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Using calls as an indicator for Antarctic blue whale occurrence and distribution across the southwest Pacific and southeast Indian Oceans

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Abstract

Understanding species distribution and behavior is essential for conservation programs of migratory species with recovering populations. The critically endangered Antarctic blue whale (*Balaenoptera musculus intermedia*) was heavily exploited during the whaling era. Because of their low numbers, highly migratory behavior, and occurrence in remote areas, their distribution and range are not fully understood, particularly in the southwest Pacific Ocean. This is the first Antarctic blue whale study covering the southwest Pacific Ocean region from temperate to tropical waters (32°S to 15°S). Passive acoustic data were recorded between 2010 and 2011 across the southwest Pacific (SWPO) and southeast Indian (SEIO) oceans. We detected Antarctic blue whale calls in previously undocumented SWPO locations off eastern Australia (32°S, 152°E) and within the Lau Basin (20°S, 176°W and 15°S, 173°W), and SEIO off northwest Australia (19°S, 115°E).In temperate waters, adjacent ocean basins had similar seasonal occurrence, in that calling Antarctic blue whales were present for long periods, almost year round in some areas. In northern tropical waters, calling whales

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were mostly present during the austral winter. Clarifying the occurrence and distribution of critically endangered species is fundamental for monitoring population recovery, marine protected area planning, and in mitigating anthropogenic threats.

Key words: ecological acoustics, Lau Basin, marine mammal, migration, passive acoustic monitoring, spatial distribution, Tasman Sea, vocalization.

The critically endangered Antarctic blue whale (*Balaenoptera musculus intermedia*) (Reilly *et al.* 2016) was heavily exploited during the whaling era, which lasted from 1904 to 1973 (Rocha *et al.* 2014). During this time, the population dropped to an estimated 0.15% of prewhaling abundance, leaving approximately 360 individuals (Branch *et al.* 2004). Whaling effort was concentrated in the Southern Ocean, so little was known about Antarctic blue whale distribution, occurrence, and behavior outside this area (Branch *et al.* 2007).

Today the occurrence and distribution of Antarctic blue whales are still not fully understood, in part because of our limited ability to observe them in their marine environment directly. Field observation of these whales is challenging because they are pelagic and highly migratory, are found in remote areas, spend much time submerged under the water, and they are few in number (Hobson 1999, Laiolo *et al.* 2007, Newsome *et al.* 2010).

Historical catch information traditionally served as a method for determining Antarctic blue whale distribution, occurrence, and movement, but this information was generally confined to areas of interest to whalers, where sightings were predictable (*i.e.*, feeding-aggregation areas) (Branch *et al.* 2007). Modern methods, such as boat surveys, photo-identification, tagging, and genetic studies, are limited by field logistics and financial constraints (Peel *et al.* 2015). More recently, passive acoustic monitoring (PAM) has been used as a cost-effective method of sampling Antarctic blue whale calls over large spatial (Samaran *et al.* 2013) and temporal scales (Gavrilov *et al.* 2012) to infer species occurrence. This information can be used to gain insights into the behavior of the species. For example, it has been suggested that Antarctic blue whales migrated annually between cold-water feeding areas and warmer-water breeding/calving areas (Mackintosh 1966, Branch *et al.* 2007). However, not all individuals undertake the annual migration as some Antarctic blue whale calls have been detected year-round in feeding areas in the southern Pacific Ocean (off the Western Antarctic Peninsula ~66°S; Širović*et al.* 2004) and in the southern Indian Ocean (off the Crozet Islands 46°S; Samaran *et al.* 2010*a*). More recently calls have also been detected year-round in warmer waters off the northern Indian Ocean (26°S; Samaran *et al.* 2013).

Antarctic blue whales are ideally suited for PAM studies because they have repetitive stylized calls of low frequency (under 30 Hz) and high amplitude (up to 189 ± 3 dB re: 1μPa at 1 m) (Širović *et al.* 2007). Acoustic studies of Antarctic blue whales have increased our understanding of their occurrence, distribution, and in turn, behavior, particularly in the Southern and Indian Oceans (Širović *et al.* 2004, Rankin *et al.* 2005, McDonald *et al.* 2006, Samaran *et al.* 2010*a*, Širović and Hildebrand 2011, Stafford *et al.* 2011, Gavrilov *et al.* 2012). Antarctic blue whale calls are currently known to be widely distributed in this region, occurring in the Southern Ocean during the austral summer (Širović *et al.* 2004, 2009; Rankin *et al.* 2005) and within the Indian Ocean, at mid-latitude sites (46°S) during the austral summer (Samaran *et al.* 2010*a*) and at low-latitude tropical water sites (6.3°S) during the austral winter (Stafford *et al.* 2004). Longitudinally in this region, calls are detected from Madagascar (58°E) (Samaran *et al.* 2013) across to southern Australia (141°E) (Tripovich *et al.* 2015).

