whales were recorded near Madagascar and off Chile (Ljungblad *et al.,* 1998; Clark and Fowler, 2001) and not during the Antarctic cruises. Not all Antarctic blue whale songs comprised all three note types; however, the songs always contained the first 28Hz component (see Rankin *et al.*, 2005 for a full description). In addition to these stereotyped long-duration songs, shorter duration, FM D-calls were also detected at some stations. Ljungblad *et al.* (1998) compared data from recordings made South of 60°S with those made off the Madagascar Plateau (25°–35°S and 40°–45°E) and described differences in the sounds produced by blue whales in those areas. These recordings amounted to the first descriptions of each of those two song types and supported the idea that acoustic monitoring was a robust means of distinguishing between Antarctic and pygmy blue whales.

Available recordings – new analyses of the compiled database

After database compilation, approximately 7,485 recorded acoustic files were available from 484 stations of the Antarctic cruises comprising a total of 1,518hrs of acoustic recordings from the analysed 586 deployed acoustic recorders (i.e. 550 sonobuoys and 36 towed or deployed hydrophones). Antarctic blue whale calls were detected on 4,183 of the 7,485 recorded files. The available hours of recordings and number of sonobuoys represent only 63% and 80% respectively of the effort documented in the cruise reports as significant numbers of the acoustic data files from the IWC SOWER cruises could not be sourced (Table 1). The 2003/2004 and 2005/2006 cruises were the only two years where the available data are equivalent to the documented data in the cruise reports. It is also apparent that some of the acoustic data collected using cabled hydrophones from earlier years are missing (Table 1). The longitudinal acoustic survey coverage of the Southern Ocean is fairly sporadic between IWC Management Areas (Fig. 1) during the IWC SOWER programme. Areas III, IV and V had the highest acoustic survey coverage (Tables 1 and 3). Most sonobuoy deployments were conducted between the ice edge and 60°S but most blue whale call detections were close to the ice edge (Fig. 1) within this region.

The acoustic survey effort in terms of the number of acoustic stations and duration of the recordings varied significantly (Two-sample KS test, $p < 0.05$) between years and Areas (Tables 1 and 3). Furthermore, the duration of the recordings at each station varied considerably as some acoustic stations had two or more sonobuoy deployments whereas others had just one deployment. Acoustic recordings were made in 11 out of 14yrs of the IWC SOWER programme. Only one acoustic recording was listed for Area

Table 3

The total number of available acoustic stations recorded on IWC SOWER cruises grouped by IWC Management Area.

Area	Total number of stations
Area I	31
Area II	19
Area III	193
Area IV	119
Area V	122
Area VI	0
Total	484

Table 4
Details of the available acoustic data recorded from other IWC blue whale cruises conducted in the low latitudes. Values in brackets refer to records in the cruise reports.

Cruise year	RV	Recording dates	Total hours recorded	Number of sonobuoys	Cruise Area	Positions (longitude)	Reference
1995/96	SM	–	0 (18.06)	0 (12)	Australia	114°–115°E	Kato *et al.* (1996)
	SM2	07–26 Dec. 1995	17.60 (78.04)	10 (43)	Australia	114°–115°E	Kato *et al.* (1996)
1996/97	SM	10–24 Dec. 1996	39.93 (182.12)	12 (52)	Madagascar	40°–44°E	Ljungblad *et al.* (1998)
	SM2	–	0 (81.18)	0 (45)	Madagascar	40°–44°E	Ljungblad *et al.* (1998)
1997/98	SM	09 Dec. 1997–02 Jan. 1998	43.32 (72.50)	16 (29)	Chile	72°–74°W	Findlay *et al.* (1998)
	SM2	17 Dec. 1997–02 Jan. 1998	100.97 (106.21)	23 (30)	Chile	70°–74°W	Findlay *et al.* (1998)
Total			201.82 (538)	61 (211)			

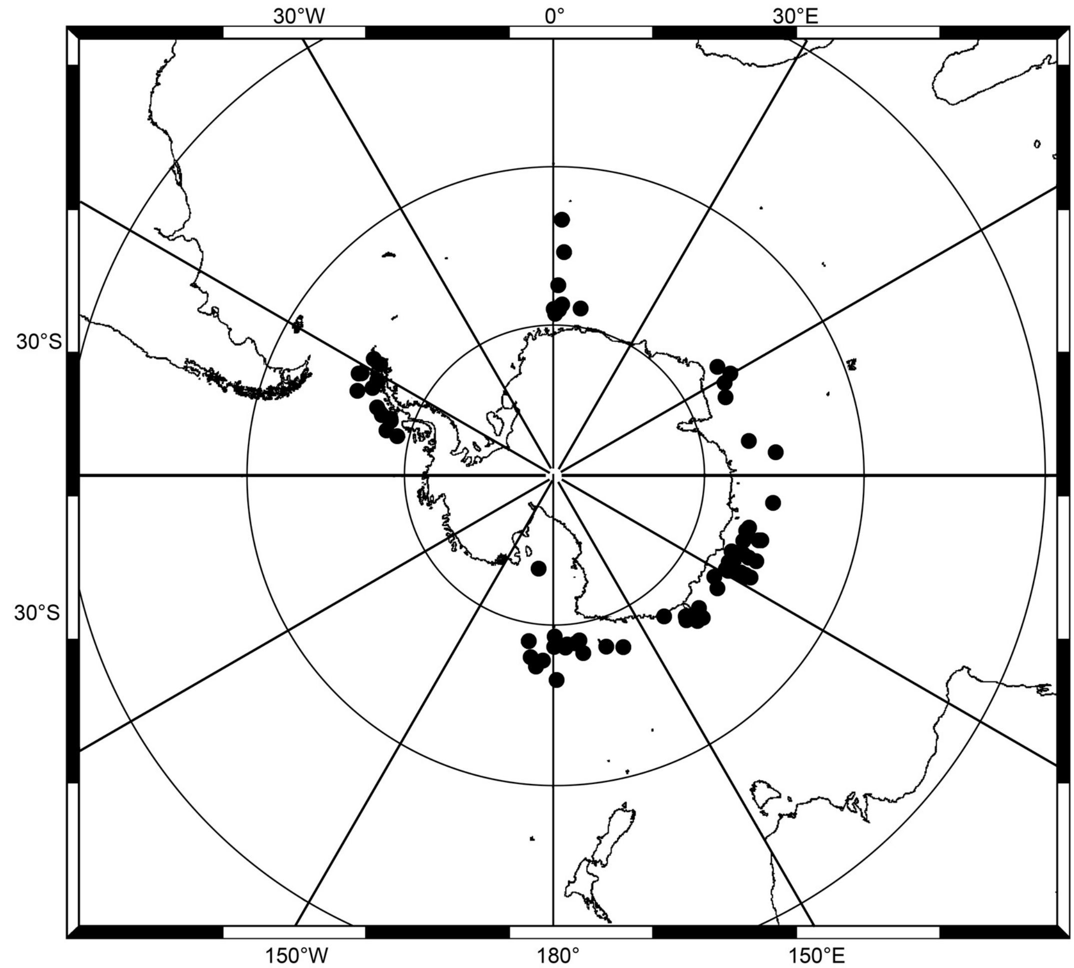

Fig. 4. Locations of all sonobuoy recordings with identified acoustic detections of humpback whales (●) from 1996 to 2009.

VI from *Shonan Maru* for 2.38hrs on 12 January 2001 in the presence of four blue whales (Ensor *et al.,* 2001), however this acoustic recording file could not be sourced for analyses. Details of the available acoustic data from the IWC SOWER blue whale cruises conducted in the low latitudes are given in Table 4. Acoustic data files from the 1997/1998 Antarctic cruise have not yet been sourced, although the data files from the preceding Chile blue whale cruise (the cruises ran back to back) have been reviewed, including the identification of files grouped with the Chile cruise data but dated within the Antarctic cruise time period.

