Geographic Variation in Southern Ocean Fin Whale Song

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ABSTRACT

This short paper describes 3 consistent regional differences in fin whale vocalizations recorded in the Southern Ocean. Long term recordings were analysed from locations in eastern and western Australia, and locations south of these in the Antarctic. Preliminary analysis indicates fin whale '20Hz pulses" off Tasmania and south to the Antarctic continent (at ~145°E) had 2 distinctive higher frequency components with peaks at ~82 and ~94Hz, while those off Western Australia and Antarctica (at ~75-80°E) had a single distinct higher frequency component with a peak near ~99Hz. This contrasts with the fin whale '20Hz pulses' recorded off the West Antarctic Peninsula which have previously been described as having higher frequency energy near 88Hz. The distinct and consistent differences between fin whale song in the three regions illustrate the potential value in using acoustic means of assessing stock or population structuring within fin whales.

INTRODUCTION

Acoustic methods are increasingly being recognized as a technique to help in the assessment of marine mammal population structure. For humpback, blue and fin whales, where only males are believed to sing (Croll *et al.,* 2002, Tyack and Clark, 2000; Oleson *et al.,*2007), song almost certainly plays a reproductive role. Differences in songs between regions are therefore likely to be useful in the assessment of common breeding stocks. Mcdonald *et al.* (2006) identified 9 different regional blue whale song types and proposed using geographic variation in song to characterize worldwide blue whale population structure. More recently, the regional differences in the characteristic fin whale '20Hz pulse' song in the North Atlantic and North Pacific Oceans have been used to assist in stock structure and population demographic analyses relevant to management (Hatch and Clark, 2004; Delarue *et al*., 2009). In fact, in the absence of other data, Mellinger and Barlow (2003) proposed using regional differences in vocalizations to establish a null hypothesis for population structure, rather than assuming thorough mixing when making management decisions.

In the Southern Ocean, regional differences have only previously been described between fin whale 20Hz pulses off the West Antarctic Peninsula, and those off eastern Antarctica (Gedamke *et al.*, 2006; Gedamke *et al*., 2007; Širovic *et al*., 2008; Gedamke and Robinson, in press). While the low frequency portion of the call similarly sweeps from ~30-15 Hz, there was occasionally an identifiable higher frequency component. In the West Antarctic Peninsula region, this centers at approximately 89Hz, while in eastern Antarctica, it appears centered at 99Hz. Here the geographic range of the eastern Antarctic call type is further described. In addition, a new acoustically and geographically distinct song type from fin whales recorded in the waters south of Tasmania is described.

METHODS

Fin whale song was examined in long term recordings of underwater sound obtained from six different locations in the waters off southern Australia and the Antarctic (figure 1). In addition, recordings from a 2006 sonobouy survey in the waters of eastern Antarctica (30°-80°E) were also examined for fin whale sounds in an effort to expand the known geographic range of described song types.

