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Occasional acoustic presence of Antarctic blue whales on a feeding ground in southern Chile

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At least two subspecies of blue whale are present in the Southern Hemisphere: Antarctic blue whales (*Balaenoptera musculus intermedia*) and pygmy blue whales (*B. m. brevicauda*) (Branch *et al*. 2007, 2009). On a mid-latitude feeding ground in the Chiloense Ecoregion (CER) in northern Chilean Patagonia (Hucke-Gaete *et al*. 2003), a genetic study found both of these blue whale subspecies to be part of separate breeding populations (Torres-Florez *et al.* 2014), although Chilean blue whales may be an altogether separate subspecies from *B. m. intermedia* and *B. m. brevicauda* (Clarke *et al*. 1978, Branch *et al*. 2007). During the commercial whaling era, both described subspecies were caught by whaling fleets off the coast of Chile (Aguayo 1974). Antarctic blue whales were also intensively caught in the Southern Ocean, depleting their population to <1% (Branch *et al.* 2007). Today, following intense exploitation through the 1960s, the Antarctic blue whale remains Critically Endangered (Reilly *et al.* 2016). Antarctic blue whales were thought to follow a south-north migration from high latitude feeding grounds south of 60°S to low- and mid-latitude wintering grounds (Mackintosh and Wheeler 1929), although the location of breeding grounds remains unknown. Some more recent evidence points to winter residence in low- and mid-latitude regions (Stafford *et al*. 1999*b*, Branch *et al*. 2007, Samaran *et al*. 2013), while other evidence supports year-round presence in the Southern Ocean (Branch *et al*. 2007, Thomisch *et al*. 2016), suggesting that Antarctic blue whale seasonal movements are more complex than the traditionally held view.

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Worldwide, one or more distinct blue whale song types have been recorded in different regions of the ocean, indicating largely distinct spatial and temporal distributions of acoustic groups, although some degree of overlap occurs temporally and spatially (*e.g.*, McDonald *et al.* 2006 and references therein; Stafford *et al.* 2011; Samaran *et al.* 2013; Buchan *et al.* 2014, 2015; Balcazar *et al.* 2017). Song is known to be produced only by male blue whales and therefore assumed to serve some reproductive function (Oleson *et al.* 2007*a*). Blue whales produce these songs throughout their migratory range (Stafford *et al.* 1999*a*, 2001), with some intra-annual variation in song production (Oleson *et al.* 2007*b*), as well as a decrease over decadal timescales in the frequency of tonal song components (McDonald *et al.* 2009, Gavrilov *et al.* 2012). In the Southern Hemisphere, there appear to be at least five distinct song types that have been attributed to males from different acoustic populations: Antarctic (Ljungblad *et al.* 1998, Širović *et al.* 2004), southeast Pacific (Cummings and Thompson 1971, Stafford *et al.* 1999*b*, Buchan *et al.* 2014), Sri Lankan (Alling *et al.* 1991), Madagascar (Ljungblad *et al.* 1998), and Australian (McCauley *et al.* 2001). The Antarctic song type (hereafter, AA) is composed from repetitions of three relatively simple units referred to as a Z-note (Ljungblad *et al.* 1998, Širović *et al.* 2004) (see Fig. 1). AA Z-note songs have been recorded primarily in the Southern Ocean (*e.g.*, Ljungblad *et al.* 1998, Rankin *et al.* 2005, Širović *et al.* 2007) throughout the year, with a peak during the austral summer (February–May) (Širović *et al.* 2004, 2009, Thomisch *et al.* 2016); year-round in the southern Indian Ocean, and during winter only in the northern Indian Ocean (Samaran *et al.* 2013); occasionally in the eastern tropical Pacific Ocean south of the equator with a peak in the austral winter (July) (Stafford *et al.* 1999*b*); occasionally between July and December in the western South Pacific (Balcazar *et al.* 2017); in the south Atlantic Ocean based on recording effort between December and February (Shabangu *et al.* 2017); off western Australia between March and November (Gavrilov *et al.* 2012); and in southern Australian waters June–October (Tripovich *et al.* 2015, Balcazar *et al.* 2017). The Southeast Pacific song type (hereafter, SEP) is composed of repetitions of phrases consisting of multiple, long duration, harmonically rich units (Cummings and Thompson 1971; Stafford *et al.* 1999*b*; Buchan *et al.* 2014, 2015). Two SEP song types (SEP1 and