Antarctic blue whale call detections

The characteristic Antarctic blue whale Z-calls (Fig. 2a) were successfully detected using the template method in that a total of 24,902 calls were counted across the region surveyed. The blue whale feeding call, D-call (Fig. 2b), was also detected using the template method and a total of 9,315 calls were counted. The acoustic presence of Antarctic blue whales from the sonobuoy deployments shows a patchy distribution over the surveyed area (Fig. 1). Not all sonobuoys deployed yielded blue whale vocalisations (Figs 1 and 9) but there was a good correlation between blue whale Z-call detections and number of sonobuoys deployed ($r = 0.66$, $n = 586$, $p > 0.05$). A weak correlation was found between D-calls and number of sonobuoys deployed ($r = 0.49$, $n = 586$, $p > 0.05$). Only 241 of the 586 available sonobuoy deployments contained either or both types of the Antarctic blue whale calls. Area III had the highest call rates of both the D- and Z-calls (Figs 10 and 11). No call

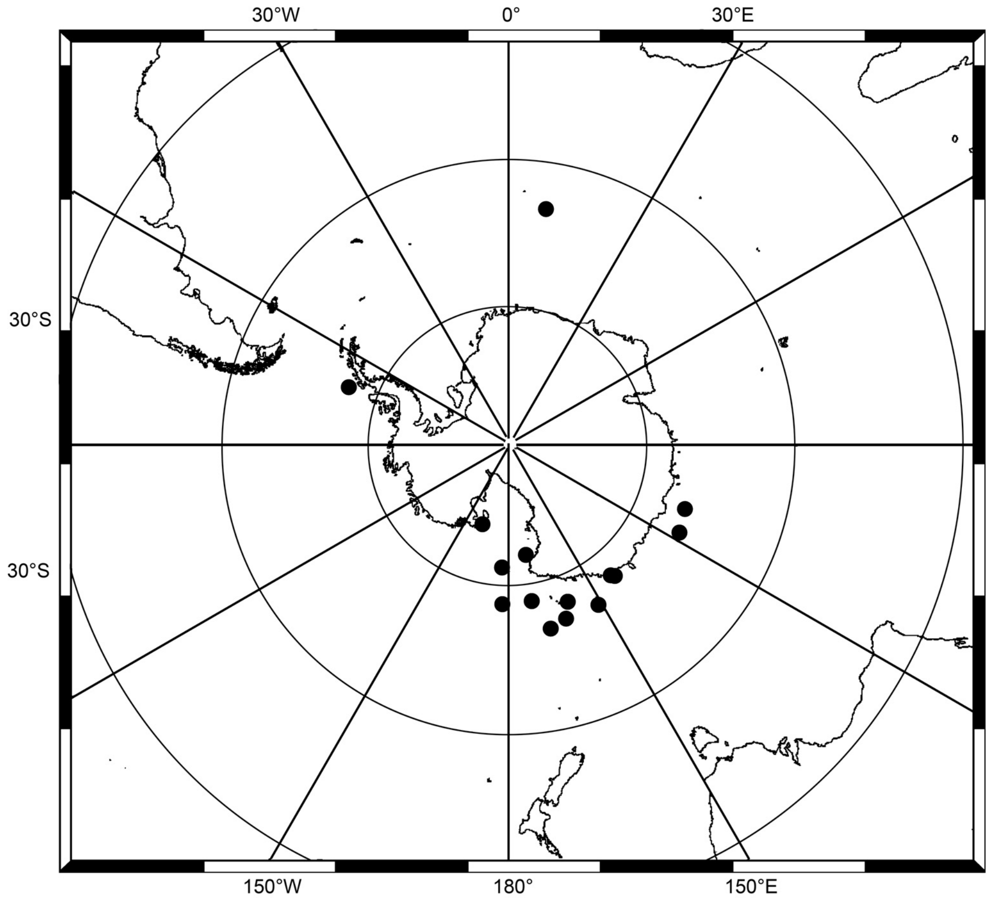

Fig. 5. Locations of all sonobuoy recordings with identified acoustic detections of killer whales (●) from 1996 to 2009.

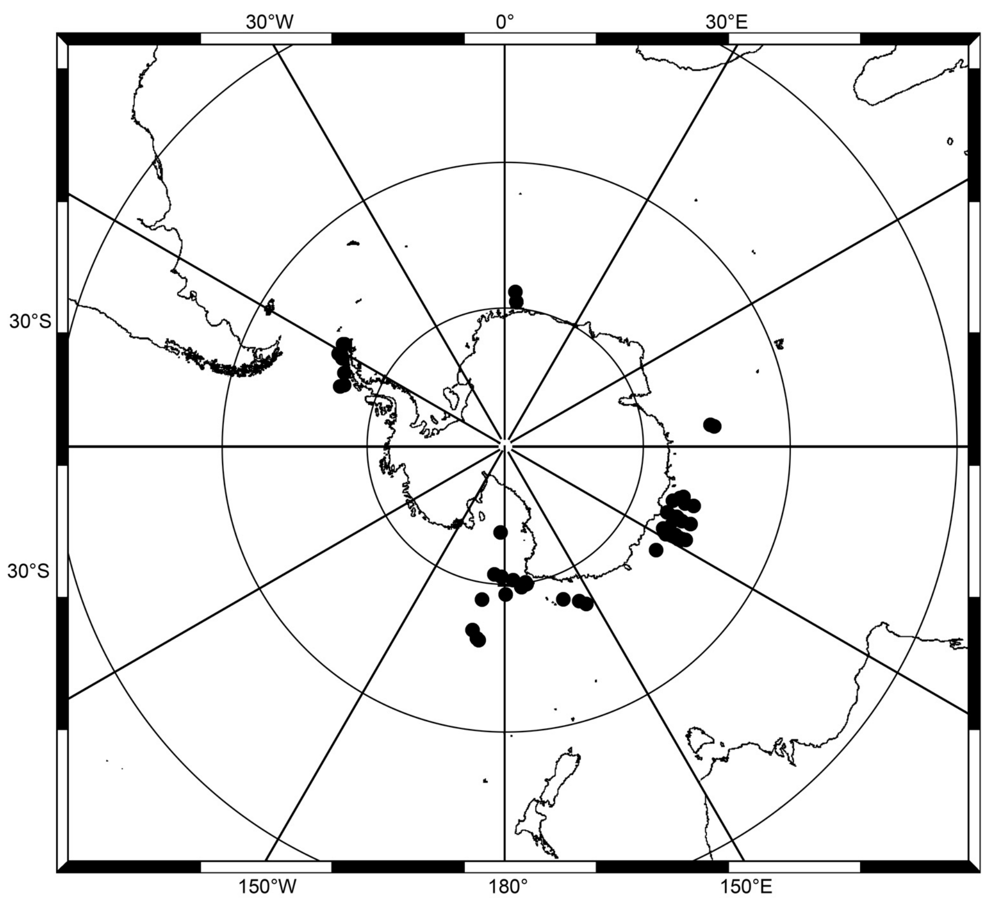

Fig. 6. Locations of all sonobuoy recordings with identified acoustic detections of unidentified and other marine mammal species including southern right whales (●) from 1996 to 2009.

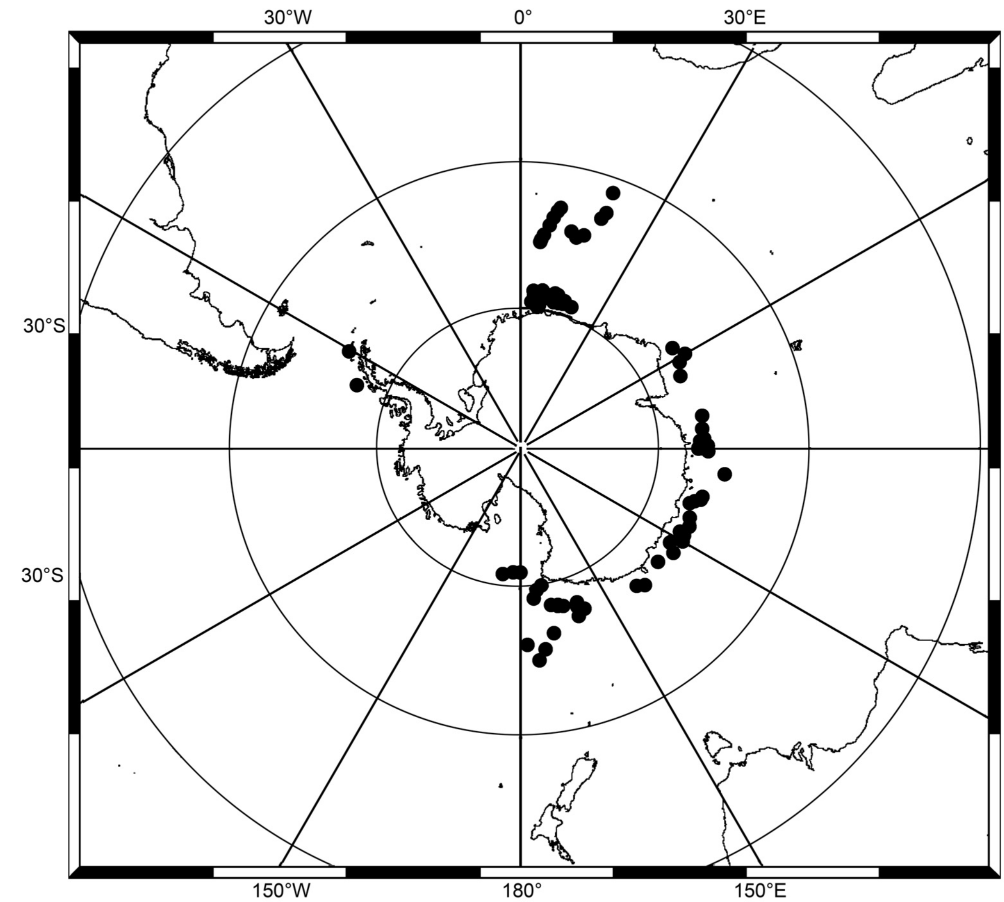

Fig. 7. Locations of all sonobuoy recordings with identified acoustic detections of sperm whales (●) from 1996 to 2009.