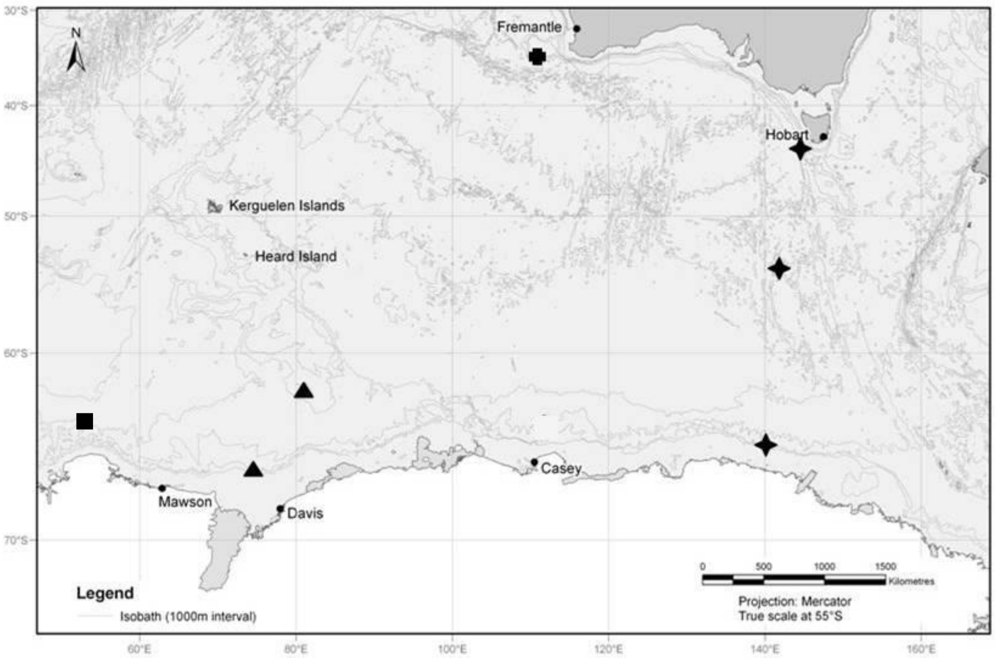

Figure 1— Locations of where acoustic records were obtained from [Circle-CTBTO hydroacoustic array, triangles-ARPs, diamonds-CU loggers, square-BrokeWest sonobuoy survey]. All sites except for the CU loggers south of Tasmania (diamonds) recorded the previously described fin whale song with higher frequency energy at 99Hz, while the new call type described here was recorded at the CU logger sites.

<u>The recording dates, locations, and instrument types utilized in this study are as follows:</u>

1) Comprehensive Test Ban Treaty Organization (CTBTO) nuclear test monitoring station: Recordings were obtained from the CTBTO which operates a hydroacoustic monitoring array approximately 114km SW of Cape Leeuwin, off the south-west coast of Australia (34.4° S, 115.1° E). The 3 hydrophones in this array are suspended in the SOFAR channel (~1050m depth) and acoustic sampling is conducted at 250Hz, with an effective bandwidth of up to 100+Hz. The data from a single hydrophone channel (#1) between January 2004 and April 2007 was analyzed.

2) Autonomous acoustic recording packages (ARPs): ARPs (Wiggins, 2003) sit on the sea floor and passively record acoustic signals for a continuous period of a year or more sampling at 500Hz with an effective bandwidth of up to 250Hz. On January 31 2005, an ARP was deployed in 1800m of water on the southern edge of the Kerguelen plateau (62.6°S, 81.3°E). On February 7, 2005 a second ARP was deployed approximately 500km to the southwest on the edge of the continental shelf off Prydz Bay (66.2°S, 74.5°E) in 2700m of water. The two ARPs were recovered and new instruments were redeployed in approximately the same locations on February 25, 2006, and February 21, 2006 respectively. The ARPs were finally recovered on March 5 and 7 2007, respectively, providing continuous recordings from these two locations for over 2 years.

3) Curtin University acoustic loggers (CU loggers): Custom acoustic loggers were developed at Curtin University (similar to those described in McCauley *et al.*, 2000) in conjunction with the Australian Antarctic Division. Due to a higher sampling rate of 4kHz (effective bandwidth 2kHz), a sampling schedule was set up to record 13 minutes every hour for the full deployment of up to more than a year. Three CU loggers were deployed roughly along a line of longitude in the waters between Tasmania and the Antarctic continent (figure 1). The central logger was deployed from December 18, 2005 through October 5, 2006 on an in-place oceanographic mooring (CSIRO's SAZ mooring at 53.7° S, 141.8° E) at a depth of approximately 1500m. The other two of the CU loggers were deployed as part of autonomous mooring packages that sat on the seafloor. One was deployed on January 21, 2006 through January 25, 2007 off the edge of the Antarctic continental shelf near Dumont D'Urville (65.6° S, 140.5°E) in a water depth of approximately 1100m. The last instrument was deployed from March 11, 2006 to January 18, 2007 on a seamount to the south-west of Tasmania (44.0°S, 144.7°E) in 1866m of water.