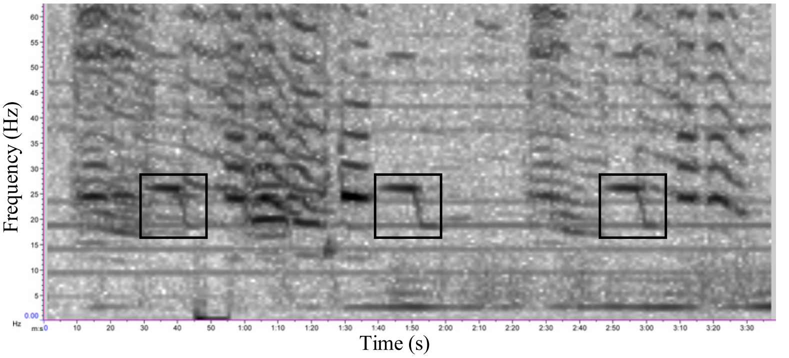

Figure 1. Spectrogram of AA blue whale Z-notes (highlighted by solid boxes). Spectrogram parameters: FFT: 4096 pt, 50% overlap, Hann window. Black boxes indicate the parts of the song selected as a template for automatic detection in Ishmael. Note: Both southeast Pacific blue whale song types (SEP1 and SEP2) can be seen in the spectrogram.

SEP2) occur seasonally in the CER (Buchan *et al.* 2015). In this communication, we report a new analysis of those same data to examine the occurrence of AA songs in the CER.

Acoustic data from the CER in northern Chilean Patagonia (43°54′S, 73°44′W) were collected continuously at a 2 kHz sample rate using Marine Autonomous Recording Units (MARUs) leased from the Cornell University Laboratory of Ornithology's Bioacoustics Research Program (Calupca *et al.* 2000). Data were collected during 5 mo deployments at different study sites between the end of January 2012 and the end of April 2013. Deployments covered two austral summers and one winter period, but were not obtained continuously for more than 10 mo at any of the study sites. MARUs were deployed at four sites (Fig. 2), chosen to provide wide geographic coverage of the CER feeding ground, *i.e.*, north oceanic (Northwest Chiloe), south oceanic (Guafo North), north inner sea (Tic Toc Bay), and south inner sea (Locos Islet). Specific MARU temporal and spatial deployment details are listed in Table 1.

Acoustic data (21,728 h) were analyzed for the occurrence of AA song Z-notes (Fig. 1). First, based on prior knowledge of Antarctic blue whale distribution (*e.g.*, Branch *et al.* 2007), it was *a priori* assumed that the overall number of Z-note