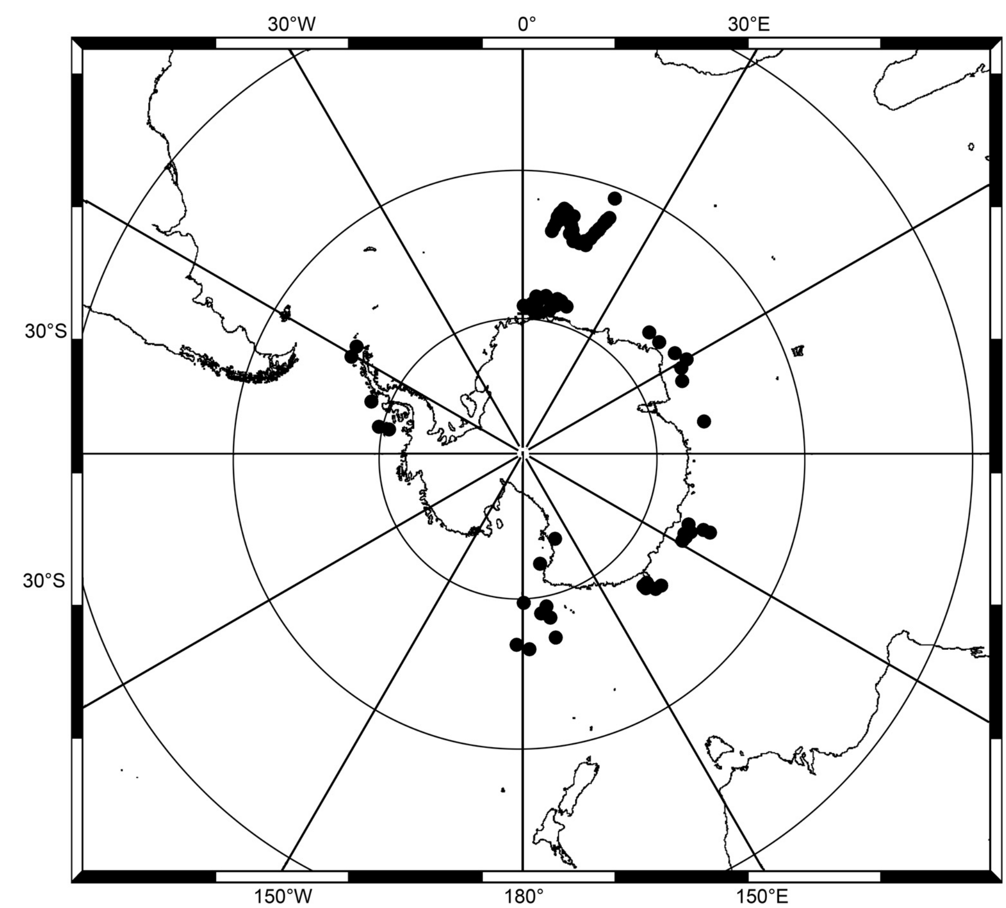

Fig. 8. Locations of all sonobuoy recordings with identified acoustic detections of all seal species (leopard, crabeater, Weddell) from 1996 to 2009.

detections were made in Area VI due to lack of acoustic survey effort.

A total of 214 sonobuoys were deployed during daytime and 372 deployed at night. More Z-calls were detected during daytime (14,724) than at night (10,178; Two-sample KS test, $p < 0.05$). This was also the case for D-calls with more calls being detected in the daytime (6,492) than at night (2,823; Two-sample KS test, $p < 0.05$). Weak correlations were found between acoustic station duration and the number of calls detected for both call types ($r = 0.33$ and 0.49 for D- and Z-calls respectively).

Data comparison

Comparisons of mean number of hours recorded in all cruises indicated that there was a significant difference between the available recorded hours from the dataset and documented recorded hours from cruise reports (Two-sample KS test, $p < 0.05$). A significant difference was observed between the number of sonobuoys available in the dataset and the sonobuoy numbers documented in cruise reports (Two-sample KS test, $p = 0.05$). There was a good agreement between our analysed blue whale call detection results and blue whale calls observed and documented in cruise reports ($r = 0.62$).

Other sounds and vocalisations detected

No calls of either Antarctic or pygmy blue whales were detected from the 1995/1996 Australia low latitude cruise, but calls of pygmy blue whales (Fig. 3) and fin whales were found in the 1996/1997 Madagascar acoustic data (Ljungblad *et al.,* 1998). No Z-calls were found in the 1997/1998 Chile cruise although D-calls and numerous southeastern Pacific 2 (SEP2) calls of the Chilean pygmy blue whale were found (Fig. 12). These call detections confirm observations in previous studies in the southeastern Pacific Ocean (Cummings and Thompson, 1971; Stafford *et al.,* 1999; Buchan *et al.,* 2010; 2014). The SEP2 call has a C2 unit which is 5s long (Fig. 12) followed by an inter-unit gap of 3s and then a 9s long D2 unit, and the overall duration of the call is approximately 17s (Buchan *et al.,* 2014). The D-calls observed from the southeastern Pacific Ocean were not considered for analysis in this study since we

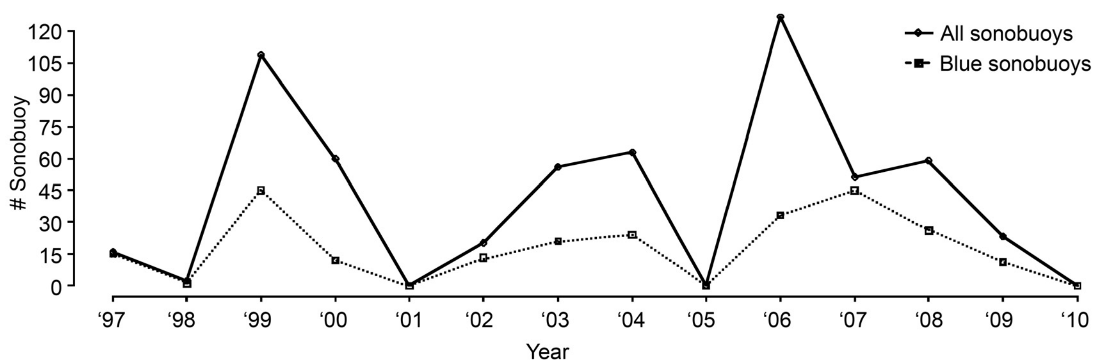

Fig. 9. Total number of sonobuoys deployed per year (all sonobuoys) and the resultant sonobuoys containing Antarctic blue whale calls (blue sonobuoys) from all IWC SOWER cruises.

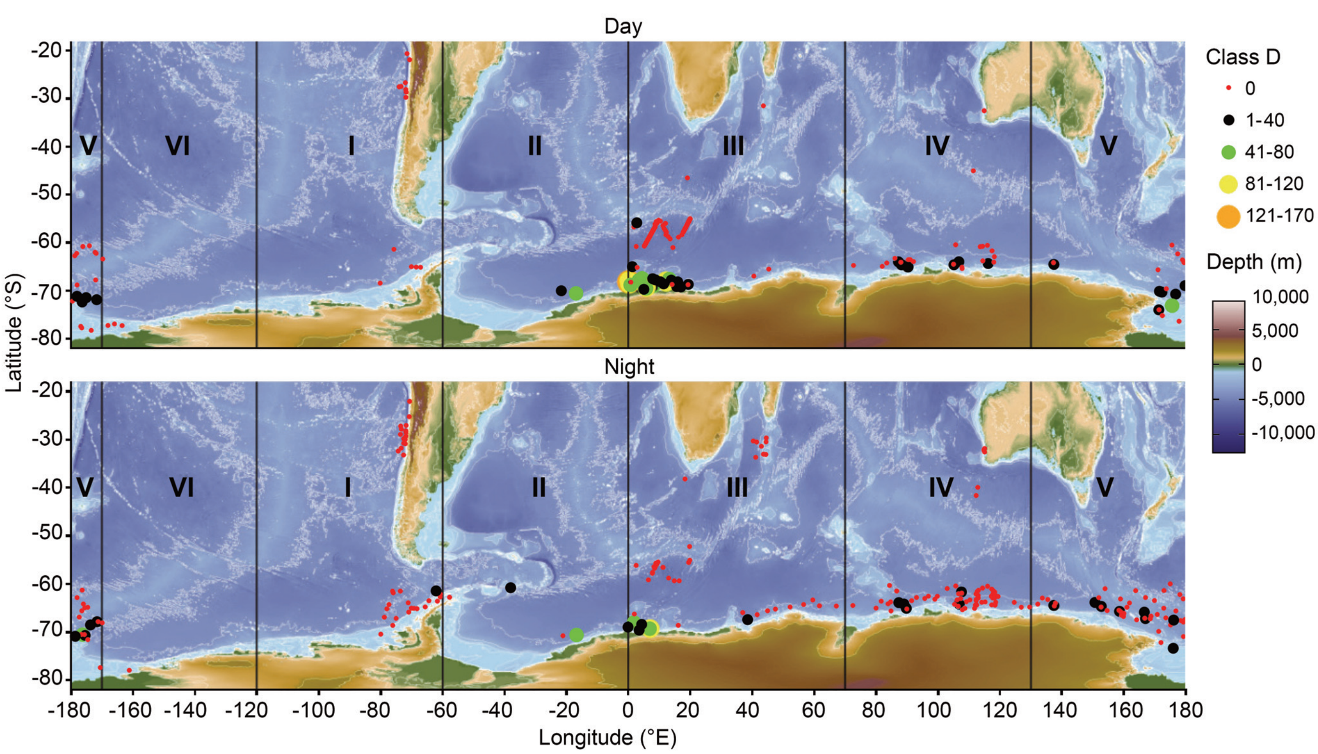

Fig. 10. Day and night distribution of D-call numbers in the Southern Ocean. Class D is the class of D-call rates.