The Pacific Ocean is currently the least understood of the Antarctic blue whale's suspected range. While Antarctic blue whale sightings were recorded during whaling efforts in the Southern and South Pacific Oceans (Branch *et al.* 2007), our current knowledge in this region is fragmented. Calls have been detected in the eastern tropical Pacific (8°N) during the austral winter (Stafford *et al.* 2004), and the southwest Pacific Ocean (SWPO) in coastal waters of northern New Zealand (36°S) during the austral winter (McDonald 2006) and those of southern New Zealand (52°S) during the austral summer (Miller *et al.* 2015). A recent study reported Antarctic blue whale calls further north, outside the Lau Basin (21°S) during the austral winter and spring (Brodie and Dunn 2015). Anecdotal evidence suggests a blue whale feeding aggregation area off western New Zealand, although these whales have not been identified to the subspecies level (Torres 2013). There have been no reports of Antarctic blue whales in the Tasman Sea, from New Zealand across to the Australian continent, and within the Lau Basin. The distribution and movement of Antarctic blue whales remains unclear in this region.

In this study we describe the occurrence and distribution of Antarctic blue whales calls during 2 yr at six sites across the SWPO and southeast Indian Ocean (SEIO). Understanding species occurrence and distribution provides information on species range, migration, seasonality, and area use, which is essential for management and conservation. Such information is particularly important for highly migratory species with recovering populations, such as the Antarctic blue whale. Our findings have important implications for recovery and conservation management because we identify new regions used by Antarctic blue whales.

Methods

Data Collection

To detect Antarctic blue whale calls, archival passive acoustic recordings were analyzed from six sites spanning about 7,370 km across the SWPO and SEIO. In the SWPO, recordings were used from3 sites: the Tasman Sea off eastern Australia, and the Tonga and Samoa sites (670 km apart) within the Lau Basin. In the SEIO, data were collected at three sites: the Bass Strait off southern Australia, the Perth Canyon off southwest Australia, and Dampier site off northwest Australia (Table 1). At each of the Tasman Sea, Bass Strait, Perth Canyon, and Dampier sites, four recorders (from the Australian Integrated Marine Observer System [IMOS]) made up an acoustic array. Recorders were approximately 2–5 km apart, and therefore acoustic data from a single recorder were analyzed. Ocean sounds were recorded for 500 s of every 900 s at a sampling rate of 6,000 Hz (upper frequency limit of 2,800 Hz at −3 dB). Acoustic data were collected between January 2010 and December 2011 for all sites (Tasman Sea, Perth Canyon, and Bass Strait) except Dampier. At the Dampier site, data were collected during a 9 mo period (from January to September 2013, Table 1). At the Tonga and Samoa sites, single moored autonomous hydrophones (developed by Oregon State University and National Oceanic and Atmospheric Administration/Pacific Marine Environmental Laboratory [NOAA/PMEL]) recorded continuous ocean sounds off Tonga at a sampling rate of 250 Hz (upper frequency limit of 110Hz at ±3 dB) and 1,000 Hz off Samoa (upper frequency limit of 440 Hz at ±3 dB). Off Tonga acoustic data were used from January to December 2009 and off Samoa from January 2010 to August 2011 (Table 1). Hydrophone and seafloor depth are outlined in Table 1. To account for the different sampling frequencies all data were down sampled to 250 Hz before analysis.

Table 1. Hydrophone deployments used for (a) spatial and temporal distribution and (b) interannual differences, analysis across the southwest Pacific Ocean (SWPO) and the southeast Indian Ocean (SEIO). Days = number of days data were collected. Detector rates = (missed call rate percentage, false detection rate percentage). * Indicates average value for time period.

