Blue whale songs recorded around South Island, New Zealand

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ABSTRACT

Previous underwater sound recordings made in New Zealand have identified a complex sequence of low frequency sounds (Kibblewhite *et al* 1967) that have been attributed to blue whales based on similarity to blue whale songs in other areas (McDonald *et al* 2006). These sounds contain a consistent series of pulsed and tonal elements that are repeated at regular intervals. We present here analyses of additional recordings of sounds with these characteristics which were recorded opportunistically during the Southern Ocean Research Partnership's recent Antarctic Blue Whale Voyage. Low frequency calls attributed to blue whales were detected all around the South Island of New Zealand during the voyage transits from Nelson, New Zealand to the Antarctic and return. Following acoustic bearings from directional sonobuoys, we visually detected blue whales and confirmed they were the source of these sounds. Blue whales were encountered in coastal waters off Greymouth on the west coast and southeast of Stewart Island, off Oamaru and Kaikoura on the east coast. Acoustic detections (with no visual confirmation) also indicated the presence of whales east of Cook Strait. These recordings, together with the historical recordings made northeast of New Zealand (Kibblewhite *et al* 1967, and McDonald *et al* 2006) suggest song types that 1) persist over several decades, 2) remain distinct from the Antarctic blue whales, and 3) are indicative of the year-round presence of a population of blue whales that inhabits the waters around New Zealand. Measurements of the four-part songs, consisting of both pulsed and tonal units, reveal sounds broadly similar to those previously recorded east of Great Barrier Island, New Zealand. However, current calls are characterised by longer durations, lower frequencies and lower pulse rates than recordings from 1997 and 1964. These measurements suggest that blue whale song in this region has changed slowly, but consistently over the past 50 years. The most intense units of these calls were detected as far south as 52°S, which represents a considerable range extension compared to the limited prior data on the spatial distribution of this population.

KEYWORDS: BLUE WHALE, VOCALIZATIONS, BIOACOUSTICS, WHALE SOUND, NEW ZEALAND

INTRODUCTION

Blue whales (*Balaenoptera musculus*) produce a variety of low-frequency sounds (Cummings and Thompson 1971; Rivers 1997; Ljungblad *et al* 1998; Stafford *et al* 1999; Rankin *et al* 2005) including complex, repeated series of tonal and pulsed units that together have been called songs (McDonald *et al* 2006). While there is some variation in the literature, we refer to the stereotypical pattern of pulsed and tonal sound units as a "call" and the repeated pattern of these calls as "song".

Blue whale calls are among the lowest frequency (typically less than 100 Hz) and most powerful sounds made by any animal. Širovic *et al* (2007) measured a mean source level of 189 dB re: 1 µPa rms @ 1 m for Antarctic blue whale calls. Globally, at least ten distinct blue whale songs have been identified that show distinct geographic patterns with overlapping call types in some areas (McDonald *et al* 2006). At least three additional song types have been identified since that study (Pangerc 2010; Cerchio *et al* 2010; Frank and Ferris 2011) and some of these recognized song types may be divided even further when more data becomes available.

There is some concordance between the ten recognised call types and the proposed subspecies of blue whale (*B. m. musculus* in the Northern Hemisphere, *B. m. intermedia* – the Antarctic blue whale, *B. m. brevicauda* – the pygmy blue whale, *B. m. indica* in the northern Indian Ocean and Chilean blue whales), however the mapping of call types to subspecies is incomplete (McDonald *et al* 2006; Samaran *et al* 2008). The historical osteological data is much less complete geographically than current genetic data, and analysis of this data has suggested complex phylogenetic relationships of maternal lineages, some of which are shared across putative subspecies (Le Duc *et al* 2007; Sremba *et al* 2012). Presently the sub-species taxonomy of blue whales is currently under review (A. Lang, pers. comm.). Whether variation in blue whale song types correlates with variation in genetics is a relatively open question, nevertheless investigation of call properties has been informative in understanding population structure in other large baleen whales including fin (Hatch and Clark 2004; Castellote *et al* 2010) and humpback whales (Cerchio *et al* 2001).