Loggers were redeployed in approximately these same three locations during the 2007/8 season. Unfortunately only the central instrument of the array (deployed December 29, 2007 at 53° 44.4' S, 141° 46.1' E) was recovered on February 27, 2009 providing a 2nd year of data at this site.

4) Brokewest sonobuoy survey: From January-March 2006, a systematic sonobuoy survey was conducted in the waters of eastern Antarctica (30°-80°E). One hundred forty five sonobuoys were deployed and monitored for approximately 1 hour across the study region. Gedamke and Robinson (in press) describe the methodology and results in detail. For comparative purposes here, the recordings with fin whale 20Hz pulse detections were examined for the presence of a higher frequency component. The location illustrated in figure 1 (63.5°S, 53.6°E) was the western-most location where a higher frequency component was detected.

Power Spectral Density (PSD) Analysis

PSD analysis was the primary form of analysis conducted on this data. Initially, for each of the long term recordings (i.e. excluding the Brokewest sonobuoy data), the power spectral density averaged over 15 minute segments in the case of the CTBTO and ARP data, and 13 minute segments (limited by the sampling regime) for the CU loggers were calculated over the entire dataset from each acoustic record. The "Pwelch" function in Matlab 7.1 [www.mathworks.com]) was run with the following parameters: FFT sizes of 250, 500, and 4000 samples for the CTBTO data , ARPs, and CU loggers, respectively, leading to 1Hz frequency bins; 50% overlap; and a Hamming window.

Spectrograms of complete datasets were drawn from the PSD analysis illustrating multi-year trends in ocean noise, and seasonal bands of acoustic energy from singing whales that clearly rise above background noise. Particularly intense segments of these acoustic bands were closely examined to determine the sound source. PSD values in 1Hz bands were also averaged over seasons when calling bands were present to more precisely determine frequency content.

RESULTS

When the year long PSD analyses are examined from the various locations, there is a clear difference between the recordings from locations at or west of 115°E, which sit in the Indian Ocean or directly south it in the Southern Ocean, and those recordings made along 140°E longitude or slightly further east, between Tasmania and Antarctica.

'Western' Locations

For the western sites, most of the recordings exhibited a seasonally present, relatively strong band of energy at approximately 99Hz. Figure 2 illustrates this for a 3 year record from the CTBTO data off the west coast of Australia, and from 2 years of an ARP recording from the southern Kerguelen Plateau.

A)

B)