Ocean basin	Site name	Location	Hydrophone/seafloor depth (m)	Recording dates	Days	Detector rates (%)
(a) Spatial and temporal distribution						
SWPO	Tasman Sea	32°19′ 21.72″S, 152°56′40.32″E	147/147	February 2010–October 2010	234	5.7, 75.5
SWPO	Tonga	20°25′ 44.64″S, 176°47′39.06″W	1,042/3,120	January 2009–December 2009	349	2.7, 75.4
SWPO	Samoa	15°8′ 30.12″S, 173°44′18.72″W	1,031/2,794	January 2010–December 2010	350	4.3, 95.7
SEIO	Dampier	19°23′ 17.46″S, 115°54′53.76″E	216/216	January 2013–September 2013	272	3.2, 98.9
SEIO	Perth Canyon	31°54′ 8.34″S, 115°1′36.42″E	465/465	January 2010–December 2010	351	6.7, 55.9
SEIO	Bass Strait	38°33′ 1.86″S, 141°15′13.92″E	168/168	February 2010–December 2010	250	3.5, 14.6
(b) Interannual differences						
SWPO	Tasman Sea	32°19′ 21.72″S, 152°56′40.32″E	147/147	February 2010–December 2011	499	6.7*, 74.7*
SWPO	Samoa	15°8′ 30.12″S, 173°44′18.72″W	1,031/2,794	January 2010–August 2011	575	3.8*, 96.8*
SEIO	Perth Canyon	31°54′ 8.34″S, 115°1′36.42″E	465/465	January 2010–December 2011	647	4.5*, 65.8*
SEIO	Bass Strait	38°33′ 1.86″S, 141°15′3.92″E	168/168	February 2010–December 2011	586	4.5*, 17.6*

Call Detection

Long-term spectral averages (30 d period) were calculated *via* Triton V.1.80, MATLAB software package (MATLAB 2012), and were initially used to screen Antarctic blue whale calls in the Tasman Sea and the Lau Basin, since no research had previously been conducted on Antarctic blue whales in these regions (Tasman Sea and upper Lau Basin, Samoa).

To detect the Antarctic blue whale call, an energy ratio detector (frequency bands 25–26.5 Hz and 14–16 Hz) was created in Ishmael (V.2.3.1) (Mellinger 2001). The detector targeted the tonal part of the call at between 25 and 26.5 Hz in frequency and between 2.5 and 15 s in duration (Fig. 1). The detector was run in Ishmael across each site (Tasman Sea, Tonga, Samoa, Bass Strait, Perth Canyon, and Dampier; Fig. 2). All calls that were positively detected were checked manually by using Osprey, a MATLAB program (spectrogram parameters: 512 samples per frame, 0.65 hop size, and Hann window). All automated detected calls were manually checked and identified either as Antarctic blue whale calls or as a false detection. False detections, calls that were not Antarctic blue whale calls, were removed from further analysis. Missed calls were calculated and expressed as percentages of the total number of calls in the data that were missed by the automated detector. The missed call rate was calculated by comparing the number of calls picked manually to the number of calls detected automatically. Calls were checked manually and the process was repeated for 12 randomly selected days, one day selected for each month of the year. False detections and missed calls were reported as a percentage of the total number of automated detections to indicate detector performance (Table 1).