Kibblewhite *et al* (1967) analysed low-frequency sounds that were recorded in 1964 from recorders off New Zealand's North Island and speculated that at least one repeated pattern (Figure 1 bottom panel) might be produced by whales. McDonald (2006) attributed that pattern of sounds to blue whales based on their similarity to other blue whale calls, and noted that the same series of sound elements (Figure 1 middle panel) was repeated in recordings made in 1997 in waters off Great Barrier Island, New Zealand. This call has been referred to as the New Zealand blue whale song type (McDonald 2006; McDonald *et al* 2006, 2009). This call consists of no less than four elements, at least three of which were consistently present in 1964 and 1997 (McDonald *et al* 2009). Although the elements have remained recognisable over this time period, their fundamental frequencies have decreased. This decrease is paralleled by similar decreases in frequency for blue whale songs worldwide (McDonald *et al* 2009).

The New Zealand type song has previously been reported off the north of New Zealand's North Island (Figure 2) yet the broader geographic distribution of this call type is not known. Here we present the first recordings of this song type made in the presence of blue whales, and we also present acoustically-derived bearings to these calls that are consistent with sighting locations of blue whales. We describe the distribution of detections of blue whale calls in January, February, and March 2013 around the South Island of New Zealand and along the southern edge of the Tasman Sea. Finally, we compare our recordings to previous recordings of blue whale songs and quantify change over time.