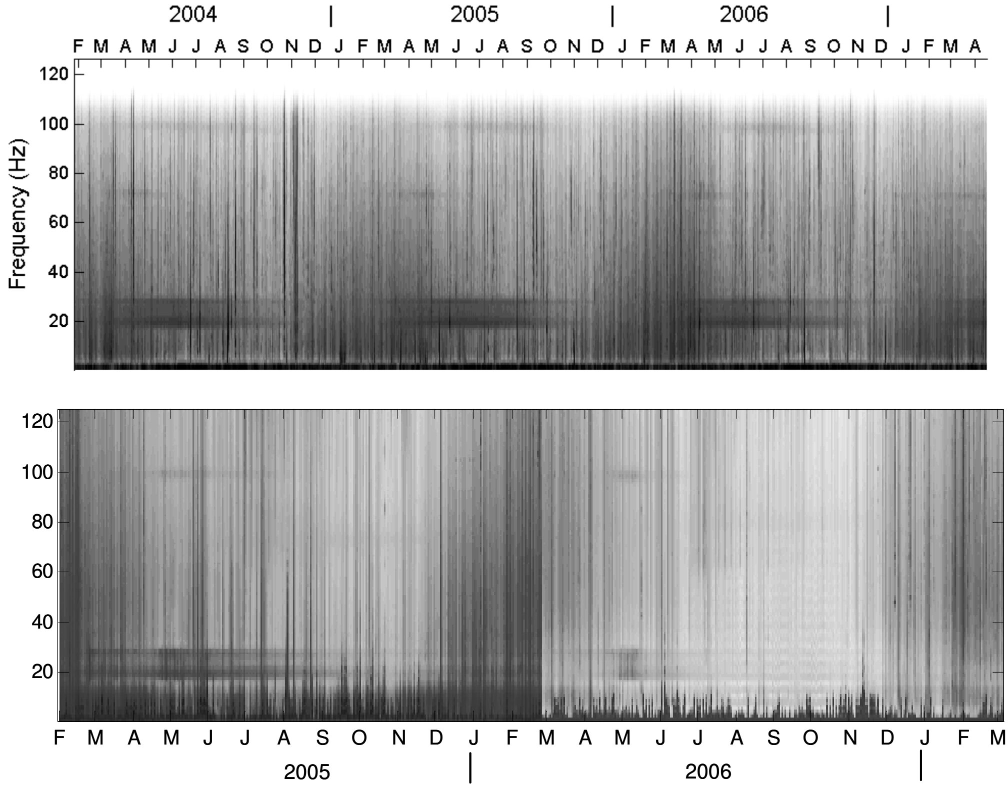

Figure 2: A) 3 year spectrogram from the CTBTO data off the Western Australia coast. B) 2 year spectrogram from the southern end of the Kerguelen Plateau. In both A and B, in addition to the fin whale 99Hz energy band, there is also energy present between ~20-30Hz due to both Antarctic blue whale song, and the lower frequency portion of fin whale 20Hz pulses. In the upper spectrogram, energy at approximately 71Hz is present from pygmy blue whales.

To verify the source of this band of energy, the PSD data was scanned for 15 minute segments that had a particularly high ratio of energy in this 99Hz band compared to surrounding bands. These particular segments were then examined more closely and demonstrated fin whale 20Hz pulses with high frequency energy around 99Hz (figure 3).

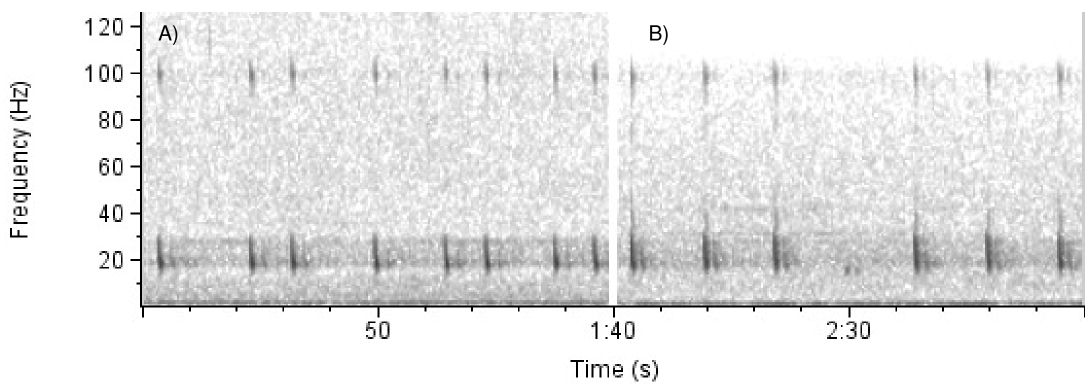

Figure 3: Spectrograms of fin whale 20Hz pulses with high frequency energy apparent near 99Hz. A)Southern Kerguelen Plateau ARP recording (sampling rate 500Hz, fft size 512 samples, 50% overlap, Hanning window). B) CTBTO recording (sampling rate 250Hz, fft size 256 samples, 50% overlap, Hanning window)

As a simple means of more accurately measuring the seasonal fin whale song frequency peaks that occur, the PSD data was averaged across all 15 minute segments during the seasonal acoustic presence of fin whales (figure 4). The distinct peak at 99Hz can easily be seen in both of these spectrums from off the west coast of Australia, and on the Kerguelen Plateau in the Southern Ocean. While the Prydz bay data is not illustrated here, it displayed a similar spectral peak at 99Hz. A long term dataset collected nearby (66.7°S, 69.8°E) in 2003 also contained this spectral peak at 99Hz (Širovic *et al*, 2008).