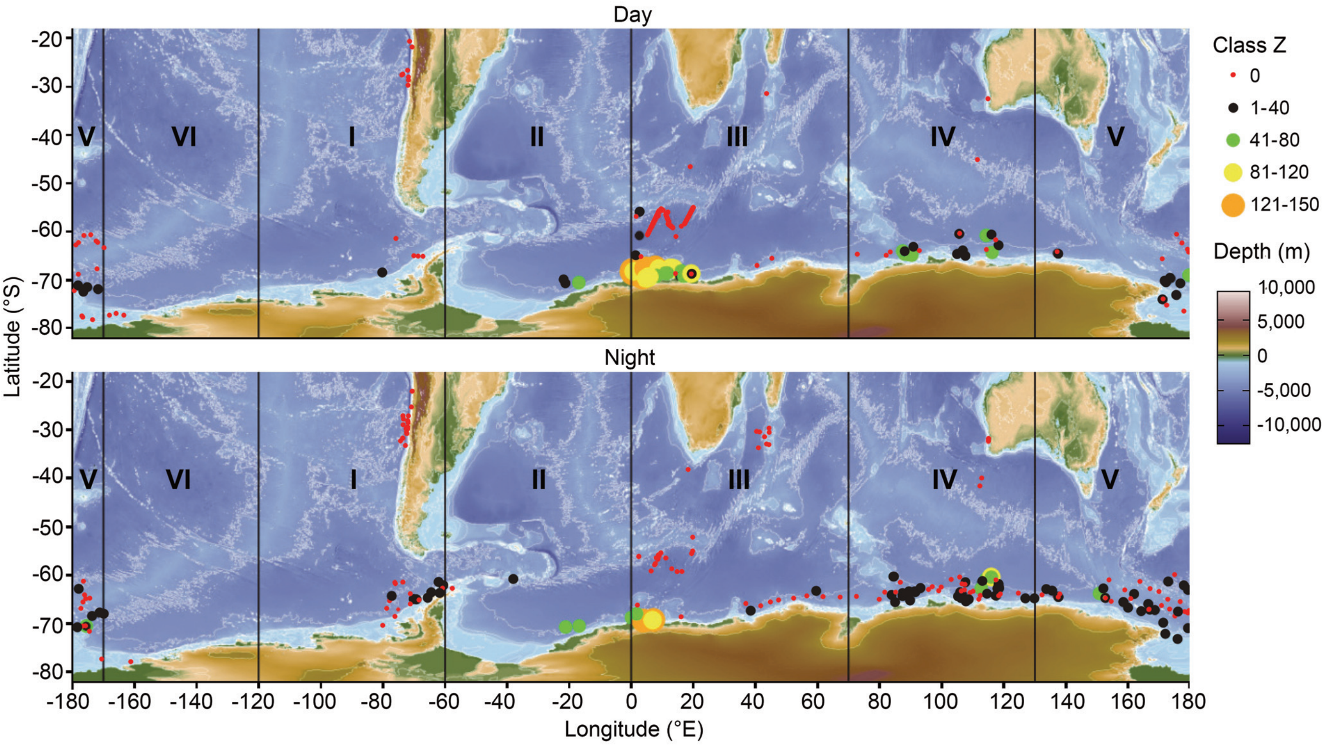

Fig. 11. Day and night distribution of Z-call rates in the Southern Ocean. Class Z is the groups of Z-call rates. Deployments from Australia, Chile and Madagascar are shown in maps for completion sake but not considered in our analyses.

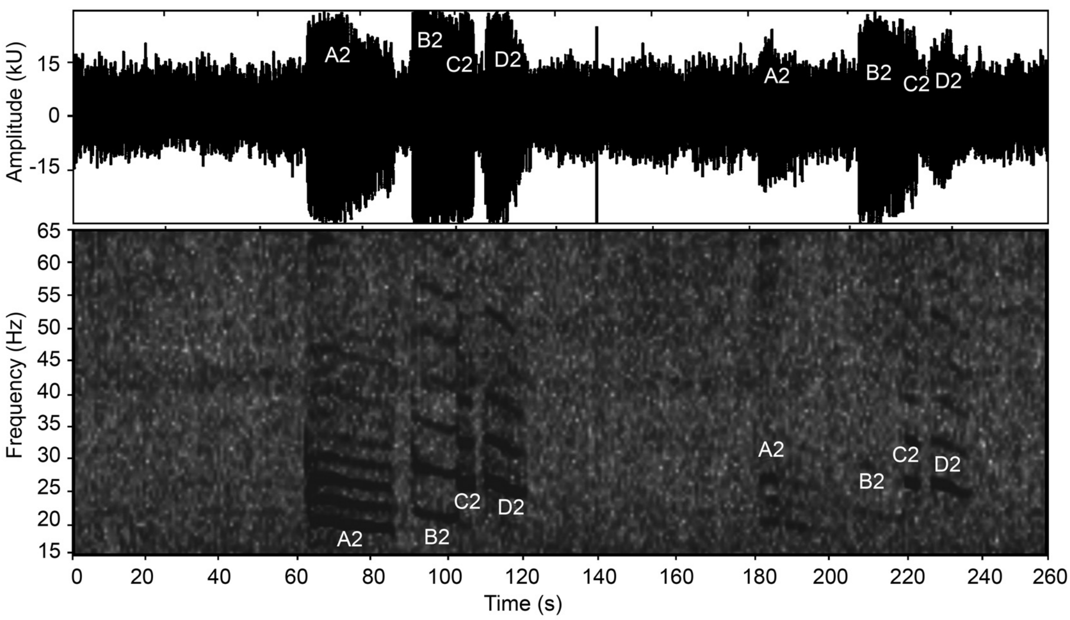

Fig. 12. Pressure waveform (top panel) and spectrogram (bottom panel) of the Chilean blue whale SEP2 song phrases (A2, B2, C2 and D2). This sonobouoy was deployed on 31 December 1997 off the southeastern Pacific Ocean at 28°39'N, 71°47'W during the 1997/1998 SOWER cruise, Chile. Spectrogram parameters: frame size 1.39s, 50% overlap, FFT size 2048s, Hanning window.

concentrated mainly on the Southern Hemisphere Antarctic blue whale population.

Detections of other marine mammal species included fin whales, humpback whales, killer whales, southern right whales, sperm whales, small odontocetes and seals (Table 1, Figs 4–8). In addition, ice noise, seismic air guns and other unidentified sounds were detected on numerous occasions.

DISCUSSION

The original goal of the acoustics component of the IWC SOWER cruises was to determine if passive acoustics could be used as a tool to help identify sighted blue whales to sub-species level. In 2006/2007 and 2007/2008, the passive acoustic method was also assessed for their utility in monitoring fin whales. Unfortunately, numerous limitations prevented the realisation of this potential during the IWC cruises, including limited resources (sonobuoys and recording tapes) available for field personnel. Most of the sonobuoys used were surplus instruments whose expiration dates had long passed, which resulted in sometimes very high failure rates. Nevertheless, the collective electronics expertise of the ships' radiomen and one of the co-authors

(DL), allowed the acousticians to modify some of the sonobuoys while at sea.

These cruises were moderately successful, despite numerous limitations, and they served to lay the foundation for future work using acoustics to study blue whales in the Southern Ocean. For instance, Ljungblad *et al.* (1998) compared data from recordings made South of 60°S with those made off the Madagascar Plateau (25°–35°S and 40°–45°E) and described differences in the sounds produced by blue whales in these areas. These recordings amounted to the first descriptions of each of these two song types and supported the idea that acoustic monitoring was a robust means of distinguishing between Antarctic and pygmy blue whales. The acoustic data collected on both Antarctic and pygmy blue whale vocalisations (Ljungblad *et al.,* 1998; Clark and Fowler, 2001; Rankin *et al.,* 2005) paved the way for numerous studies delineating occurrence and habitat usage of blue whales based on PAM and further strengthened the concept of 'acoustic populations' of blue whales (Stafford *et al.,* 2004; 2011; McDonald *et al.,* 2006; Samaran *et al.,* 2010a; 2010b; 2013). Further, recent surveys that actively used passive acoustics to detect, identify, track, and approach blue whales in the Southern Ocean for photo-identification and biopsy referred to IWC SOWER reports and publications (Clark and Fowler, 2001; Rankin *et al.,* 2005; Gedamke and Robinson, 2010) to select a target research area, develop methods and train field personnel (Miller *et al.,* 2015). The success of the Australian Antarctic Division, Southern Ocean Research Partnership (SORP) 2013 blue whale survey was based on the foundation built by the IWC SOWER cruises (Double *et al.,* 2013; Miller *et al.,* 2013a).