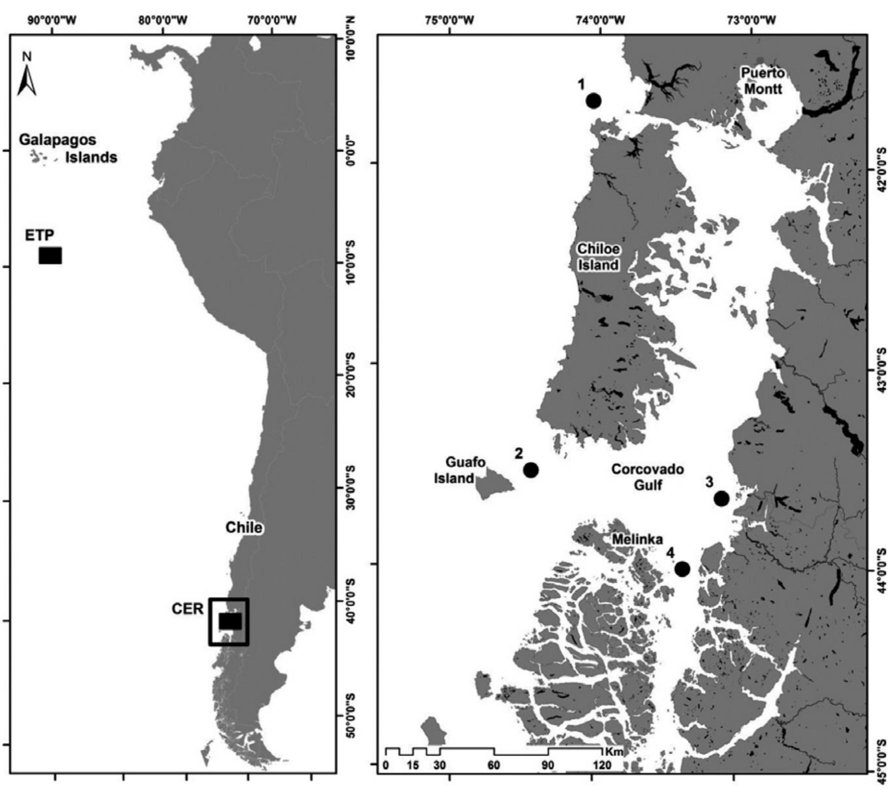

Figure 2. Map of CER study area with the four hydrophone deployment sites: (1) Northwest Chiloe, (2) Guafo North, (3) Tic Toc Bay and (4) Locos Islet, (taken from Buchan *et al.* 2015).

Table 1. Hydrophone deployment details in the CER blue whale feeding ground: location, latitude, longitude, deployment depth (m), start and end dates of recording, and total number of hours of acoustic data (modified from Buchan *et al*. 2015).

Deployment site	Latitude (S) Longitude (W)	Deployment depth (m)	Start date	End date	Total hours
Northwest Chiloe	41°41.179′ 74°02.442′	140	23 Jan 2012	25 Jun 2012	3,688
Guafo North	43°31.889′ 74°26.488′	200	31 Jan 2012	17 Jun 2012	3,370
Guafo North	43°31.918′ 74°26.092′	210	4 Dec 2012	28 Apr 2013	3,497
Tic Toc	43°39.618′ 73°07.789′	200	6 Dec 2012	29 Apr 2013	3,495
Locos Islet	44°00.966′ 73°23.379′	170	19 Jun 2012	6 Dec 2012	4,077
Locos Islet	44°01.015′ 73°23.419′	170	6 Dec 2012	29 Apr 2013	3,492

Note: deployment sites are shown on Figure 2 as 1 = Northwest Chiloe, 2 = Guafo North, 3 = Tic Toc Bay, and 4 = Locos Islet.

occurrences in the data set would be low. For detecting these potentially rare sounds, it was considered important to use an approach that ensured a low number of false negatives (missed target sounds) by any automatic detector process. Second, the high numbers of SEP song occurrences in this data set (reported in Buchan *et al*. 2015) and the presence of instrument noise in the frequency band of interest meant that the probability of false positive (incorrect) detections by an automatic detector was high. Given these considerations, automatic detection was carried out in two steps.

Step 1—Data were viewed as spectrograms (4096 pt FFT, 25% overlap, Hann window) using Ishmael (Mellinger 2001). An automatic template detector targeting the complete Z-note (see black boxes in Fig. 1) was built with the Ishmael spectrogram correlation tool (Mellinger and Clark 2000). The frequency contour of the detector template of all three components of the Z-note were specified as: (1) between 1 s and 10 s at 27.7 Hz, (2) 10–11 s at 27.7–19.5 Hz, and (3) 11–19 s at 19.5–18.8 Hz. A frequency contour width of 2 Hz was specified, which is the instantaneous bandwidth of the frequency contour of interest. This frequency contour was the detection template applied to the data set for cross-correlation, at a low threshold setting (0.1) and a short minimum duration of detected event (above the set threshold) of 0.1 s, to ensure low false negatives. A detection neighborhood of 4 s was set, which is minimum time separation between detected events to avoid double detection of the same event (Mellinger 2001). An analyst then visually scanned all detections and manually deleted all false positives, leaving only true positives (corrected detections).

Step 2—To check that the detector in Step 1 yielded low false negatives, a randomly selected 20% subset of all days when no Z-notes were detected (no true positives) from all sites (*i.e.,* 4,244 h), was viewed in Raven Pro 1.4 (Bioacoustics Research Program 2008), using the same spectrogram parameters as Step 1. This subset was visually scanned by an analyst who counted all Z-notes. Only four Z-notes were counted on one single day from the subset data, producing a negligible false negative rate of less than 0.002% (as a percentage of total uncorrected detections from step 1). The number of Z-notes per month and the number of days with ≥1 Z-note per month were then used to examine acoustic presence.