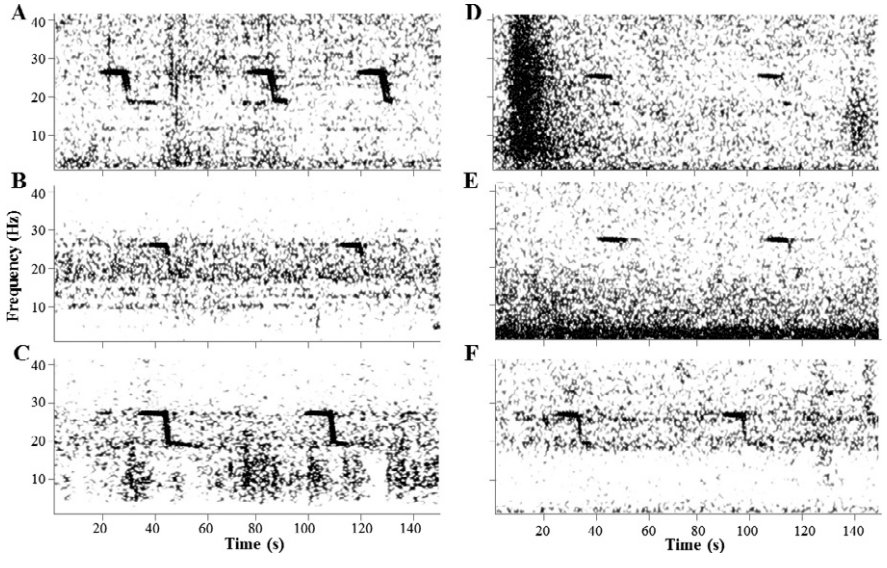

Figure 1. Examples of the Antarctic blue whale calls detected from: (a) Dampier on 22 May 2013, (b) Perth Canyon on 9 August 2010, (c) Bass Strait on 7 August 2010, (d) Samoa on 16 January 2011, (e) Tonga on 23 July 2009, and (f) Tasman Sea on 28 April 2011. Spectrogram parameters show 512 samples per frame, 0.625 hop size in Hann window.

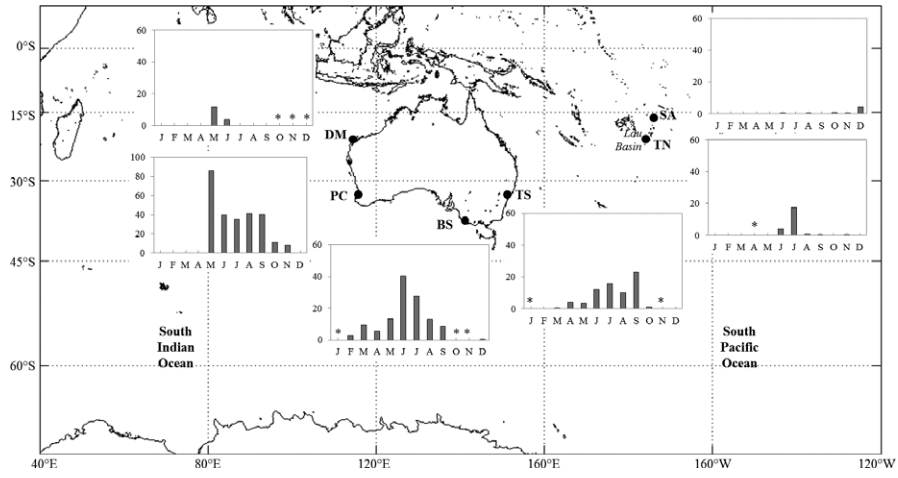

Figure 2. Percentage of hours per month with calls over a 12 mo period (January to December) at the Dampier (DM) in 2013, the Perth Canyon (PC) in 2010, Bass Strait (BS) in 2010, Tasman Sea (TS) in 2010, Tonga (TN) in 2010, and Samoa (SA) in 2009 sites. Asterisk (*) months indicate that data were not available.

Data Analysis

Antarctic blue whale calls can vary in their appearance, and are reported to occur as 3-unit, 2-unit, and/or single-unit calls. However they all share the tonal component that is used to detect the Antarctic blue whale call (Rankin *et al.* 2005). In this study the 3-, 2-, and single-unit calls were detected (Fig. 1). The occurrence of Antarctic blue whale calls were used as a proxy for the occurrence of Antarctic blue whales across months and sites, therefore we do not report number of calls. Furthermore Antarctic blue whale calling rates are unclear; therefore we cannot report number of individual whales in an area. This call (in its 3-, 2-, and single-unit form) has been suggested to be produced by males (Oleson *et al*. 2007), therefore call counts do not likely account for females in an area. As a result, call detections are conservative and that did not account for nonvocal males nor for detections that may have been missed during high-density calling periods when calls overlapped or were masked by background noise.

Spatial and Temporal Occurrence

Data were analyzed for the occurrence of Antarctic blue whale calls during a 12 mo period (January to December; Table 1a). This time period was limited by the availability of acoustic data collected at the Tonga and Dampier sites. The number of calls detected per month was converted to percentage of hours per month with calls to account for the different sampling schedules of the IMOS and NOAA data sets. Seasonal occurrence and spatial distribution patterns of Antarctic blue whales were inferred from these percentages. The first calls detected at a site were used to determine when calling whales arrived in the area and the last ones were used as indicators for when they left. Months with the highest percentage of calls indicated seasonal peaks.

Results

Spatial Distribution

Antarctic blue whale calls were positively detected across all six sites (Fig. 2). The hours with calls detected per month varied among sites. However, calls were detected across more months and more hours per month at mid latitudes than at low latitudes sites, across ocean basins. We had low rates of missed calls across all sites and relatively high rates of false detections except in the Bass Strait site (Table 1).

