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Blue and fin whale acoustic presence around Antarctica during 2003 and 2004

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ABSTRACT

Seasonal and spatial variations of blue (*Balaenoptera musculus*) and fin whale (*B. physalus*) calls were analyzed from recordings collected with Acoustic Recording Packages (ARPs) deployed between January 2003 and July 2004 at four circumpolar locations: the Western Antarctic Peninsula (WAP), the Scotia Sea (SS), Eastern Antarctica (EA), and the Ross Sea (RS). Call characteristics were compared among sites using the average pressure spectrum levels from 1 month of data at each location. Presence of calls was analyzed using automatic call detection and acoustic power analysis methods. Blue whale calls were recorded year-round, with the highest detections in February–May and November. This suggests that the blue whale population may not migrate synchronously, and may indicate long duration calls are more common during migrations. Fin whale calls were detected only during February–July. Two distinct fin whale call types were recorded, suggesting a possible separation into two populations. The calls at the EA site had a secondary frequency peak in the pressure spectrum at 99 Hz and the calls at the WAP and the SS sites had a peak at 89 Hz. No fin whale calls were detected at the RS site. Acoustics are a good tool to monitor large whales in the Southern Ocean.

Key words: blue whale, *Balaenoptera musculus*, fin whale, *Balaenoptera physalus*, passive acoustics, Southern Ocean, circumpolar, distribution.

Blue whale (*Balaenoptera musculus*) sightings are not very common in the Southern Ocean and both blue and fin whale (*B. physalus*) populations are currently at very low levels (Branch and Butterworth 2001, Branch *et al.* 2004) following decades of

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commercial exploitation during the 20th century (Clapham and Baker 2001). Blue and fin whales make low frequency, high intensity sounds that travel long distances and are suitable for acoustic monitoring (Širović *et al.* 2007).

The calls of these two species have different frequency and temporal characteristics and are easily distinguished from one another. Antarctic blue whales produce long duration calls starting with a tone, approximately 8 s long at 28 Hz, followed by a 1-s downsweep to 19 Hz, and a slower 8-s downsweep to 18 Hz (Širović *et al.* 2004, Rankin *et al.* 2005). They also produce short, 1–4 s duration, frequency-modulated calls ranging in frequency between 80 and 38 Hz (Rankin *et al.* 2005, Širović *et al.* 2006). Fin whales off the Western Antarctic Peninsula (WAP) produce short, less than 1 s duration calls downswept in frequency between 28 and 15 Hz, and they often have a second higher frequency component at 89 Hz (Širović *et al.* 2004). Both species make calls that tend to be repeated at regular intervals, approximately 64 s for blue whales and 13 s for fin whales off the WAP (Širović *et al.* 2004).

It has been suggested that differences in intraspecific call characteristics can be used as a tool to investigate population differences in blue whales (McDonald *et al.* 2006*a*) and fin whales (Hatch and Clark 2004). The Antarctic blue whales appear to be part of a single population, as they make the same kind of call circumpolarly (Ljungblad *et al.* 1998, Clark and Fowler 2001, Širović *et al.* 2004, Rankin *et al.* 2005, McDonald *et al.* 2006*a*, Branch *et al.* 2007), and at least a part of the population is known to migrate to lower latitudes during the austral winter (Stafford *et al.* 2004, Branch *et al.* 2007). Although fin whales in the Antarctic are considered to comprise a single population, tagging data suggest mostly latitudinal movement of the animals (Brown 1954, 1962*a*, *b*). Previously, fin whales have been recorded acoustically only near the Antarctic Peninsula region in the Southern Ocean (Širović *et al.* 2004, 2006), thus it has not been possible to investigate their population differences in the Southern Ocean using acoustics.