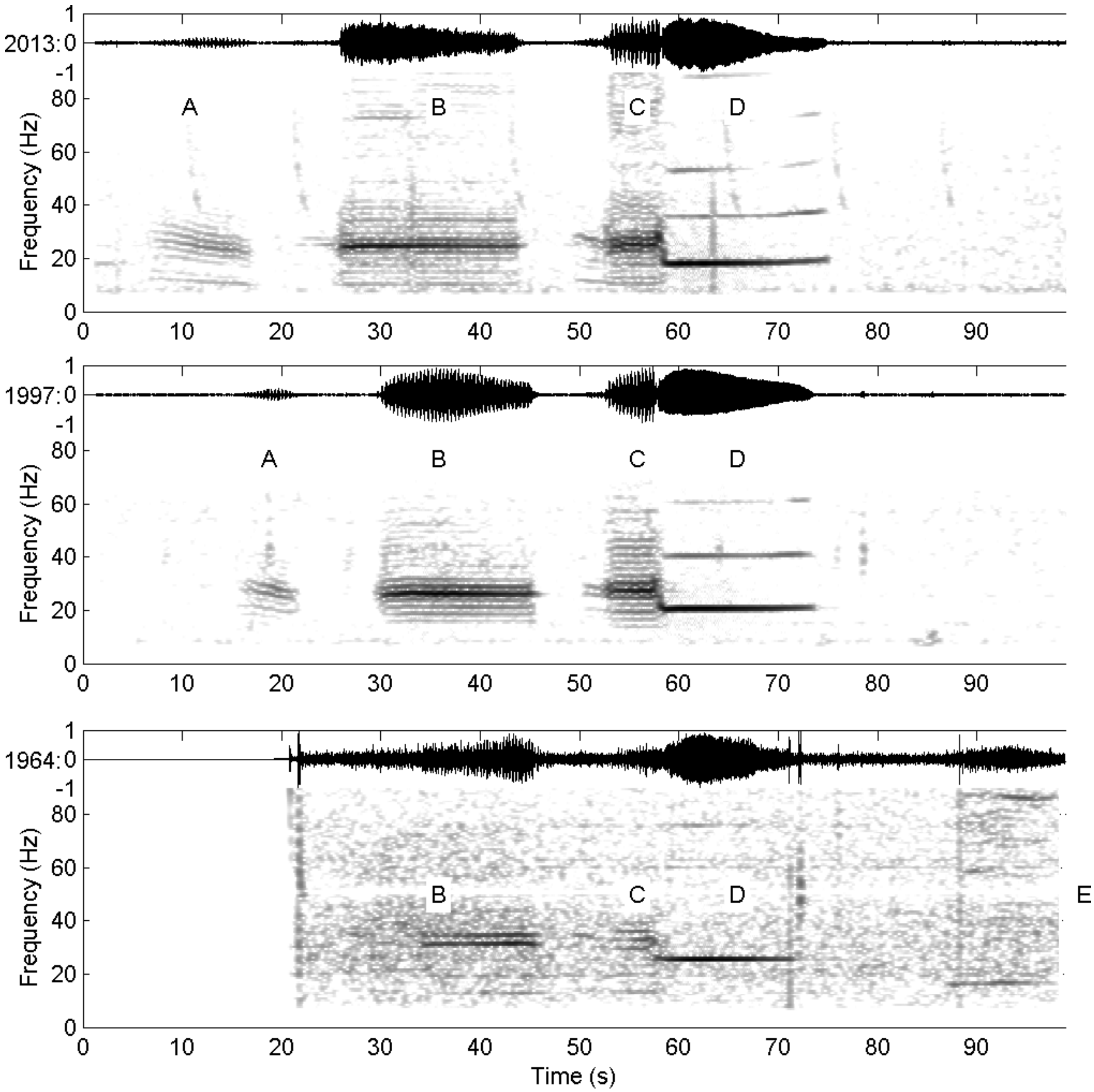

Figure 1 - Pressure waveform and spectrogram of four-unit call produced by New Zealand blue whales in 2013 (top), 1997 (middle) and 1964 (bottom). Spectrogram parameters: 400 Hz sample rate, 512 point FFT with Hamming window, 93.75% overlap. All spectrograms are aligned on the sharp transition between the pulsed and tonal units (C and D) at approximately 60 s. Note: A notch filter at 50 Hz was applied to the recording from 1964 to remove constant tonal noise at that frequency that would otherwise obscure the whale call in the pressure waveform.

METHODS

Visual observations

Blue whales were detected visually on the western coast of the South Island, New Zealand, while the research vessel, *FV Amaltal Explorer*, was on passage to the main study area further south to undertake the Southern Ocean Research Partnership's Antarctic Blue Whale Voyage. Taking advantage of unused 'contingency time' during the return transit, acoustically derived bearings to blue whales were followed yielding further sightings of blue whales on the eastern coast of the South Island. Visual survey was conducted by experienced observers on the open-air flying bridge and in the enclosed bridge; observers on the flying bridge alternated searching with naked eye and binoculars. Distance and angle relative to the ship was measured using binoculars with reticles and angle boards for all visually detected cetaceans. Upon sighting whales, the vessel altered course, closing to confirm species identification and obtain images for photo-identification.

Audio recordings

Audio recordings were made opportunistically during the transit south, and adaptively during the north-bound return transit. Recordings were made using directional (DIFAR) sonobuoys (AN/SSQ 53D, Ultra Electronics Sonar Systems and AN/SSQ 53F, SonobuoyTechSystems). Signals from the hydrophones and sensors were broadcast over VHF radio and received onboard the research vessel via a 21 m-high aerial. The recording chain for all sonobuoy deployments consisted of a WiNRaDiO G39WSBe VHF receiver with the voltage output calibrated as a function of modulation frequency. The raw voltage output of the receiver was connected to the instrument input of an RME Fireface UFX sound board with the gain set to 20 dB (*ie* full scale input voltage of 8.39 V peak-to-peak). The digitised signals from the UFX were saved as 16-bit WAV files with a 48 kHz sample rate using passive acoustic monitoring software PAMGuard (www.pamguard.org, Gillespie *et al* 2008). PAMGuard also generated real-time spectrograms, while RME TotalMix software allowed the incoming audio to be monitored aurally.

Acoustic tracking and targeting

Analysis of the directionality of sound sources followed the methods of Miller (2012) and Miller *et al* (2013). This involved saving audio clips of sound sources (*eg* units of whale calls), and performing a series of signal processing steps on these clips via a suite of Matlab scripts. Signal processing included the 'validation' of the sonobuoy compass and measurement of a compass correction for each sonobuoy as described in Miller *et al* (2013). The final output of the signal processing was a true bearing from the sonobuoy to the sound source of interest.

The bearing to whale calls was plotted on an electronic chart along with the position of the ship and deployment location of the sonobuoy. Groups of bearings that appeared to come from the same direction and had regular repetition rates were *tracked* as a group of whales that were then given a unique designation. On the return transit the ship *targeted* these groups of whales, diverting towards the whales and deploying additional sonobuoys as necessary. *Tracking* and *targeting* were conducted in real-time on the transits while the sightings team maintained visual observations.