SWPO

Seasonal occurrence—At the Tasman Sea site, calls were detected from austral autumn (March) through spring (October) 2010. No calls were detected in February. When calls were first detected in March, the percentage of hours with calls increased, peaked in July and September before decreasing in October (Fig. 2). No data were available for January, November, and December 2010.

Off Tonga, calls were detected from austral winter (June) through spring (November) 2009; however, no calls were detected in October. Hours with calls detected per month increased from June and peaked in July, after which the percentages decreased, with only a few hours with calls in August, September, and November (Fig. 2).

Off Samoa, calls were detected during austral winter (June) through summer (December) 2010. No calls were detected from January to March or in July and September. Hours per month with calls increased from June to a peak in December (Fig. 2).

Interannual difference—At the Tasman Sea site, calls were detected from austral autumn (April) through spring (October), in 2011, with a few hours with calls in late spring and summer (November and December) (Fig. 3). Across the 2 yr calls were first detected in the Tasman Sea in austral autumn (March/April) and continued through spring (October), with a peak in winter (June–August).

Off Samoa, calls peaked twice, in 2011, during the summer (January) and winter (June/July). No data were available from August to December 2011. Calls were

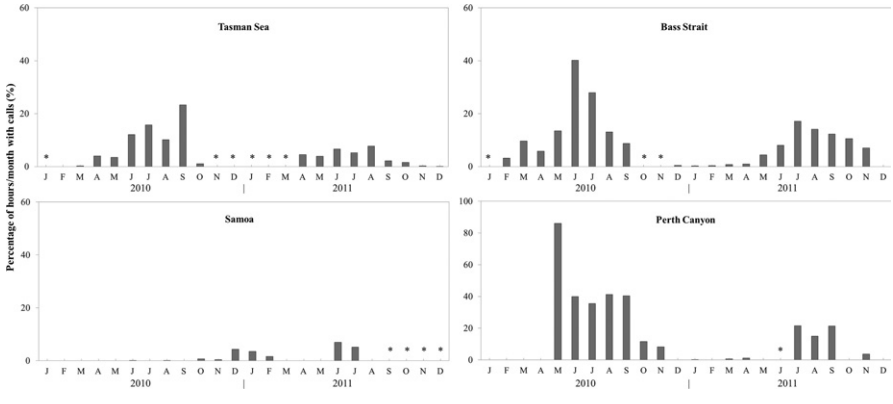

Figure 3. Percentage of hours per month with calls from January 2010 to December 2011 at the Tasman Sea, Samoa, Bass Strait, and Perth Canyon sites. Asterisk (*) months indicate that data were not available.

generally detected off Samoa during austral winter (June to August) and summer (December to February), with a peak in the summer (December to January) (Fig. 3).

SEIO

Seasonal occurrence—In the Bass Strait, calls were detected from austral summer (February) through summer (December) 2010. The percentage of hours with calls varied among months, with a clear seasonal trend. Hours with calls increased from February and peaked in June, then decreased until September. A few hours with calls were found in December; however, no data were available for January, October, and November (Fig. 2).

In the Perth Canyon, calls were detected from austral autumn (May) through spring (November) 2010. The percentage of hours with calls varied between months, with a clear seasonal trend. No calls were detected from January to April, but the percentage of hours with calls peaked in May then decreased until November, with no calls in December (Fig. 2).

At the Dampier site, calls were detected in austral autumn (May) and winter (June) 2013. No calls were detected from January to April, but the percentage of hours with calls peaked in May, and then decreased in June, with no calls detected for the rest of the recording period, ending in September (Fig. 2).

Interannual difference—In the Bass Strait, two years of data for 2010–2011 (Table 1b) showed percentage of hours per month with calls varied between years; however, a clear seasonal trend was evident for both years with a winter calling peak. In 2011 calls were detected in all months except December. Calls were initially detected in austral summer (January), increased through the winter months (June to August), then decreased as November approached, when the calls were last detected as shown in Fig. 3.

In the Perth Canyon, a large difference occurred in the percentage of hours with calls between the two years of the study period (Fig. 3), with no clear seasonal trend evident in 2011, as was seen in 2010. In 2011, calls were first detected in summer (January) to spring (November), with no calls detected in February, May, October, and December. No data were available for June 2011. Calls were generally detected in the Perth Canyon from austral autumn (May/March) through spring (November), with a general peak in winter (June/July, Fig. 3).