Given their low numbers, difficult sighting conditions in the Southern Ocean, and the propagation characteristics of their calls (Clark 1990, Širović *et al.* 2007), blue and fin whales are good subjects for acoustic monitoring (Clark and Fristrup 1997, Širović *et al.* 2006). Most of the Southern Ocean cetacean acoustic data published thus far have been from sonobuoy recordings made during the summer months (Ljungblad *et al.* 1998, Clark and Fowler 2001, Rankin *et al.* 2005, Širović *et al.* 2006). The WAP region is the exception with year-round autonomous hydrophone recordings, indicating year-round calling blue whale and seasonal calling fin whale presence (Širović *et al*. 2004). The visual surveys in this region are also constrained mainly to the summer months (Miyashita *et al.* 1995, Kasamatsu *et al.* 1996, Branch and Butterworth 2001, Matsuoka *et al.* 2003), with the exception of the cruises that occurred off the WAP during the Southern Ocean Global Ocean Ecosystem Dynamics (GLOBEC) program (Thiele *et al.* 2004, Friedlaender *et al.* 2006). As the majority of commercial whaling also occurred outside of the winter months (Mackintosh 1965), direct knowledge of the presence and absence of baleen whales in this polar region during the winter is limited.

Methods

Acoustic data were recorded continuously using Acoustic Recording Packages (ARPs) at four circumpolar locations during 2003 and 2004 (Fig. 1). ARPs for this study were deployed off the WAP (WAP, 62°16.69′S, 62°07.80′W, depth 1,632 m),

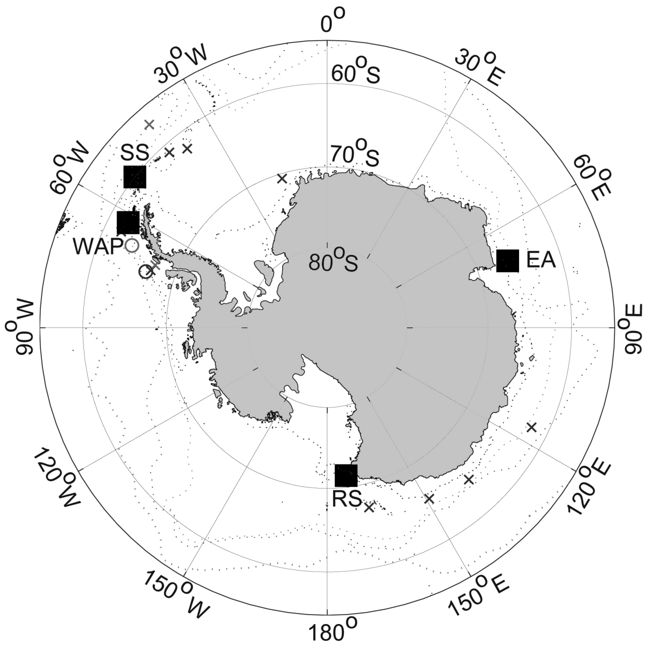

Figure 1. Locations of ARPs used in this study are shown as squares: the Western Antarctic Peninsula (WAP), the Scotia Sea (SS), Eastern Antarctica (EA), and the Ross Sea (RS). The continental shelf break is denoted by a 1,000-m bathymetry contour, shown as a broken line closest to the continent. The fronts of the Antarctic Circumpolar Current are (from the pole toward the equator): southern boundary of the Antarctic Circumpolar Current (SB), southern Antarctic Circumpolar Current front (sACCf), and the polar front (PF). Gray crosses (sonobuoys) and circles (long-term moorings) denote locations of past fin whale call recordings south of 60°S as reported by Širović *et al.* (2004, 2006). A review of past blue whale call recording location is given in Branch *et al.* (2007).

in the SS (SS, 60°00.02′S, 51°53.88′W, depth 2,813 m), in the RS (RS, 71°24.90′S, 172°39.96′E, depth 2,198 m), and off EA (EA, 66°44.24′S, 69°48.72′E, depth 1,321 m). Data at the WAP site were recorded from 28 February 2003 until 1 March 2004, at the SS site from 13 January until 21 April 2003, at the EA site from 8 February 2003 until 17 January 2004, and at the RS site from 2 March until 16 July 2004. Details on ARP configurations and characteristics are given in Wiggins (2003). The acoustic data were recorded at a rate of 500 samples/s at the WAP and the EA sites, and at 1,000 samples/s at the other two sites.