Distribution and occurrence of Antarctic blue whale call types

The higher number of Antarctic blue whale calls (31% and 56% more Z- and D-calls respectively) found during daytime, despite more sonobuoys being deployed at night-time might be an indication that Antarctic blue whales are vocally active mostly during daytime and less vocal at night-time. A similar observation has been made from autonomous acoustic recorders off the Maud Rise and Benguela ecosystem off South Africa (Shabangu *et al.*, 2019). Alternatively, the higher daytime call numbers might arise because daytime acoustic recordings were often conducted in the presence of visually sighted blue whales whereas night-time acoustic recordings were conducted blindly without knowledge of the blue whale presence or absence. Low numbers and rates of Antarctic blue whale calls observed in December could be due to the fact that most of the IWC SOWER cruises usually started in late December when the majority of the Antarctic blue whales may still have been in transit from the low latitude overwintering grounds to the Southern Ocean feeding grounds (Mackintosh and Wheeler, 1929).

Sea ice extent in December could also have affected the number of vocally active Antarctic blue whales as suggested by Širovic *et al.* (2004) since recordings from stationary autonomous Acoustic Recording Packages (ARPs) in Area II also found low call numbers in December. These IWC SOWER data showed that Antarctic blue whale call rates peaked in February (Shabangu *et al.,* 2017), which is closer to the blue whale call peak period of March and April observed by Širovic *et al.* (2004) from their ARPs. Despite most acoustic recordings being conducted earlier than mid-February, a considerable number of calls were detected in this month showing the availability of Antarctic blue whales in high numbers in the Southern Ocean at this time of the year when sea ice retreat is maximal. The increased call rates of Antarctic blue whales observed in the later years of the IWC SOWER programme (Shabangu *et al.,* 2017) may be indicative of the initial population recovery of 8.2% estimated by Branch *et al.* (2004). The increase in blue whale call rates in later years is not due to more dedicated ship time to record blue whale calls as there was no increase in the number of hours dedicated to acoustic research in those years (Table 1). The observed good correlation between blue whale call detections and number of sonobuoys deployed demonstrate that greater coverage effort in particular Areas of interest improved the precision of the distribution and occurrence estimates (Aglen, 1989). However, it is worth noting that a special effort was dedicated to certain IWC Areas with suspected high blue whale prevalence.

Antarctic blue whale calls have previously been detected in the South Pacific Ocean as far North as 08°S (Stafford *et al.,* 2004) and as far North as 08°S in the Indian Ocean (Samaran *et al.,* 2013). Nevertheless, during these analyses no Antarctic blue whale calls were found off Australia, in the southeastern Pacific, or South of Madagascar in the low latitude cruises, presumably reflecting the summer periods during which they were carried out. The IWC SOWER low latitude acoustic data were collected within a single summer month each year when the majority of Antarctic blue whales would be expected to be further South than the region surveyed whereas the data analysed by Stafford *et al.* (2004) were collected over 24 months. Calls of pygmy blue and fin whales were found during our analyses of the incomplete acoustic data from Madagascar, confirming Ljungblad *et al.*'s (1998) observation. The 1995/1996 Australia blue whale cruise reported pygmy blue whale calls (Kato *et al.,* 1996), however, such calls were not found from the incomplete acoustic dataset analysed here.

Ljungblad *et al.* (1998) and Rankin *et al.* (2005) analysed a subset of the IWC SOWER acoustic data from 1996/1997, 2001/2002 and 2002/2003 respectively. This study is the first of its kind to review and analyse a more complete IWC SOWER acoustic dataset for Antarctic blue whale vocalisations. However, the difference between the available and reported acoustic datasets from the cruise reports is of concern and a fuller reconciliation of the IWC SOWER cruises acoustic dataset is recommended if possible. This IWC SOWER acoustic dataset is a valuable acoustic time series of Antarctic blue whale vocalisations. It is further recommended that the archiving and management of these data be centralised to ensure that these circum-Antarctic data are readily available to future studies. The Acoustic Trends Working Group (ATWG) of the Southern Ocean Research Partnership (SORP) is adopting a similar approach for its ongoing acoustic data collection (see van Opzeeland *et al.,* 2014).

Although the reconciliation of the full circumpolar IWC SOWER acoustic dataset could not be completed, the compilation of this dataset has allowed for the merging of both acoustic data from the recordings and associated metadata (including both spatial and temporal data) from the station and acoustic record forms. Further analyses of these data (and particularly call rates) by location (position, depth and distance from the ice edge), and timing (both across the summer season and by time of day) and in association with observed groups of blue whales and broader blue whale densities obtained from line-transect visual observations will provide important information on Antarctic blue whale calling behaviour, migrations and distribution. For instance, Shabangu *et al.* (2017) used the IWC SOWER blue whale recordings to examine the occurrence of Antarctic blue whale call types in the context of oceanographic variability in the region and over the 14-yr span of data collection. They found that the number of D-calls recorded was positively related to the number of animals seen during visual observations but the call rate of Z-calls was not. Call rates for both types were dictated by region and the location of the southern boundary of the Antarctic Circumpolar Current (ACC). Such knowledge about blue whale acoustic behaviour is important to the analysis and understanding of autonomous acoustic recordings and other long-term acoustic recordings from the Southern Ocean region.

IWC SOWER data mining potential

Compiling most of the IWC SOWER acoustic dataset and analysing it for the presence and different types of blue whale calls recorded over more than a decade of survey effort was a first step towards expanding the utility of these data. With a more coherent understanding of the available data, in-depth studies can be undertaken that will improve an understanding of the role sound production plays in blue whale ecology. Numerous further studies using these IWC SOWER recordings would be valuable and deserve serious consideration. Although the acoustic equipment was not calibrated, these recordings could provide important baseline data regarding ambient noise, and vocal repertoire and seasonal calling behaviours of species other than blue whales. The combination of photo-identification, biopsy, and behavioural data with the acoustic data can provide valuable insights that are otherwise difficult and expensive to obtain.

Currently, there are no data on what proportion of blue whales produce downsweeps, nor what proportion of males sing. Analysis of IWC SOWER acoustic data in conjunction with sighting survey and behavioural data (for which there were at least 120 instances over the years, [Table 1]) may be used to develop distribution curves for acoustically active blue whales. That is, when blue whales that appeared to be feeding were sighted, what types of sounds were recorded, which of those could be attributed to the observed animal, and what was the behavioural context under which those sounds were produced? What was the whale doing when no sounds were recorded? Was acoustic behaviour different when females with calves were present? Resultant understandings of Antarctic blue whale variability in acoustic behaviour and the associated behavioural context will lead to better understandings of acoustic function. Vocal rates under different contexts will inform efforts to determine absolute or relative population sizes from remote passive acoustic monitoring as has been suggested by the IWC-sponsored SORP blue and fin whale acoustics working group (Samaran *et al.,* 2012).

In cases when two DiFAR sonobuoys were deployed at the same time, processing of the same blue whale sound on each buoy can be used to localise calling whales. Although these opportunities were not taken advantage of during IWC SOWER cruises, this type of post-cruise analysis is readily feasible (Rankin *et al.,* 2005). For whales from which a biopsy was obtained, acoustic localisation can be used to compare vocal behaviours between females and males (for possible data see Rankin *et al.,* 2005). This information is critical for the application of passive acoustic monitoring for population estimation. Based on data from the eastern North Pacific population of blue whales, there is evidence that only male blue whales sing (McDonald *et al.,* 2006; Oleson *et al.,* 2007), while both males and females appear to produce D-calls (Oleson *et al.,* 2007). If this is the case, then the use of 28-Hz song notes to determine acoustic occurrence only accounts for males in a population. Assuming the present-day sex ratio for blue whales is similar to that during commercial whaling (47:53 female: male, Branch *et al.,* 2004), then correction factors could be made to account for non-singing females.

One of the requirements of estimating abundance from passive acoustic monitoring is knowledge of the range at which sounds of interest can be detected. The source level of a signal (i.e. how loud it is) is needed to estimate detection range and therefore detection probability. Presently there are few source level estimates for Antarctic blue whales (Širović *et al.,* 2007; Samaran *et al.,* 2010b). For Antarctic blue whales there are estimates of detection range based on known sighting locations and calls attributed to those sightings based on DiFAR processing. Although our hydrophones were uncalibrated, these data can be used to calculate relatively robust measures of received level by which to estimate source levels, which, when combined with estimating distances of whales from a hydrophone can be used to estimate source levels. Data from the IWC SOWER cruises might be used to obtain statistical data, including detection ranges, from Antarctic blue whale source levels, particularly where the animals are a known distance from a sonobuoy. Thus, factors such as call detection range, probability of call detection, cue rate per individual, and group sizes may be evaluated. These parameters are crucial to the successful estimation of animal densities and relative abundance of vocalising whales in an area (see Marques *et al.,* 2013). What complicates this analysis is that the frequency response of the recording systems and the gain settings used over the years were not generally reported and the age of the sonobuoys may have influenced the received levels of signals. Our observed good agreement between sightings and acoustic detections are encouraging for whale abundance estimation using passive acoustic monitoring as it indicates that passive acoustic monitoring can successfully capture the number of animals in an area.