A total of 3,795 Z-notes were present (corrected detections) on 34 separate days between January 2012 and the end of April 2013 at the four sites in the CER feeding ground. The presence of Antarctic blue whales in this area is consistent with previous reports from genetic studies (Torres-Florez *et al.* 2014) and whaling data (Aguayo 1974). The number of Z-notes was relatively low compared to Z-note detections at mid-latitudes in the Indian Ocean (10s of thousands in total, see Samaran *et al.* 2013), however, it is possible that this is due to different detection ranges at these sites, in what are very different ocean environments (coastal *vs.* offshore), rather than a real difference in the distribution of animals. These numbers were also low compared to SEP song phrase detections in the same data set for this area (100s of thousands in total, see Buchan *et al.* 2015). This suggests that Antarctic blue whales pass through this feeding ground only occasionally, in contrast with southeast Pacific blue whales that likely use this area as their primary summer feeding ground (Hucke-Gaete *et al.* 2003, Buchan *et al.* 2015, Buchan and Quiñones 2016). It is important to bear in mind that all conclusions based on PAM of blue whale song types (the Z-note or other), only provide information on the presence of singing males (Oleson *et al.* 2007*a*), whose movements may differ from females and juveniles.

Antarctic blue whales are known to spend the austral summer on their Southern Ocean feeding grounds (*e.g.*, Branch *et al.* 2007). Likewise, at similar latitudes to the CER in the Indian Ocean, Samaran *et al.* (2013) found a decrease in AA Z-notes during the austral summer, interpreted as a southward seasonal migration of Antarctic blue whales. Therefore, fewer AA Z-notes in the CER during the austral summer would be expected. Resolving seasonal patterns is difficult here because this data set is inherently limited by poor winter coverage, *i.e.*, only one winter deployment in the south inner sea at Locos Islet, where no Z-notes were detected even in the summer. With this caveat in mind, AA Z-notes were detected exclusively during the austral summer and autumn (January through to June; Fig. 3), which overlaps with the Antarctic blue whale feeding season in the Southern Ocean and the feeding season of southeast Pacific blue whales in the CER (Hucke-Gaete *et al.* 2003; Buchan *et al.* 2015; Galletti-Vernazzani *et al.* 2012, 2017). Wintertime PAM coverage in the CER should be a future priority to clarify Antarctic blue whale winter distribution in this area.

Often, days when calls were detected occurred consecutively, or within a few days of each other. Nine days was the longest period of consecutive days with AA Z-notes at the same recording site (April 2013 at Guafo North). Observationally, the regular quality of the inter-note intervals and the consistent amplitude of notes observed in AA Z-note sequences, suggest that such bouts of Z-notes in this data might have been produced by a single singer (although the same singer did not necessarily produce all separate bouts).

Spatially, southeast Pacific blue whales are known to use feeding sites throughout the entire CER feeding ground (Hucke-Gaete *et al.* 2003, Hucke-Gaete 2004, Buchan *et al.* 2015, Galletti-Vernazzani *et al.* 2012, 2017), indicating that food for blue whales is abundant at both inner and outer sea sites. It is interesting that AA Z-notes were detected almost exclusively at the two oceanic study sites, Northwest Chiloe and Guafo North, with no detections at the inner sea Locos Islet site and very few at the inner sea Tic Toc Bay site (Fig. 3). These results could suggest that Antarctic blue whales rarely enter the inner sea of the CER feeding ground and may prefer to remain further offshore; or that migrating animals in transit offshore are being detected at offshore sites (explaining January and April offshore detection peaks). From whaling data, few Antarctic blue whales were found near shore off the coast of