Discussion

We detected Antarctic blue whale calls at six sites (Tasman Sea, Tonga and Samoa, Bass Strait, Perth Canyon, and Dampier) distributed across the SWPO (173°W) and SEIO (115°E) through different latitudes (38°S to 15°S). Antarctic blue whales had not been previously reported from four of these sites (Tasman Sea, Tonga, Samoa, and Dampier). The percentage of hours with calls varied seasonally across sites. This is the first dedicated Antarctic blue whale study covering the broad SWPO region.

Southwest Pacific Ocean

Spatial distribution—The occurrence of Antarctic blue whale calls in the Tasman Sea (off the east Australian coast 32°S, 152°E) and within the Lau Basin(off Tonga 20°S, 176°W and Samoa 15°S, 173°W) extends our knowledge of Antarctic blue

whale distribution. Antarctic blue whale calls had previously been detected in the west Pacific Ocean within the coastal waters off northern (~36°S, 175°E; McDonald 2006) and southern New Zealand (~51°S, 150°–168°E; Miller *et al.* 2015); further north, outside the lower Lau Basin (21°S, 174°W; Brodie and Dunn 2015); and across the Pacific Ocean, off the eastern tropical Pacific (8°N, 95°–110°W; Stafford *et al.* 2004).

Seasonal occurrence—We found seasonal differences in the occurrence of Antarctic blue whale calls across latitudes. Calls were first detected in the austral autumn at our most southern SWPO site (Tasman Sea, 32°S) and then later in the year (predominately winter) at our two northern sites within the Lau Basin (off Tonga, 20°S, and Samoa, 15°S; Fig. 2). This timing of call occurrence is consistent with the spatial behavior of the whales, given that Antarctic blue whales are believed to move northward from high-latitude summer feeding areas to wintering grounds at lower latitude (Mackintosh 1966, Branch *et al.* 2007).

However, the occurrence of Antarctic blue whale calls at the Samoa site (low-latitude warm waters) during summer (Fig. 1d) is not consistent with the traditional movement of Antarctic blue whales. Previous studies showed Antarctic blue whale calls at high-latitude (cold water) feeding areas during the summer (Širović *et al.* 2004, 2009; Rankin *et al.* 2005; Gedamke and Robinson 2010) and at low latitudes (warm water) during the winter (Stafford *et al*. 2004; McDonald 2006; Samaran *et al.* 2010*a*, 2013; Gavrilov *et al*. 2012; Tripovich *et al.* 2015). This is the first study to detect Antarctic blue whale calls in tropical waters (off Samoa, 15°S) during the summer. Historical blue whale catch information does not indicate the occurrence of Antarctic blue whales in tropical waters during summer, and there are limited data from the tropics in general (Branch *et al.* 2007). While long-range propagation characteristics of the Antarctic blue whale call could mean that the calls we detected were produced by animals at a distance, however, preliminary propagation modeling has shown that Antarctic blue whale are located within 63 km of the Samoa hydrophone (Balcazar *et al.*, unpublished data). If detections were from whales calling at relatively close range, the occurrence of Antarctic blue whales within warm waters during the summer may not be representative of the general population; however, it does highlight the variability in distribution and behavior among individuals. Individuals may delay or forego the annual migration back to high-latitude summer feeding areas and remain at low latitudes during the summer. In addition, year-round detections of Antarctic blue whale calls at both high (Širović *et al.* 2004, Branch *et al.* 2007) and mid latitudes (Branch *et al*. 2007; Samaran *et al*. 2010*a*, 2013) have shown that not all Antarctic blue whales follow the annual migration.

Calls associated with blue whales in New Zealand waters (Kibblewhite *et al.* 1967, McDonald 2006) have been detected at the same Tasman Sea and Tonga hydrophones included in the current study (Balcazar *et al.* 2015). Calls from different blue whale populations have previously been detected sympatrically, particularly those of Antarctic and pygmy blue whales (*Balaenoptera musculus brevicauda*) in the Indian Ocean (Samaran *et al.* 2010*a*, 2013; Erbe *et al.* 2015; Tripovich *et al*. 2015). We suggest that the broader SWPO region is an important site for different blue whale populations.