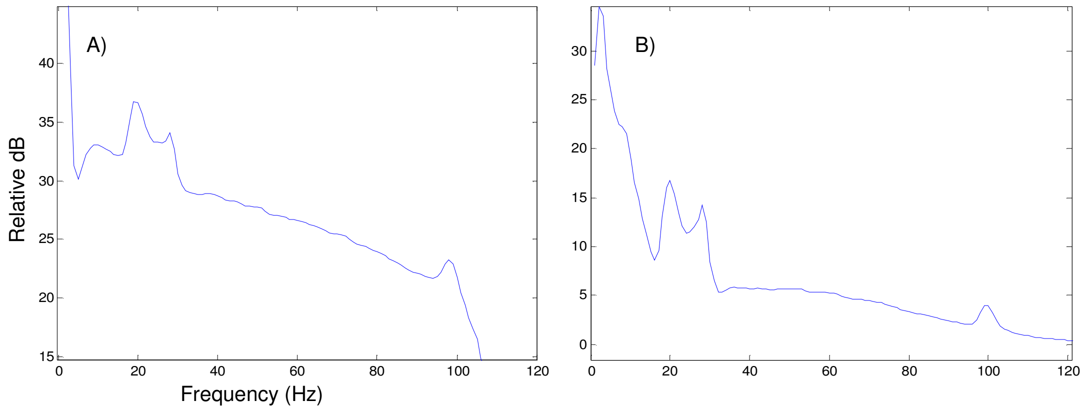

Figure 4: Average PSD values from the A) CTBTO data May-August 2006. B) Kerguelen Plateau ARP mid May-mid June 2005. Note that the y-axis is a relative measure of dB so the values within each dataset are accurate relative to other values in the same dataset, but these are not absolute calibrated dB levels.

Finally, during the BrokeWest sonobuoy survey, fin whale 20Hz pulses were detected at 9 sites. One of these recordings contained intense fin whale calls with associated higher frequency energy at ~99Hz (Gedamke and Robinson, in press). This one recording would represent the furthest west (figure 1) that this particular fin whale song type has been recorded.

<u>'Eastern' Locations</u>

For the 3 eastern sites, located generally south of Tasmania to the Antarctic continent (figure 1), a prior analysis noted that the 99Hz band was not readily apparent (Gedamke *et al.*, 2007) as in the recordings from further west. Upon closer inspection, however, the recordings did exhibit unidentified seasonally present bands of energy at both ~82 and ~94Hz. These bands of energy were most apparent in the central recording site near 54°S (figure 5), were fainter in the southernmost site near the Antarctic continent, and were barely perceptible in the site closest to Tasmania. At each of the 3 sites, however, individual fin whale singers were found producing 20Hz pulses with the dual upper frequency components (Figure 6).