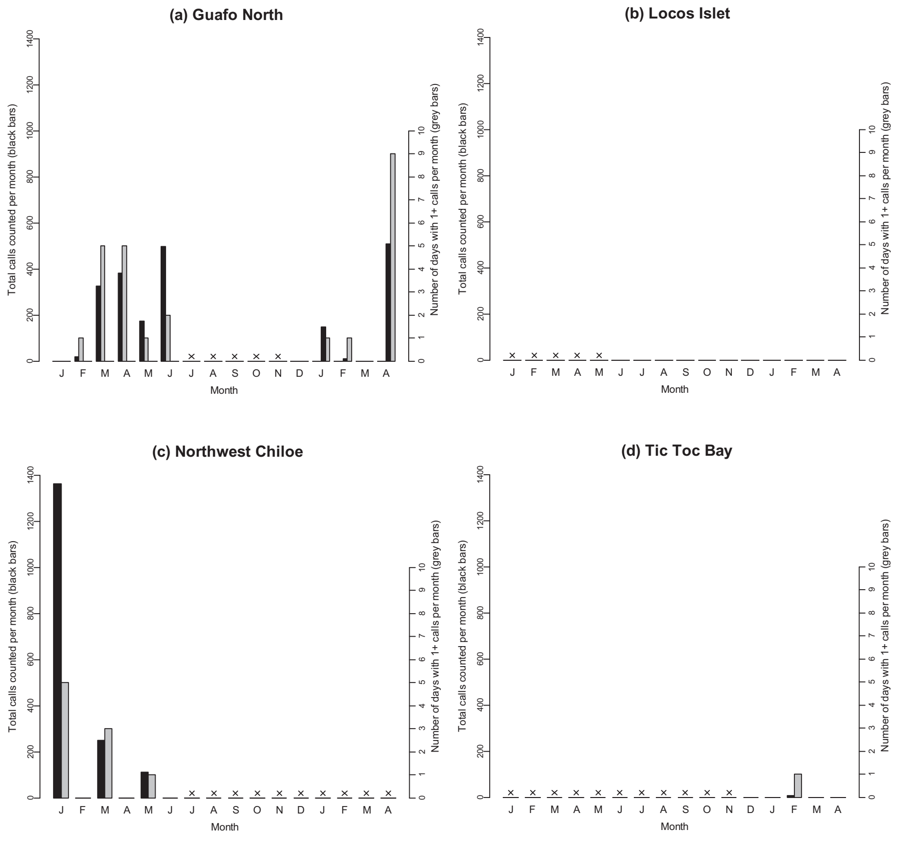

Figure 3. Temporal occurrence of Antarctic blue whale Z-notes in the CER, Northern Chilean Patagonia, between January 2012 and April 2013 at (a) Northwest Chiloe (site 1 Fig. 2), (b) Guafo North (site 2 Fig. 2), (c) Tic Toc Bay (site 3 Fig. 2), (d) Locos Islet (site 4 Fig. 2). Dark bars indicate total Z-notes counted per month and light bars indicate total number of days with ≥1 Z-note present. Crosses indicate lack of data for these months.

Africa during the austral summer, leading to the conclusion that they have a more offshore distribution during the summer months (Mackintosh and Wheeler 1929). However, inner sea and offshore differences in this study could also be due to different detection ranges due to varying propagation conditions between sites; determining detection range will be important to resolve this matter.

In conclusion, the temporal and spatial patterns in AA Z-note occurrence in the CER blue whale feeding ground in Northern Chilean Patagonia indicates that some Antarctic blue whale males occasionally venture on to the CER feeding ground during the austral summer feeding season. The CER may provide occasional alternative or complementary resources for Antarctic blue whales whose primary feeding ground is the Southern Ocean. The CER may also provide a possible "stop-off" point for wandering males in search of food and/or breeding opportunities, along a north-south migration route between the Southern Ocean and the eastern tropical Pacific (Stafford *et al.* 1999*b*). As available habitat for Antarctic blue whale prey, *i.e.*, Antarctic krill, *Euphausia superba*, is projected to decline due to climate change (*e.g.*, Kawaguchi *et al.*

2013, Piñones and Fedorov 2016), alternative subantarctic feeding grounds, such as the CER, may become increasingly important for sustaining Critically Endangered Antarctic blue whales.

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Literature Cited

Aguayo, A. 1974. Baleen whales off continental Chile. Pages 209–217 *in* W. E. Schevill, ed. The whale problem: A status report. Harvard University Press, Cambridge, MA.

Alling, A., E. M. Dorsey and J. C. D. Gordon. 1991. Blue whales *Balaenoptera musculus* off the northeast coast of Sri Lanka: Distribution, feeding and individual identification. UNEP Marine Mammal Technical Report 3:247–258.

Balcazar, N. E., H. Klinck, S. L. Nieukirk, D. K. Mellinger, K. Klinck, R. P. Dziak and T. L. Rogers. 2017. Using calls as an indicator for Antarctic blue whale occurrence and distribution across the southwest Pacific and southeast Indian Oceans. Marine Mammal Science 33:172–186.