Southeast Indian Ocean

Spatial distribution—This is the first study to detect the occurrence of Antarctic blue whale calls off tropical northwest Australia (off Dampier, 19°S, 115°E). Our

study extends the known distribution of Antarctic blue whales in the SEIO from the temperate waters off southern Australia to northern tropical water. Previous acoustic studies have reported Antarctic blue whale calls off southern Australia, in the Bass Strait (39°S, 141°E; Tripovich *et al*. 2015), and off southwest Australia, off Cape Leeuwin (35°S, 114°E; Stafford *et al*. 2004), and Perth Canyon (32°S, 115°E; Erbe *et al.* 2015).

Seasonal occurrence—We found that Antarctic blue whale calls showed seasonal variability across latitudes in the SEIO. At the most southern site (Bass Strait, 39°S), calls were first detected in the austral summer; further north, off southwest Australia (Perth Canyon 32°S), calls were detected in autumn; and at the most northwest site (Dampier, 19°S), calls were present from autumn to winter, consistent with the traditional northward movement(Mackintosh 1966, Branch *et al.* 2007). Antarctic blue whale calls are present in the Antarctic waters adjacent to the SEIO during summer (Rankin *et al.* 2005, Miller *et al.* 2015) and off Cape Leeuwin (southwest Australia) throughout summer and spring (Stafford *et al.* 2004, Gavrilov *et al.* 2012). Our study also extends the known temporal occurrence of Antarctic blue whale calls in the Perth Canyon (southwest Australia). We detected calls from austral autumn (April/May) and into spring (November), extending the previously reported occurrence by approximately 3 mo (Erbe *et al.* 2015).

In the Bass Strait (southern Australia) we found calls were present as early as the austral summer (February). This coincides with the timing of high productivity in the Bonney Upwelling, off southern Australia between austral summer and autumn (Gill 2002). Two blue whale subspecies, the Antarctic blue whale and the pygmy blue whale, have previously been observed in this region. The Bass Strait is a well-studied feeding aggregation area for the pygmy blue whale, where they aggregate during the peak of primary productivity during the austral summer and autumn (Gill 2002, Gill *et al.* 2011). We detected Antarctic blue whale calls over a long period of time (up to 11 mo in 2011), and we suggest that Antarctic blue whales may also be aggregating at this feeding site. While previous visual surveys in the Bass Strait did not report the occurrence of Antarctic blue whales (Gill 2002), Tripovich *et al*. (2015) suggests that they may be opportunistically feeding alongside pygmy blue whales in the Bass Strait on their migration north from Antarctica to warmer waters.

Our study also extends the previously reported seasonal occurrence of Antarctic blue whale calls in the Perth Canyon (southwest Australia). We detected calls in austral autumn (April/May) through spring (November), which extends the previously reported temporal occurrence of Antarctic blue whale calls from winter to spring, covering 7 mo (Erbe *et al.* 2015). We suggest that Antarctic blue whales may also be aggregating in the Perth Canyon to opportunistically feed during their northward migration. The Perth Canyon is another well-known pygmy blue whale feeding area (Rennie *et al.* 2009). While pygmy blue whales aggregate in the Perth Canyon during the austral summer (Rennie *et al.* 2009), the peak timing of primary productivity in the Perth Canyon is in winter (Koslow *et al.* 2008). The timing of our Antarctic blue whale detections is consistent with the peak timing in primary productivity in the Perth Canyon.

Suggested Area Use in the SWPO and SEIO

Antarctic blue whale calls were detected during 7 to 11 consecutive months at the southern temperate sites (Tasman Sea, Bass Strait, and Perth Canyon) and from 2 to 3 mo at the more northern tropical sites (Dampier, Tonga, and Samoa; Fig. 2).

The timing of detections in the Bass Strait and Perth Canyon coincide with the peak primary productivity at the Bonney Upwelling, off the Bass Strait (Lewis 1981, Nieblas *et al.* 2009) and the Perth Canyon (Koslow *et al.* 2008), which supports the suggestion that Antarctic blue whales feed opportunistically in the region on their migration north from Antarctica to warmer waters (Tripovich *et al.* 2015). Although Antarctic blue whales predominantly feed in high-latitude waters off the Antarctic ice edge (Širović *et al.* 2004, Širović and Hildebrand 2011, Attard *et al.* 2012), feeding opportunistically outside high latitudes may occur when whales are in waters of high productivity (Stafford *et al.* 2004; Branch *et al.* 2007; Samaran *et al*. 2010*a*, 2013; Anderson *et al.* 2012; Tripovich *et al.* 2015). The strongest evidence supporting Antarctic blue whales feeding in areas outside of Antarctic waters is the autumn/summer detections of Antarctic blue whale calls at mid-latitude sites that have high primary productivity (Branch *et al.* 2007; Samaran *et al.* 2010*a*, 2013; Anderson *et al.* 2012).