Call frequency characteristics were compared between regions using the average pressure spectrum levels from 1 month of late summer and early fall data at each site. Spectra were calculated using 500-point Fast Fourier Transform (FFT) for the WAP and EA data and 1,000-point FFT for the data from the RS and the SS, giving 1 Hz resolution for all data. Fifty percent overlap and a Hanning window were used for all data. These spectra were averaged over 15 min into average pressure spectrum levels. One month (30 d) of average pressure spectrum levels were further averaged from periods with high calling rates to illustrate typical spectral characteristics of calls at each site, and these are reported between 10 and 200 Hz for all sites. The periods used were 1–30 March 2003 for SS and 1–30 April 2003 for WAP and EA. At the RS site, 30 d were chosen between 3 March and 13 April 2004 when there was no ship noise. (RVIB *N. B. Palmer* was in the area on 5–13 and 29–30 March. Other ship noise is rare in this area.) Possible sources of increased power at different frequency bands were investigated by visually scanning data spectrograms (1,000-point FFT, 90% overlap, Hanning window).

All data were analyzed for presence of blue and fin whale calls using two methods: call counts from automatic detections and acoustic power calculations from average pressure spectrum levels. The calls were detected automatically using spectrogram correlation method available in the software program *Ishmael* (Mellinger and Clark 2000, Mellinger 2001). Call kernels were developed based on the frequency characteristics of calls from the WAP as reported in Širović *et al.* (2004). The kernel used for blue whale calls started with a 9-s flat tone at 27.7 Hz, followed by a 1-s downsweep to 19.5 Hz and a 7-s downsweep to 18.8 Hz. Fin whale calls were detected with a 1 s duration kernel sweeping down in frequency from 28 to 15 Hz. Detections were saved in individual wav files and all detection files were verified visually. False detections were deleted and not used in subsequent analyses. Total detected calls were summed and plotted over 8-d periods. These results are comparable to the automatic detection results used in Širović *et al.* (2004).

Acoustic power calculations were made by calculating the ratio of sound power in 1 Hz bands characteristic for blue whale calls and noise, and fin whale calls and noise. We assumed noise levels decrease linearly in this frequency range. Thus, for blue whales, acoustic power calculations were made from the ratio of sound power in 1 Hz bands centered on 28 Hz (blue whale) and the average of the 1 Hz bands centered on 15 and 41 Hz (noise). For fin whales at the EA site, acoustic power calculations were made from the ratio of sound power in the 1 Hz band centered on 99 Hz (fin whale) and the average of the 1 Hz bands centered on 90 and 108 Hz (noise). At other sites, the sound power in 1 Hz band centered on 89 Hz was used for fin whale signal, and the average of the 1 Hz bands centered on 80 and 98 Hz for noise. The acoustic power was averaged over 8 d, for easier comparison to the automatic call detections.

Results

Averaged pressure spectrum levels from all sites show representative spectral peaks for different species and combinations of species (Fig. 2). Data from the RS site contained only blue whale calls and those calls manifested themselves clearly in the average spectrum levels showing a narrow peak at 28 Hz and a secondary peak at 19 Hz. The WAP and the SS sites showed a combination of blue and fin whale sounds, as indicated by the *ca.* 2 dB increase in the 15–30 Hz frequency band. The maximum at 18–20 Hz and a secondary, narrow peak at 89 Hz represent fin whale calls. The EA site had a second peak at 99 Hz, instead of the second peak at 89 Hz as found at the WAP and SS sites, indicative of fin whale calls (Fig. 3). The increase in power spectrum levels at 28 Hz at all sites indicated blue whale calls.

There were large differences among the four sites in the numbers of blue and fin whale call detections. The highest number of blue whale calls, almost 8,000 in an 8-d period, was detected at the RS site, while the lowest number of calls, less than 350 in 8 d, was detected at the EA site. The SS and the WAP sites had intermediate numbers with peak rates just below 2,500 and 700 call detections in