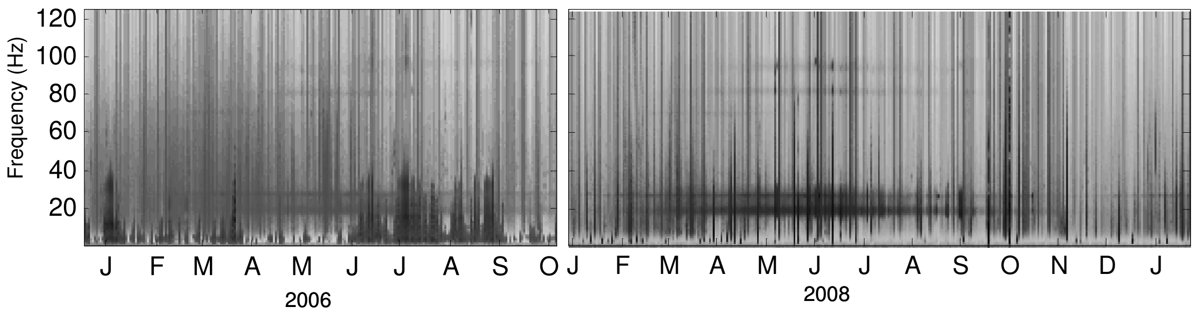

Figure 5: Spectrogram for ~2 non-continuous years of data from the central logger between Tasmania and Antarctica (~54°S).

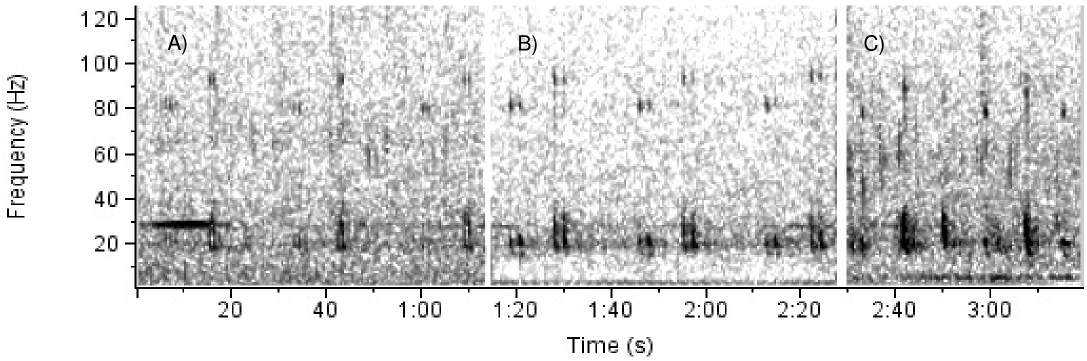

Figure 6: Spectrogram from each of the easternmost loggers showing the dual upper frequencies associated with the 20Hz pulses in this region. A) Logger nearest Tasmania (~44.0°S). B) Central logger (~54.7°S). C) Logger near Dumont d'Urville (~65.6°S). [sampling rate 4kHz, fft size 4096 samples, 50% overlap, hanning window]

Finally, averages of the PSD data over the seasons when these energy bands were most predominant illustrate the dual peaks from the 20Hz pulse higher frequency components (figure 7). The 94Hz peak is noticeably smaller in the Dumont d'Urville data. This same type of analysis showed nearly imperceptible upper frequency peaks in the Tasmanian logger data suggesting a lower acoustic presence of this fin whale song type.

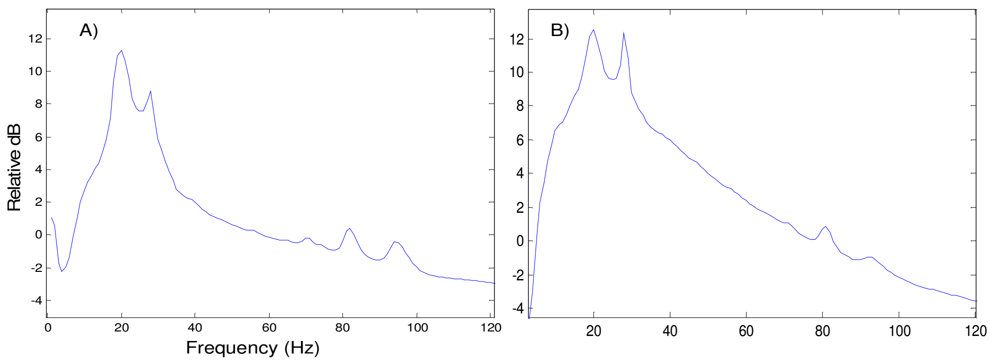

Figure 7: Spectral average of acoustic power vs. frequency from the A) Central logger (~54.7°S) from February-July 2008. B) Logger near Dumont d'Urville (~65.5°S) from April-May 2006 with less prominent spectral peaks. Note that the y-axis is a relative measure of dB so the values within each dataset are accurate relative to other values in the same dataset, but these are not absolute calibrated dB levels.