At the Tasman Sea site Antarctic blue whale calls were detected over a long period, approximately eight consecutive months; however, few calls were detected relative to the other sites. This long period of occurrence in the area may suggest that Antarctic blue whales may not use the area solely as a migratory corridor from high-latitude feeding areas (cold water) to low-latitude wintering areas (warm water), but that they may move in and out of the Tasman Sea area. Blue whales, presumed to be pygmy blue whales, feed off western New Zealand (Torres 2013). Antarctic blue whales may use the New Zealand feeding site, and the intermittent call detections off the east Australian coastline may indicate that the whales move to and from Australia and New Zealand across the Tasman Sea. Future acoustic research in the New Zealand feeding area would provide insight into the importance of the Tasman Sea for blue whales.

It is less clear how whales are using the northern sites (Lau Basin sites, off Tonga and Samoa, and northwest Australia off Dampier), where few calls were detected and only during brief periods of a month or so. These regions may be the northern distribution limits of the Antarctic blue whale in the SWPO and SEIO or regions that whales are traveling through. Alternatively, Antarctic blue whales may call less, or even cease calling, while in tropical waters during the austral summer.

The distance over which whale calls could be detected can be influenced by different propagation characteristics due to the bathymetry and the depth of the hydrophones but possibly also over the period of time which calls were detected (Stafford *et al.* 1998, Širović *et al.* 2007, Samaran *et al.* 2010*b*, Miller *et al.* 2015). Antarctic blue whales can be detected at a range of approximately 180 km, in the Indian Ocean (hydrophone within the sound channel; Samaran *et al*. 2010*b*) and approximately 200 km in the Southern Ocean (hydrophone outside the sound channel; Sirovic *et al.* 2007) suggesting the calls we detected across our study area are within this range. Furthermore, the hydrophones around Australia are within shallow water (147–465 m) and not within the sound channel (approximately 1,000 m), suggesting calls detected may be within the maximum range previously reported. In comparison in deep waters (approximately 2,750 m) within the Lau Basin preliminary localizations results show Antarctic blue whales are present within the Lau Basin (Balcazar *et al.*, unpublished data). In studies where localization data or propagation models are not available, care should be taken when accessing inferring areas of detection by looking at bathymetry and instrument depths.

In this study we checked and identified all calls detected and found that missed calls where relatively low and similar across all sites and false detections

where generally high except off the Bass Strait. Low missed calling rates and high false detection rates were not a problem in this study as we wanted to capture as many calls as possible across all sites to account for low calling rates at some sites, in particular low latitudes sites. If we had, had high missed call rates and lower false call rates, we may have missed calling whales at these sites. Care should be taken when compared calling rates between sites, in this study we have interpreted the occurrence of calling whales at individual sites to minimize discrepancies between sites.

Highly migratory and widely distributed marine species are difficult to access and observe. Our limited ability to directly study these species has limited our understanding of their ecology and behavior. Blue whale numbers are increasing (Branch *et al.* 2004, 2007; Monnahan *et al.* 2015), but our understanding of Antarctic blue whale occurrence and distribution remains unclear in some regions, such as the southern Pacific. Conservation success depends on how species respond to environmental change. Therefore, understanding the extent of species occurrence and distribution is fundamental for monitoring population recovery and in decision making (locally and across ocean basins). Monitoring Antarctic blue whale population recovery is important for the longevity of the species. Increases to underwater noise from activities such as shipping and resource exploration potentially interfere with the communication space of marine species (Clark *et al.* 2009, Williams *et al.* 2015). These threats need to be monitored and mitigated, particularly in areas where these activities overlap with the distribution of critically endangered species that rely on underwater communication for breeding (Williams *et al.* 2013). Results from this research can be integrated into conservation decision making in species recovery plans, marine park planning, and in resource exploration (for example the timing of exploration activities). This is particularly important in high ship traffic areas such as the Tasman Sea and Perth Canyon. Additionally, this research can provide baseline information for future research. We report the presence of Antarctic blue whales in low-latitude tropical waters during the breeding season, which may allow us to begin to hypothesize about the location of unknown breeding areas of these whales.

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