There is recent evidence that the fundamental frequency of the Antarctic blue whale 28-Hz song note is changing both within a season and over years on a wintering ground (Gavrilov *et al.,* 2012; Ward *et al.,* 2017). The IWC SOWER acoustic database has data from over the span of a decade that could be used to determine if this decrease exists on the feeding grounds. The data could also be used to examine variability in individual tonal frequencies and if/how these change within a season and across regions and years. In addition, analysis of some very low frequency sounds (9–11Hz) in relation to behaviour could be examined to identify any vocal response to direct vessel approach (see Ljungblad *et al.,* 2001).

Other species

There are ways by which these data might be useful. For example, since the initiation of the IWC SOWER programme, four distinct morpho-types of killer whale (A, B, C and D) have been identified from Antarctic waters (Pitman and Ensor, 2003; Pitman *et al.,* 2010). Each form is readily distinguishable in the field, and each is thought to occupy different ecological niches based on prey and habitat preferences (Pitman and Ensor, 2003). The IWC SOWER dataset contains at least 18 instances of recordings of killer whale vocalisations. A database of call types from each of these forms (based on photo-identification) could contribute to acoustic identification as has been done for killer whales in other parts of the world (Ford, 1989; Deecke *et al.,* 2011; Riesch and Deecke, 2011).

For at least one Southern Hemisphere sperm whale population there is no evidence for recovery following the cessation of whaling (Carroll *et al.,* 2014). It may be feasible to investigate the IWC SOWER recordings to see if there has been a change in relative occurrence of sperm whale sounds on a circumpolar basis, or conversely if there has been low recruitment and therefore a change in age structure which might be investigated by looking at inter-click interval to determine animal size (e.g. Adler-Fenchel, 1980; Miller *et al.,* 2013b). Finally, seal vocalisations recorded around the Antarctic could be used to determine whether individuals might be identified or if pan-Antarctic geographic variation exists (i.e. Rogers and Cato, 2002; Van Parijs and Clark, 2006; Terhune *et al.,* 2008).

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REFERENCES

Adler-Fenchel, H.S., 1980. Acoustically derived estimate of the size distribution for a sample of sperm whales (*Physeter catodon*) in the Western North Atlantic. *Can. J. Fish. Aquat. Sci.* 37:2,358–61.

Aglen, A. 1989. Empirical results on precision-effort relationships for acoustic surveys. International Council for the Exploration of the Sea C.M.1989/B:30.

Alling, A., Dorsey, E.M. and Gordon, J.C.D. 1991. Blue whales (*Balaenoptera musculus*) off the northeast coast of Sri Lanka: Distribution, feeding, and individual identification. pp. 247–58. *In*: S. Leatherwood and G.P. Donovan (eds.) *Cetaceans and Cetacean Research in the Indian Ocean Sanctuary.* Nairobi, Kenya: UNEP Mar. Mamm. Tech. Rep. No. 3

Bioacoustics Research Program. 2013. Raven Pro: Interactive sound analysis software (Version 1.5) [Computer Software]. Ithaca, NY: The Cornell Lab of Ornithology. [Available at: *http://www.birds.cornell.edu/raven*].

Blyth, E. 1859. On the great rorqual of the Indian Ocean, with notices of other cetals, and of the Syrenia or marine pachyderms. *J. Asiat. Soc. Bengal* 28:481–98.

Branch, T.A., Matsuoka, K. and Miyashita, T. 2004. Evidence for increases in Antarctic blue whales based on Bayesian modelling. *Mar. Mamm. Sci.* 20:726–54.

Branch, T.A., Stafford, K.M., Palacios, D.M., Allison, C., Bannister, J.L., Burton, C.L.K., Cabrera, E., Carlson, C.A., Vernazzani, B.G., Gill, P.C., Hucke-Gaete, R., Jenner, K.C.S., Jenner, M.N.M., Matsuoka, K., Mikhalev, Y.A., Miyashita, T., Morrice, M.G., Nishiwaki, S., Sturrock, V.J., Tormosov, D., Anderson, R.C., Baker, A.N., Best, P.B., Borsa, P., Brownell, R.L., Childerhouse, S., Findlay, K.P., Gerrodette, T., Ilangakoon, A.D., Joergensen, M., Kahn, B., Ljungblad, D.K., Maughan, B., McCauley, R.D., McKay, S., Norris, T.F., Whale, O., Rankin, S., Samaran, F., Thiele, D., Van Waerebeek, K. and Warneke, R.M. 2007. Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. *Mammal Rev.* 37(2):116–75.

Buchan, S.J., Rendell, L. and Hucke-Gaete, R. 2010. Preliminary recordings of blue whale (*Balaenoptera musculus*) vocalizations in the Gulf of Corcovado, northern Patagonia, Chile. *Mar. Mamm. Sci.* 26(2):451–9.

Buchan, S.J., Hucke-Gaete, R., Rendell, L. and Stafford, K. 2014. A new song recorded from blue whales in the Corcovado Gulf, Southern Chile, and an acoustic link to the Eastern Tropical Pacific. *Endanger. Species Res.* 23:241–52.

Burmeister, H. 1871. 1871. *Boletin del Museo Publico de Buenos Aires* 1871:11–20. [In Spanish].

Carroll, G., Hedley, S., Bannister, J., Ensor, P. and Harcourt, R. 2014. No evidence for recovery in the population of sperm whale bulls off Western Australia, 30 years post-whaling. *Endanger. Species Res.* 24:33–43.

Clark, C.W. and Fowler, M. 2001. Status of archival and analysis effort of acoustic recordings during SOWER and IWC cruises 1996–2000. Paper SC/53/IA28 presented to the IWC Scientific Committee, July 2001, London (unpublished). 9pp. [Paper available from the Office of this Journal].

Clark, C.W. and Gagnon, G.C. 2002. Low-frequency vocal behaviors of baleen whales in the North Atlantic: Insights from IUSS detections, locations and tracking from 1992 to 1996. *Journal of Underwater Acoustics* (USN) 52(3):609–40.

Cummings, W.C. and Thompson, P.O. 1971. Underwater sounds from the blue whale, *Balaenoptera musculus*. *J. Acoust. Soc. Am.* 50(4):1,193–8.

Deecke, V.B., Nykaenen, M., Foote, A.D. and Janik, V.M. 2011. Vocal behaviour and feeding ecology of killer whales *Orcinus orca* around Shetland, UK. *Aquat. Biol.* 13(1):79–186.

Donovan, G.P. 1991. A review of IWC stock boundaries. *Rep. Int. Whal. Commn* (special issue 13):39–68.

Donovan, G.P. 2004. Blue whales off Peru, December 1982, with special reference to pygmy blue whales. *Rep. Int. Whal. Commn* 34:473–76.

Donovan, G.P., Hammond, P.S., Larsen, F., Reilly, S.B., Kato, H., Clark. C.W. and Brownell, R.L. 1996. Report of the Scientific Committee, Annex E. Report of the sub-committee on Southern Hemisphere baleen whales. Appendix 2. An approach for responding to the Commission's resolution. *Rep. Int. Whal. Commn* 46:126–7.

Double, M.C., Barlow, J., Miller, B.S., Olson, P., Andrews-Goff, V., Leaper, R., Ensor, P., Kelly, N., Lindsay, M., Peel, D., Calderan, S., Collins, K., Davidson, M., Deacon, C., Donnelly, D., Olavarria, C., Owen, K., Rekdahl, M., Schmitt, N., Wadley, V. and Gales, N. 2013. Cruise report of the 2013 Antarctic blue whale voyage of the Southern Ocean Research Partnership. Paper SC/65a/SH21 presented to the IWC Scientific

Committee, May 2013 (unpublished). 16pp. [Paper available from the Office of this Journal].

Edds, P.L. 1982. Vocalisations of the blue whale, *Balaenoptera musculus*, in the St. Lawrence River. *J. Mammal.* 63:345–7.

Ensor, P., Findlay, K., Hara, T., Hedley, S., Pitman, R., Sekiguchi, K., Tsurui, T. and Yamagiwa, D. 1997. 1996–97 IWC – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) Antarctic cruise, Area II. Paper SC/49/SH7 presented to the IWC Scientific Committee, September 1997 (unpublished). 47pp. [Paper available from the Office of this Journal].

Ensor, P., Pastene, L.A., Cawthorn, M., Findlay, K., Hedley, S., Iwakami, H., Kleivane, L., Pitman, R., Tsurui, T. and Sakai, K. 1998. 1997–98 IWC Southern Ocean Whale and Ecosystem Research (IWC – SOWER) Antarctic cruise, Area II. Paper SC/50/Rep1 presented to the IWC Scientific Committee, April 1998 (unpublished). 45pp. [Paper available from the Office of this Journal].