DISCUSSION

The distinctive characteristics differentiating eastern Antarctic fin whale song, with a 20Hz pulse higher frequency component near 99Hz, from fin whale song near the Western Antarctic Peninsula, with a higher frequency component near 89 Hz has been previously noted (Gedamke *et al.* 2006; Širovic *et al.* 2008; Gedamke and Robinson, in press). Here, we describe a new song type produced by Southern Ocean fin whales in the region south of Tasmania. This third regional song type has dual higher frequency components near 82 and 94Hz, differentiating it from the previously described fin whale song of other regions.

The long term nature of the recordings with distinct, stable, seasonally present bands of energy over multiple years indicates that these are not simply individual variations that might occur between singing whales. Rather, there are clearly unique characteristics of the songs specific to the different regions. Since whales of the genus Balaenoptera have relatively simple and stable song types that vary little over time, as opposed to the ever changing and complex song of the humpback whale, it does appear that the consistency of these relatively subtle differences is suggestive of some degree of regional population structuring. Mcdonald *et al.* (2006) recently described distinct differences in song types between blue whales from different regions, and suggested that song may be another characteristic to use with genetic and morphological data in defining blue whale populations. Similar suggestions have been made with fin whale song in the North Atlantic and North Pacific (Hatch and Clark, 2004; Delarue *et al*., 2009). Here, I suggest that these differences in fin whale song types may also be useful in defining distinct stocks or population structuring within fin whales in the Southern Ocean.

Based on the acoustic data presented here, figure 8 represents a preliminary attempt to delineate these regions of apparent acoustic structuring. These acoustic regions could be consistent with fin whales in the Indian Ocean producing one song type, in the western Pacific Ocean producing another, and finally from the eastern Pacific, or Atlantic Ocean producing the third. Additional recordings from a wider geographic range are needed to address this possibility, as well as determine whether additional song types are present in the large data poor regions between recording sites (figure 8).

Clearly any suggestion that these regions represent different breeding stocks of whales needs further investigation. Since evidence is increasingly strong, however, that baleen whale song is associated with reproduction, being produced by males in at least humpback, blue, and fin whales (Croll *et al.,* 2002; Tyack and Clark, 2000; Oleson *et al.,*2007) stable and distinct regional differences in songs are likely to be useful for the assessment of common breeding stocks. As suggested by Mellinger and Barlow (2003), in the absence of evidence to the contrary, the distinct and stable differences in song characteristics shown here may be a useful starting point in delineating breeding stocks of southern hemisphere fin whales.

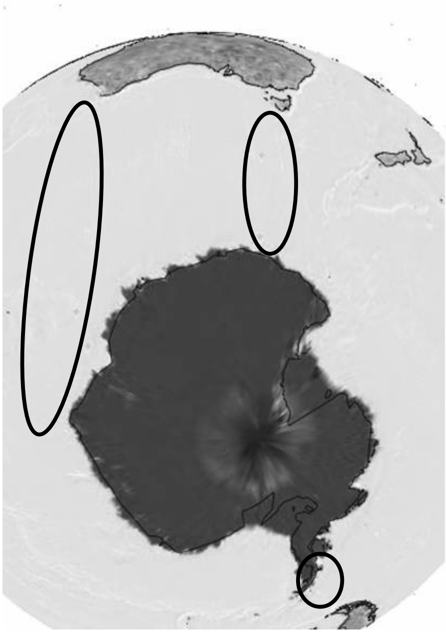

Figure 8: Regions with distinct differences in fin whale song.

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