Bioacoustics Research Program. 2008. Raven Pro: Interactive sound analysis software (Version 1.3). The Cornell Lab of Ornithology, Ithaca, NY. Available at http://www.birds.cornell.edu/raven.

Branch, T. A., K. M. Stafford, D. M. Palacios, *et al.* 2007. Past and present distribution, densities and movements of blue whales *Balaenoptera musculus* in the Southern Hemisphere and northern Indian Ocean. Mammal Review 37:116–175.

Branch, T. A., Y. A. Milkhalev and H. Kato. 2009. Separating pygmy and Antarctic blue whales using long-forgotten ovarian data. Marine Mammal Science 25:833–854.

Buchan, S. J., and R. A. Quiñones. 2016. First insights into the oceanographic characteristics of a blue whale feeding ground in northern Patagonia, Chile. Marine Ecology Progress Series 554:183–199.

Buchan, S. J., R. Hucke-Gaete, L. E. Rendell and K. M. Stafford. 2014. A new song recorded from blue whales in the Corcovado Gulf, Southern Chile, and an acoustic link to the Eastern Tropical Pacific. Endangered Species Research 23:241–252.

Buchan, S. J., R. Hucke-Gaete, L. E. Rendell and K. M. Stafford. 2015. Seasonal occurrence of southeast Pacific blue whale songs in southern Chile and the eastern tropical Pacific. Marine Mammal Science 31:440–458.

Calupca, T. A., K. M. Fristrup and C. W. Clark. 2000. A compact digital recording system for autonomous bioacoustic monitoring. Journal of the Acoustical Society of America 108:2582–2582.

Clarke, R., A. Aguayo L. and S. Basulto del Campo. 1978. Whale observation and whale marking off the coast of Chile in 1964. Scientific Reports of the Whales Research Institute, Tokyo 30:117–177.

Cummings, W. C., and P. O. Thompson. 1971. Underwater sounds from the blue whale, *Balaenoptera musculus*. Journal of the Acoustical Society of America 50:1193–1198.

Galletti-Vernazzani, B., C. A. Carlson, E. Cabrera and R. L. Brownell, Jr. 2012. Chilean blue whales off Isla Grande de Chiloe, 2004-2010: distribution, site-fidelity and behavior. Journal of Cetacean Research and Management 12:353–360.

Galletti-Vernazzani, B., J. A. Jackson, E. Cabrera, C. A. Carlson and R. L. Brownell, Jr. 2017. Estimates of abundance and trend of Chilean blue whales off Isla de Chiloé, Chile. PLOS ONE 12(1):e0168646.

Gavrilov, A. N., R. D. McCauley and J. Gedamke. 2012. Steady inter and intra-annual decrease in the vocalization frequency of Antarctic blue whales. Journal of the Acoustical Society of North America 131:4476–4480.

Hucke-Gaete, R. 2004. Distribución, preferencia de hábitat y dinámica espacial de la ballena azul en Chile: 1997-2004 [Distribution, habitat preference and spatial dynamics of the blue whale in Chile: 1997–2004]. Ph.D. thesis, Universidad Austral de Chile, Valdivia, Chile. x + 146 pp.

Hucke-Gaete, R., L. P. Osman, C. A. Moreno, K. P. Findlay and D. K. Ljungblad. 2003. Discovery of a blue whale feeding and nursing ground in southern Chile. Proceedings of the Royal Society London B (Supplement) 271:S170–S174.

Kawaguchi, S., A. Ishida, R. King, *et al*. 2013. Risk maps for Antarctic krill under projected Southern Ocean acidification. Nature Climate Change 3:843–847.

Ljungblad, D. K., C. W. Clark and H. Shimada. 1998. A comparison of sounds attributed to pygmy blue whales (*Balaenoptera musculus brevicauda*) recorded south of the Madagascar Plateau and those attributed to 'true' blue whales (*Balaenoptera musculus*) recorded off Antarctica. Report of the International Whaling Commission 48:439–442.

Mackintosh, N. A., and J. F. G. Wheeler. 1929. Southern blue and fin whales. Discovery Reports 1:257–540.