Ensor, P., Sekiguchi, K., Doherty, J., Kleivane, L., Ljungblad, D., Marques, F., Matsuoka, K., Narita, H., Pitman, R. and Sakai, K. 1999. 1998–99 IWC – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) Antarctic cruise, Areas III and IV. Paper SC/51/CAWS6 presented to the IWC Scientific Committee, May 1999 (unpublished). 61pp. [Paper available from the Office of this Journal].

Ensor, P., Findlay, K.P., Hucke-Gaete, R., Kleivane, L., Komiya, H., Ljungblad, D., Marques, F., Muira, T., Sekiguchi, K. and Shimade, H. 2000. 1999–2000 IWC – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) Antarctic cruise, Areas I and II. Paper SC/52/IA1 presented to the IWC Scientific Committee, June 2000 (unpublished). 51pp. [Paper available from the Office of this Journal].

Ensor, P., Matsuoka, K., Marques, F., Miura, T., Murase, H., Pitman, R., Sakai, K. and Van Waerebeek, K. 2001. 2000–2001 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) circumpolar cruise, Area V, VI and I. Paper SC/53/IA5 presented to the IWC Scientific Committee, July 2001 (unpublished). 56pp. [Paper available from the Office of this Journal].

Ensor, P., Sekiguchi, K., Cotton, J., Hucke-Gaete, R., Kariya, T., Komiya, H., Ljungblad, D., Narita, H., Olson, P. and Rankin, S. 2002. 2001–2002 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) circumpolar cruise, Area V. Paper SC/54/IA2 presented to the IWC Scientific Committee, April 2002 (unpublished). 51pp. [Paper available from the Office of this Journal].

Ensor, P., Matsuoka, K., Hirose, K., Ljungblad, D., Minami, K., Olson, P., Rankin, S., Stevick, P., Tsunekawa, M. and Ugarte, F. 2003. 2002–2003 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) circumpolar cruise, Area V. Paper SC/55/IA1 presented to the IWC Scientific Committee, May 2003 (unpublished). 65pp. [Paper available from the Office of this Journal].

Ensor, P., Matsuoka, K., Komiya, H., Ljungblad, D., Miura, T., Morse, L., Olson, P., Olavarria, C., Mori, M. and Sekiguchi, K. 2004. 2003–2004 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) circumpolar cruise, Area V. Paper SC/56/IA13 presented to the IWC Scientific Committee, July 2004 (unpublished). 68pp. [Paper available from the Office of this Journal].

Ensor, P., Findlay, K., Friedrichsen, G., Hirose, K., Komiya, H., Morse, L., Olson, P., Sekiguchi, K., Van Waerebeek, K. and Yoshimura, I. 2005. 2004–2005 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) cruise, Area III. Paper SC/57/IA1 presented to the IWC Scientific Committee, June 2005 (unpublished). 90pp. [Paper available from the Office of this Journal].

Ensor, P., Komiya, H., Olson, P., Sekiguchi, K. and Stafford, K. 2006. 2005–2006 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) cruise. Paper SC/58/IA1 presented to the IWC Scientific Committee, June 2006 (unpublished). 58pp. [Paper available from the Office of this Journal].

Ensor, P., Komiya, H., Beasley, I., Fukutome, K., Olson, P. and Tsuda, Y. 2007. 2006–2007 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) cruise. Paper SC/59/IA1 presented to the IWC Scientific Committee, June 2007 (unpublished). 58pp. [Paper available from the Office of this Journal].

Ensor, P., Minami, K., Morse, L., Olson, P. and Sekiguchi K. 2008. 2007–2008 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) cruise. Paper SC/60/IA1 presented to the IWC Scientific Committee, June 2008 (unpublished). 51pp. [Paper available from the Office of this Journal].

Ensor, P., Komiya, H., Kumagai, S., Kuningas, S., Olson, P. and Tsuda, Y. 2009. 2008–2009 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) cruise. Paper SC/61/IA19 presented to the IWC Scientific Committee, June 2009 (unpublished). 54pp. [Paper available from the Office of this Journal].

Figueroa, H.K. 2006. XBAT: Extensible BioAcoustic Tool. [Available at: *http://xbat.org*].

Findlay, K., Pitman, R., Tsurui, T., Sakai, K., Ensor, P., Iwakami, H., Ljungblad, D., Shimada, H., Thiele, D., Van Waerebeek, K., Hucke-Gaete, R. and Sanino-Vattier, G.P. 1998. 1997/1998 IWC – Southern Ocean Whale and Ecosystem Research (IWC – SOWER) blue whale cruise, Chile. Paper SC/50/Rep2 presented to the IWC Scientific Committee, April 1998 (unpublished). 40pp. [Paper available from the Office of this Journal].

Findlay, K., Thornton, M., Stafford, K. and Best, P.B. 2012. The South African Blue Whale Project (SABWP) – An introduction and objectives for the forthcoming year. Paper SC/64/O16 presented to the IWC Scientific Committee, June 2012 (unpublished). 7pp. [Paper available from the Office of this Journal].

Gavrilov, A.N., McCauley, R.D. and Gedamke, J. 2012. Steady inter and intra-annual decrease in the vocalization frequency of Antarctic blue whales. *J. Acoust. Soc. Am.* 131(6):4,476–80.

Gedamke, J. and Robinson, S.M. 2010. Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30–80°E) in January–February 2006. *Deep Sea Res.* II 57:968–81.

Ichihara, T. 1966. The pygmy blue whale, *Balaenoptera musculus brevicauda*, a new subspecies from the Antarctic. *In*: Norris, K.S. (ed.) *Whales, Dolphins, and Porpoises*. pp. 79–111. University of California Press, Berkeley, Los Angeles, CA. i–xv+789pp.

Kato, H., Bannister, J., Burton, C., Ljungblad, D., Matsuoka, K. and Shimada, H. 1996. Report on the Japan/IWC blue whale cruise 1995–96 off the southern coast of Australia. Paper SC/48/SH9 presented to the IWC Scientific Committee, June 1996 (unpublished). 35pp. [Paper available from the Office of this Journal].

Kelly, N., Miller, B., Peel, D., Double, M.C., De la Mare, W. and Gales, N. 2012. Strategies to obtain a new circumpolar abundance estimate for Antarctic blue whales: survey design and sampling protocols. Paper SC/64/SH10 presented to the Scientific Committee of the International Whaling Commission, June 2012 (unpublished). 34pp. [Paper available from the Office of this Journal].

Ljungblad, D.K. and Stafford, K.M. 2005. Circumpolar cruise, Area V. Abstracts of the 16th Biennial Conference on the Biology of Marine Mammals, 12–16 December 2005, San Diego CA. p.171. [Abstract].

Ljungblad, D. K., Stafford, K. M., Shimada, H. and Matsuoka, K. 1997. Sounds attributed to blue whales recorded off the southwest coast of Australia in December 1995. *Rep. Int. Whal. Commn* 47:435–9.

Ljungblad, D.K., Clark, C.W. and Shimada, H. 1998. A comparison of sounds attributed to pygmy blue whales (*Balaenoptera musculus brevicauda*) recorded south off the Madagascar Plateau and those attributed to 'true' blue whales (*Balaenoptera musculus*) recorded of Antarctica. *Rep. Int. Whal. Commn* 48:439–42.

Mackintosh, N.A. and Wheeler, J.F.G. 1929. Southern blue and fin whales. *Discov. Rep. I*:259–540.

Marques, T.A., Thomas, L., Martin, S., Mellinger, D., Ward, J., Moretti, D., Harris, D. and Tyack, P. 2013. Estimating animal population density using passive acoustics. *Biol. Rev.* 8:287–309.

Mathworks Inc, 2014. MATLAB R2014a version 8.3.0.532. The MathWorks, Inc., Natick, Massachusetts, United States.

McDonald, M.A. 2004. DIFAR hydrophones applied to whale research. *Can. Acoust.* 32(2):155–60.

McDonald, M., Calambokidis, J., Teranishi, A. and Hildebrand, J. 2001. The acoustic calls of blue whales off California with gender data. *J. Acoust. Soc. Am.* 109:1728–35.

McDonald, M.A., Hildebrand, J.A. and Mesnick, S.L. 2006. Biogeographic characterization of blue whale song worldwide: using song to identify populations. *J. Cetacean Res. Manage.* 8:55–65.

McDonald, M.A., Hildebrand, J.A. and Mesnick, S.L. 2009. Worldwide decline in tonal frequencies of blue whale songs. *Endanger. Species Res.* 9:13–21.

Mellinger, D.K., 2001. Ishmael 1.0 User's Guide. NOAA Technical Memorandum OAR PMEL-120, available from NOAA/PMEL/OERD, 2115 SE OSU Drive, Newport, OR 97365-5258.

Mellinger, D.K. and Clark, C.W. 2003. Blue whale (*Balaenoptera musculus*) sounds from the North Atlantic. *J. Acoust. Soc. Am.* 114:1,108–19.

Miller, B.S., Barlow, J., Calderan, S., Collins, K., Leaper, R., Kelly, N., Peel, D., Olson, P., Ensor, P. and Double, M.C. 2013a. Long-range acoustic tracking of Antarctic blue whales. Paper SC/65a/SH18 presented to the IWC Scientific Committee, May 2013 (unpublished). 17pp. [Paper available from the Office of this Journal].