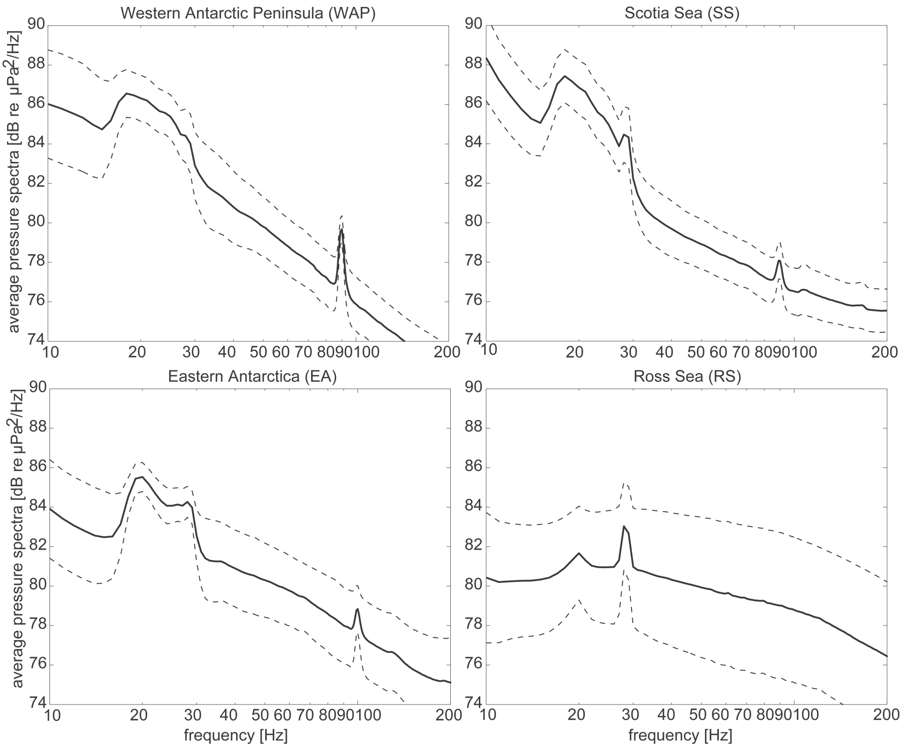

Figure 2. Average pressure spectrum levels (solid line, 1 Hz resolution) with standard deviations (broken lines) at all four sites during 30 d of peak calling periods: the Western Antarctic Peninsula (WAP) from 1 to 30 April 2003; the Scotia Sea (SS) from 1 to 30 March 2003; Eastern Antarctica (EA) from 1 to 30 April 2003; the Ross Sea (RS) from 3 March to 13 April 2004, with days of high shipping noise omitted.

8 d, respectively (Fig. 4). The peak in the number of detected blue whale calls at the RS and the SS sites occurred in February and March, while at the WAP and the EA sites it occurred in late April and early May. The maximum number of call detections at the EA site, however, occurred in November. Sites in the WAP and EA had data from a full year and blue whale calls were detected throughout the year, including the winter months, albeit in small numbers. A low level of acoustic power indicative of blue whale calls was detected also at the EA and the RS sites during the winter.

The highest numbers of fin whale calls were detected at the SS site (just over 12,000 call detections in 8 d), no fin whale calls were detected at the RS site, and the WAP and the EA sites had maxima of about 300 and 6 call detections in 8 d, respectively (Fig. 5). Some fin whale calls were detected at the WAP site as late as July, but fin whale calls were mostly detected from February through late May. No fin whale calls were detected at the WAP or the EA sites from mid-July through February. The number of individual fin whale call detections at the EA site was low, but there was a persistent "band" of calls visible in spectrograms (see Fig. 3b), which explains the relatively high average power at both blue and fin whale frequencies (28 and 99 Hz, respectively) from February until July 2003. However, this band of

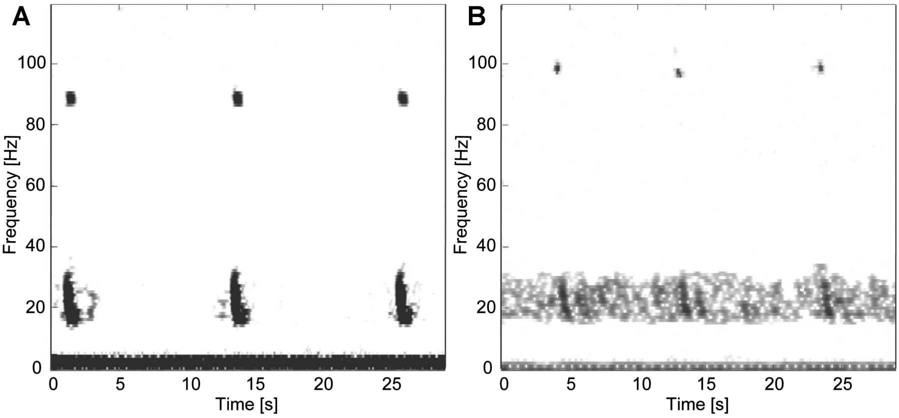

Figure 3. Fin whale call spectrograms characteristic of (A) the Western Antarctic Peninsula and the Scotia Sea, and (B) Eastern Antarctica (500-point FFT, 90% overlap, Hanning window). In (B) note the "noise" in the 15–28 Hz band from weak fin whale calls.