McCauley, R. D., C. Jenner, J. L. Bannister, C. L. K Burton, D. H. Cato and A. Duncan. 2001. Blue whale calling in the Rottnest Trench - 2000, western Australia. Report R2001-6, Centre for Marine Science and Technology, Curtin University of Technology, Perth, Australia. 56 pp.

McDonald, M. A., S. L. Mesnick and J. A. Hildebrand. 2006. Biogeographic characterisation of blue whale song worldwide: Using song to identify populations. Journal of Cetacean Research Management 8:55–56.

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

Mellinger, D. K. 2001. Ishmael 1.0 user's guide. NOAA Technical Report OAR-PMEL-120, NOAA Pacific Marine Environmental Laboratory, Seattle, WA. Available at http://bioacoustics.us/ishmael.html.

Mellinger, D. K., and C. W. Clark. 2000. Recognizing transient low-frequency whale sounds by spectrogram correlation. Journal of the Acoustical Society of North America 107:3518–3529.

Oleson, E. M., J. Calambokidis, W. C. Burgess, M. A. McDonald, C. A. LeDuc and J. A. Hildebrand. 2007*a*. Behavioural context of call production by eastern North Pacific blue whales. Marine Ecology Progress Series 330:269–284.

Oleson, E. M., S. M. Wiggins and J. A. Hildebrand. 2007*b*. Temporal separation of blue whale call types on a southern California feeding ground. Animal Behaviour 74:881–894.

Piñones, A., and A. V. Fedorov. 2016. Projected changes of Antarctic krill habitat by the end of the 21st century. Geophysical Research Letters 43:8580–8589.

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

Reilly, S. B., J. L. Bannister, P. B. Best, *et al*. 2016. *Balaenoptera musculus* ssp. *intermedia*. The IUCN Red List of Threatened Species 2016:e.T41713A98837960. Downloaded on 11 October 2016.

Samaran, F., K. M. Stafford, T. A. Branch, J. Gedamke, J.-R. Royer, R. P. Dziak and C. Guinet. 2013. Seasonal and geographic variation of the southern blue whale subspecies in the Indian Ocean. PlOS ONE 8(8):1–10.

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

Širović, A., J. A. Hildebrand, S. M. Wiggins, M. A. McDonald, S. E. Moore and D. Thiele. 2004. Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. Deep Sea Research Part II: Topical Studies in Oceanography 51 (17):2327–2344.

Širović, A., J. A. Hildebrand and S. M. Wiggins. 2007. Blue and fin whale call source levels and propagation range in the Southern Ocean. Journal of the Acoustical Society of America. 122:1208–1215.

Širović, A., J. A. Hildebrand, S. M. Wiggins and D. Thiele. 2009. Blue and fin whale acoustic presence around Antarctica during 2003 and 2004. Marine Mammal Science 25:125–136.

Stafford, K. M., S. L. Nieukirk and C. G. Fox. 1999*a*. An acoustic link between blue whales in the eastern tropical Pacific and the northeast Pacific. Marine Mammal Science 15:1258–1268.

Stafford, K. M., S. L. Nieukirk and C. G. Fox. 1999*b*. Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. Journal of the Acoustical Society of America 106:3687–3698.

Stafford, K. M., S. L. Nieukirk and C. G. Fox. 2001. Geographical and seasonal variation of blue whale calls of the North Pacific. Journal of Cetacean Research Management 3:65–76.

Stafford, K. M., E. Chapp, D. R. Bohnenstiel and M. Tolstoy. 2011. Seasonal detection of three types of "pygmy" blue whale calls in the Indian Ocean. Marine Mammal Science 27:828–840.

Thomisch, K., O. Boebel, C. W. Clark, W. Hagen, S. Spiesecke, D. P. Zitterbart and I. C. Van Opzeeland. 2016. Spatio-temporal patterns in acoustic presence and distribution of Antarctic blue whales *Balaenoptera musculus intermedia* in the Weddell Sea. Endangered Species Research 30:239–253.

Torres-Florez, J. P., R. Hucke Gaete, R. LeDuc, *et al*. 2014. Blue whale population structure along the eastern South Pacific Ocean: Evidence of more than one population. Molecular Ecology 23(24):5998–6010.

Tripovich, J. S., H. Klinck, S. Nieukirk, *et al*. 2015. Temporal segregation of the Australian and Antarctic blue whale call types (*Balaenoptera musculus* spp.). Journal of Mammalogy 96:603–610.

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