Miller, B.S., Growcott, A., Slooten, E. and Dawson, S.M. 2013b. Acoustically derived growth rates of sperm whales (*Physeter macrocephalus*) in Kaikoura, New Zealand. *J. Acoust. Soc. Am.* 134:2438–45.

Miller, B.S., Collins, K., Barlow, J., Calderan, S., Leaper, R., McDonald, M., Ensor, P., Olson, P.A., Olavarria, C. and Double, M.C. 2014. Blue whale vocalizations recorded around New Zealand: 1964–2013. *J. Acoust. Soc. Am.* 135:1,616–23.

Miller, B.S., Barlow, J., Calderan, S., Collins, K., Leaper, R., Olson, P., Ensor, P., Peel, D., Donnelly, D., Andrews-Goff, V., Olavarria, C., Owen, K., Rekdahl, M., Schmitt, N., Wadley, V., Gedamke, J., Gales, N. and Double, M.C. 2015. Validating the reliability of passive acoustic localisation: a novel method for encountering rare and remote Antarctic blue whales. *Endanger. Species Res.* 26:257–69.

Oleson, E.M., Calambokidis, J., Barlow, J. and Hildebrand, J.A. 2007. Blue whale visual and acoustic encounter rates in the Southern California Bight. *Mar. Mamm. Sci.* 23(3):574–97.

Payne, R.S. and Guinee, L.N. 1983. Humpback whale (*Megaptera novaeangliae*) songs as an indicator of 'stocks'. pp333–358. *In*: Payne, R. (ed.) *Communication and Behavior of Whales*. Westview Press, Boulder CO. 643pp.

Pitman, R.L. and Ensor, P. 2003. Three forms of killer whales (*Orcinus orca*) in Antarctic waters. *J. Cetacean Res. Manage.* 5:131–9.

Pitman, R.L., Durban, J.W., Greenfelder, M., Guinet, C., Jorgensen, M., Olson, P.A., Plana, J., Tixier, P. and J.R. Towers. 2010. Observations of a distinctive morphotype of killer whale (*Orcinus orca*), type D, from sub-Antarctic waters. *Polar Biol.* 34:303–6.

R Development Core Team, 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [Available at: *http://www.R-project.org/*].

Rankin, S., Ljungblad, D., Clark, C. and Kato, H., 2005. Vocalizations of Antarctic blue whales, *Balaenoptera musculus intermedia*, recorded during the 2001/2002 and 2002/2003 IWC/SOWER circumpolar cruises, Area V, Antarctica. *J. Cetacean Res. Manage.* 7:13–20.

Reeves R.R., Clapham, P.J., Brownell, R.L., Jr. and Silber, G.K. 1998. Recovery plan for the blue whale (*Balaenoptera musculus*). National Marine Fisheries Service, Silver Spring, MD. 42pp.

Rice, D.W. 1998. *Marine Mammals of the World: Systematics and Distribution*. Society for Marine Mammalogy Special Publication No. 4. Lawrence, KS: Allen Press.

Riesch, R. and Deecke, V.B. 2011. Whistle communication in mammal-eating killer whales (*Orcinus orca*): further evidence for acoustic divergence between ecotypes. *Behav. Ecol. Sociobiol.* 65(7):1,377–87.

Rogers, T.L. and Cato, D.H. 2002. Individual variation in the acoustic behaviour of the adult male leopard seal, *Hydrurga leptonyx*. *Behaviour* 139(10):1,267–86.

RStudio Team. 2015. RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. [Available at: *http://www.rstudio.com/*].

Samaran, F., Adam, O. and Guinet, C. 2010a. Discovery of a mid-latitude sympatric area for two Southern Hemisphere blue whale subspecies. *Endanger. Species Res.* 12(2):157–65.

Samaran, F., Guinet, C., Adam, O., Motsch, J.-F. and Cansi, Y. 2010b. Source level estimation of two blue whale subspecies in southwestern Indian Ocean. *J. Acoust. Soc. America* 127(6):3,800–08.

Samaran, F., Stafford, K., Gedamke, J., Van Opzeeland, I., Miller, B.S., Adam, O., Baumgartner, M., Mussoline, S., and Pressiat, G. 2012. Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean. pp.13–37. Annex 1.5. *In:* Annual Report of the Southern Ocean Research Partnership (SORP) 2011/12. (Compiled by: E. Bell.) Paper SC/64/O13 presented to the IWC Scientific Committee, Panama City, Panama. 38pp. [Paper available from the Office of this Journal].

Samaran, F., Stafford, K.M., Branch, T.A., Gedamke, J., Royer, J-Y., Dziak, R.P. and Guinet, C. 2013. Seasonal and geographic variation of southern blue whale subspecies in the Indian Ocean. *PLos ONE* 8(8):e71561.

Sekiguchi, K., Fukotome, K., Morse, L., Shinyashiki, Y. and Oedekoven, C. 2010. 2009–2010 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC SOWER) cruise. Paper SC/62/IA1 presented to the IWC Scientific Committee, June 2010 (unpublished). 56pp. [Paper available from the Office of this Journal].

Shabangu, F.W. and Findlay, K. 2014. Passive acoustic monitoring of marine mammals in South Africa, with special reference to Antarctic blue whales. pp.153–73. *In:* Funke, N., Claassen, M., Meissner, R. and Nortje, K. (eds) *Reflections on the State of Research and Development in the Marine and Maritime Sectors in South Africa*. Council for Scientific and Industrial Research, Pretoria. i–ii+316pp.

Shabangu, F.W., Findlay, K.P., Yemane, D., Stafford, K.M., van den Berg, M., Blows, B. and Andrew, R.K. 2019. Seasonal occurrence and diel calling behaviour of Antarctic blue whales and fin whales in relation to environmental conditions off the west coast of South Africa. *J. Mar. Syst.* 190:25–39.

Shabangu, F.W., Yemane, D., Stafford, K.M., Ensor, P. and Findlay, K.P. 2017. Modelling the effects of environmental conditions of the acoustic occurrence and behavior of Antarctic blue whales. *PLoS ONE* 12(2):e0172705.

Širovic, A., Hildebrand, J.A., Wiggins, S.M., McDonald, M.A., Moore, S.E. and Thiele, D. 2004. Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. *Deep-Sea Res. II* 51:2,327–44.

Širovic, A., Hildebrand, J.A. and Wiggins, S.M. 2007. Blue and fin whale call source levels and propagation range in the Southern Ocean. *J. Acoust. Soc. Am.* 122:1,208–15.

Stafford, K. M., Chapp, E., Bohnenstiel, D. R. and Tolstoy, M. 2011. Seasonal detection of three types of 'pygmy' blue whale calls in the Indian Ocean. *Mar. Mamm. Sci.* 27:828–40.

Stafford, K.M., Nieukirk, S.L. and Fox, C.G. 1999. Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. *J. Acoust. Soc. Am.*106:3,687–98.

Stafford, K.M., Nieukirk, S.L. and Fox, C. G. 2001. Geographic and seasonal variation of blue whale calls in the North Pacific. *J. Cetacean Res. Manage.* 3:65–76.

Stafford, K.M., Bohnenstiehl, D.W.R., Tolstoy, M., Chapp, E., Mellinger, D.K. and Moore, S.E. 2004. Antarctic-type blue whale calls recorded at low latitudes in the Indian and eastern Pacific Oceans. *Deep-Sea Res. I* 51:1,337–46.

Terhune, J.M., Quin, D., Dell'Apa, A., Mirhaj, M., Plötz, J., Kindermann, L., and Bornemann, H. 2008. Geographic variations in underwater male Weddell seal trills suggest breeding area fidelity. *Polar Biol.* 31(6):671–80.

Thomas, P.O., Reeves, R.R. and Brownell, R.L., Jr. 2015. Status of the world's baleen whales. *Mar. Mamm. Sci.* 32(2):682–734.

Thompson, P.O., Findley, L.T., Vidal, O. and Cummings, W.C. 1996. Underwater sounds of blue whales, *Balaenoptera musculus*, in the Gulf of California, Mexico. *Mar. Mamm. Sci.* 12(2):288–92.

Thompson, P. O. and Friedl, W.A. 1982. A long term study of low frequency sounds from several species of whales off Oahu, Hawaii. *Cetology* 45:1–19.

Van Opzeeland, I., Samaran, F., Stafford, K.M., Findlay, K., Gedamke, J. Harris, D. and Miller, B.S. 2014. Towards collective circum-Antarctic passive acoustic monitoring: The Southern Ocean Hydrophone Network (SOHN). *Polarforschung* 83(2): 47–61.

Van Parijs, S. and Clark, C.W. 2006. Long term mating tactics in an aquatic mating pinniped – the bearded seal, *Erignathus barbatus*. *Anim. Behav.* 72:1,269–77.

Ward, R., Gavrilov, A.N. and McCauley, R.D. 2017. 'Spot' call: A common sound from an unidentified great whale in Australian temperate waters. *J. Acoust. Soc. Am.* 142(2):EL231–EL236.

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