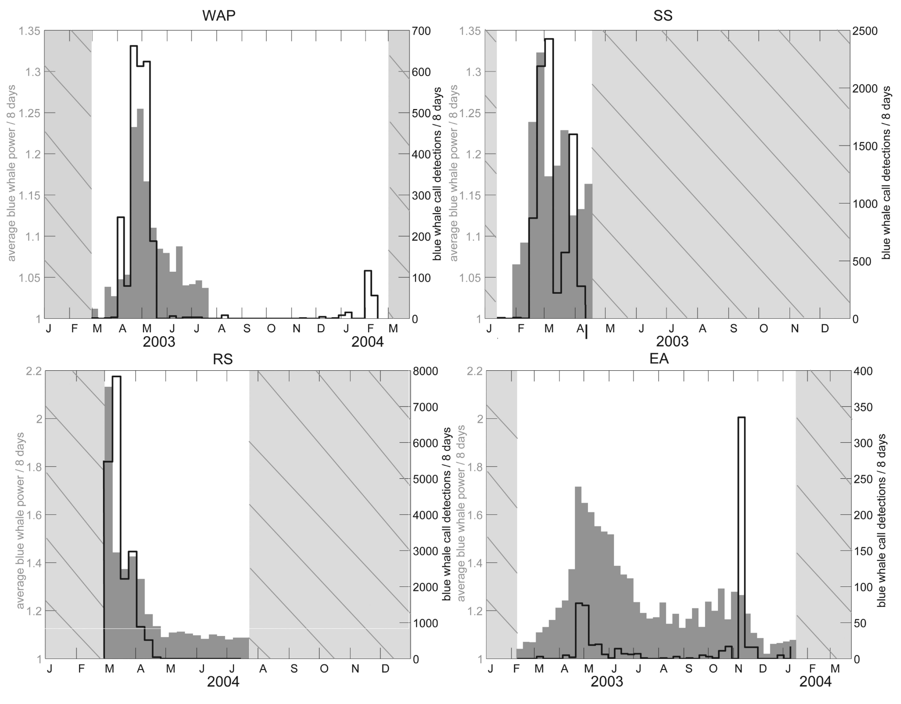

Figure 4. Blue whale call automatic detections (black line) and acoustic power (gray, shaded bar) at all sites. Gray, crosshatched rectangles represent periods during which there were no acoustic data. Note that scales for acoustic power at the WAP and the SS are the same, while the RS and EA are the same. Automatic detection scales are different at all sites.

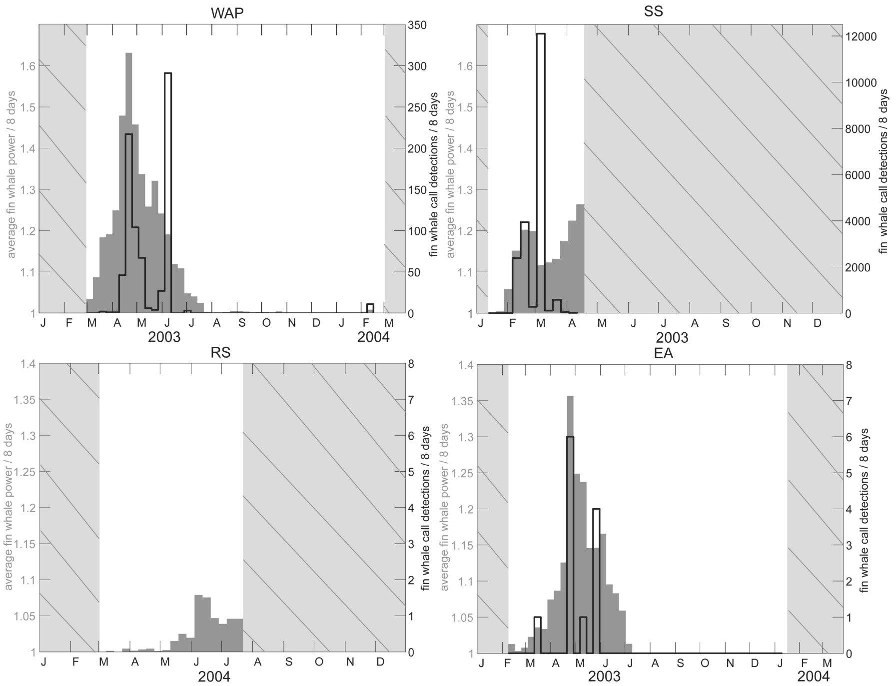

Figure 5. Fin whale call automatic detections (black line) and acoustic power (gray, shaded bar) at all sites. Gray, crosshatched rectangles represent periods during which there were no acoustic data. Note that scale for acoustic power is the same at the WAP and the SS, while the RS and EA are the same. Automatic detection scales are the same for the RS and EA, and different at other two sites. Also note that there were no fin whale detections at the RS site, and the increase in fin whale acoustic power in June and July was most likely from leopard seal calls.

presumably distant fin whale calls decreased the signal-to-noise ratio, resulting in fewer individual automatically detected calls.

The ARP deployed at the WAP site was on the same location as S1 from Širović *et al.* (2004) and it provides the longest time series of blue and fin whale call detections at one location in the Southern Ocean to date (April 2001 to February 2004). The number of blue whale call detections peaked at this site in February 2002, but the overall number of call detections during this study (February 2003 to March 2004) was similar to the number of detections at that location during the same time period in 2001/2002 (Širović *et al.* 2004). Blue whale calls were detected in the winter months (June–September) of 2001 and 2003, but no blue whale calls were detected at the site during the winter of 2002. Fewer fin whale calls were detected during the 2003/2004 deployment season than in the earlier two deployment seasons, but they exhibited the same seasonal characteristics over the three seasons.

Acoustic power results showed generally similar patterns of seasonal variation as the automatic call detection method and these methods have been shown to produce results that are not significantly different (Širović *et al.* 2004). The acoustic power indicative of blue whale calls was the highest at the RS site, indicating calls were produced very close to the instrument, by more whales, or a combination of these factors. This was also the area with the highest number of detected blue whale calls, but the timing of the highest acoustic power and call detections were offset by a week. The WAP site in April 2003 appeared to be the closest to the location of calling fin whales, or had the highest number of fin whales calling.

Discussion

The year-round presence of blue whales was evident at sites farther north (the WAP and EA), but there were no blue whales calls at the RS site after April. This year-round presence counters the traditional migration hypothesis that blue whales should be at lower latitudes during austral winter (Brown 1954). Even though call detections decrease during the winter, and there is evidence of Antarctic-type blue whale calls at lower latitudes during July (Stafford *et al.* 2004), our data suggest some animals remain at high latitudes year-round. It is possible that blue whales move north with the forming ice and some remain close to the ice edge during the austral winter. This is supported by calls detected at the WAP site during the winter with lower ice coverage (Širović *et al.* 2004). Alternatively, the migration could be staggered through the year. Seasonal presence of fin whale call detections and their start in February indicate that fin whales probably leave the Southern Ocean during the winter months, which is consistent with the January onset of a high proportion of fin whale catches in the whaling records (Mackintosh 1965).

The highest numbers of blue whale calls were detected during February–May and in November, suggesting these calls could be produced by blue whales primarily while they are arriving or departing the area. A lack of call detections in December and January, during the reported blue whale peak presence in the Antarctic (Mackintosh 1966) could imply that this long duration call is associated with a particular behavioral state and is produced while swimming, rather than milling or feeding, as has been shown for the long-duration blue whale calls produced by males in the eastern North Pacific (McDonald *et al.* 2001, Oleson *et al.* 2007).

Blue whales make the same type of call throughout the Southern Ocean and it has been suggested they are a part of the same population (McDonald *et al.* 2006*a*). On the other hand, the differences in fin whale calls could be indicators of separate populations (Hatch and Clark 2004). Results from tagging studies, showing little longitudinal movement of fin whales around the continent among the years (Brown 1954, 1962*a*, *b*), support a possibility of distinct populations.

Pressure spectrum level analysis of calls indicated that the pressure is not always equally distributed throughout the frequency range at which the call is occurring. Blue whale long duration calls, for example, had the highest pressure levels at 28 Hz, and in the short duration calls the highest pressure was distributed more broadband, roughly between 60 and 80 Hz. Secondary peaks in the pressure level of fin whale calls changed between regions and were at 89 Hz at the WAP and the SS sites, but at 99 Hz at the EA site. Pressure spectrum level, therefore, could be an additional measure for finding differences in calls between populations.

The differences in call detections between the sites indicate possible regional differences in the use of the Southern Ocean by these two species. The RS site was the farthest south and it had the highest blue whale call detections, but no detected fin whale calls. On the other hand, the farthest north site in the SS had the highest number of fin whale calls detections. This is consistent with the knowledge that blue whales prefer the ice edge, while fin whales are generally found farther north (Mackintosh and Wheeler 1929, Mackintosh 1966). All the deployment sites were positioned in deep water (>1,300 m), but close to the continental shelf break. Relative differences in the numbers of calls between the sites indicate that continental shelf break is not a feature directly influencing the distribution of calling blue and fin whales. Instrument locations varied relative to the three major oceanographic fronts: the polar front (PF), the southern Antarctic Circumpolar Current (ACC) front (sACCf), and the southern boundary of the ACC (Orsi *et al.* 1995). Tynan (1998) suggested that the southern boundary was a prime location for blue, fin, and humpback whales. Our data suggest, however, that prime blue whale habitat for calling (the RS site) is south of the southern boundary. Fin whale call detections, on the other hand, were high at sites located between the sACCf and the SB (the SS and the WAP). Unfortunately, all the data were not collected concurrently and some differences between sites could be due to interannual variations, as well.

Both blue and fin whale calls can propagate over long distances in the Southern Ocean (Širović *et al.* 2007) and while some sites probably recorded local blue and fin whale calls (*e.g.*, the RS and the WAP), others recorded calls likely coming from distant whales (*e.g.*, fin whale calls at the EA site). At the EA site, the acoustic power peak in the April–May period was partly due to "noise" from the 15–28 Hz fin whale calls that could have been distant. But some of that peak power came also from blue whale calls.

Even though acoustic power has the potential to provide information on the distribution of calling animals, additional analyses may be required to resolve ambivalences that arise from the acoustic power analysis when calls of interest are of similar frequency ranges. The increase in the acoustic power indicative of fin whale calls at the RS site in June and July, for example, was not caused by fin whale calls. Spectrogram visual investigation showed that it was a result of pulsing calls likely produced by seals (Rogers *et al.* 1995). However, in our case, the acoustic power analysis allowed us to avoid the ambiguity that any measurements at lower frequencies would have caused because of the frequency overlap of blue and fin whale calls.

The overall noise levels at the RS site were different than at the other three locations, with lower noise below 40 Hz and higher above 80 Hz. Some of the difference in the number of blue whale detection numbers at the RS site, therefore, could be the result of this lower noise. The noise differences could have arisen from different environmental conditions. The ARP in the RS was placed in a lee of the ACC, so it could have lower noise due to long swells. As the farthest south location, it also has the most transient noise from sea ice (frequencies around 100 Hz and above), and reduced levels of long-term low frequency noise due to the ice cover. The noise levels around Antarctica were about 3 dB lower than off California in the band below 100 Hz, while they were about 6 dB higher around 200 Hz (McDonald *et al.* 2006*b*). These differences can be explained by the lack of shipping (noise below 150 Hz) in the Southern Ocean, and the increased storm and sea ice activity (contributing to noise at frequencies around 100 Hz and above). Baleen whales appear to be a major contributor to noise in the 15–30 Hz band in both regions, adding between 3 and 5 dB to the ambient noise.

Our results show year-round presence of calling blue whales with the highest level of blue whale call detections during February–May and in November. This indicated that calling might be occurring during the migration, but also that the whole population may not undergo the migration synchronously. Fin whales call during late summer and in the fall in the Southern Ocean. The differences in fin whale calls between areas suggest at least two distinct fin whale populations around the Antarctic continent. Even though the detection of whale calls is a clear indicator of whale presence, the absence of calls can mean either that there are no whales, or that the whales are not calling. Differences in call characteristics between regions, however, may indicate separate populations. Given the relative paucity of baleen whale sighting data from the Southern Ocean during the non-summer months, acoustics are a good tool to learn more about the seasonal and interannual movements, as well as a way to explore possible population differences of baleen whales in this remote area.

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