In order to present a more accessible summary plot of the directional information from all sonobuoys, kernel smoothing (Wand and Jones 1995) was applied to all the bearings to whale vocalisations per sonobuoy to yield a continuous bearing density function (BDF). Peaks in the BDF that were greater than a threshold value were selected as representative of a target group. The threshold value was computed per sonobuoy as $1/(2\sigma n)$ where σ represents the nominal angular precision of bearings from the sonobuoy, and *n* was the total number of bearings obtained at that sonobuoy. The value of σ was set to 10° for all sonobuoys.

Measurement of calls and comparison with old recordings

Only calls with high signal-to-noise ratio, (SNR), comprising a small portion of the total number of recorded vocalisations, were selected for measurement of acoustic properties. In addition to the recordings from 2013, eight hours of recording from 1997 made by the Center for Monitoring Research (CMR) of Arlington, Virginia (part of the same dataset analysed by McDonald 2006), and five calls recorded in 1964 by Kibblewhite (1967) were analysed using the same methods.

When measuring units of calls, we followed the naming scheme of Cummings and Thompson (1971) where each unit was assigned a letter sequentially, starting with A. Thus, the four-part call was represented as ABCD, which departs slightly from the numeric scheme used by McDonald (2006). As described by McDonald (2006), units A and B were clearly separated by a short silence, which we refer to as the inter-unit interval, while units C and D were differentiated by an abrupt change from a pulsed to a tonal signal. Within high SNR recordings, unit C was often associated with a faint downswept precursor which was also noted by McDonald (2006). This precursor, however, was not included in unit C measurements to enable a more consistent representation of this unit throughout the 2013 recordings and during comparisons with McDonald's (2006) analysis.

Recordings were re-sampled at a sample rate of 1,000 Hz for analysis. The following characteristics were measured: duration, inter-unit interval, inter-call interval, peak-frequency, fundamental frequency, intra-unit change in frequency, pulse repetition rate. Temporal and frequency characteristics were measured from spectrograms (bandwidth 0-60 Hz, 2048 FFT, Hanning window with 90% FFT overlap) using Adobe Audition 1.5 (Adobe Systems Incorporated 2004) and SpectraPLUS 5.0 (Pioneer Hill Software LLC, 2010), respectively. Pulse repetition rates were measured from waveforms displayed in Audacity 2.0.3 (2013).

Within SpectraPLUS 5.0 the average spectrum function was used to measure the peak frequencies of units B, C and D while the start and end frequencies of units A and D were hand-picked from the spectrogram. To facilitate pulse repetition rate measurements within Audacity, a very steep low pass filter (roll off = 48 dB, cut off frequency = 40 Hz) was applied to calls to remove any higher frequency sounds that may mask the waveform of the vocalisation. Furthermore, amplification was applied to the signal in order to re-scale the amplitude of whale vocalisations so they would fit within the amplitude limits of the waveform display panel in Audacity. Pulse rate was measured as the total number of pulses in the envelope of the waveform divided by the duration of the unit. Frequency and pulse repetition rate characteristics were measured for each unit only when the SNR of the entire four-part call was high.

RESULTS

Visual observations

There were 12 sightings of blue whales (totalling at least 18 individuals) around the South Island of New Zealand during this study. Six sightings (11 animals) occurred on the west coast with the five latter sightings comprising a loose aggregation of 10-11 whales. During two of these sightings on the west coast sonobuoys were deployed in the vicinity of blue whales after initial approach. The remaining six sightings (7 animals in three separate locations) occurred on the east coast during the return transit as a result of following bearings to blue whale songs that were detected in real time (see Figure 3).

Acoustic recordings

New Zealand type blue whale calls were recorded on 44 of 61 sonobuoys deployed around the South Island of New Zealand and subantarctic waters south of New Zealand (between 155 to 175°E longitude and 41 to 54°S latitude, Figure 2). From these sonobuoys a total of 130 hours of audio were recorded, with 30% of this audio consisting of simultaneous recordings from two sonobuoys deployed in different locations.

Typically detections comprised only the most intense components of the most intense units, *ie* the 24 Hz component of the units B and C, and/or the 18 Hz component of unit D. Only on recordings from sonobuoys deployed within a few kilometres of whales were all four units consistently detected within each call.

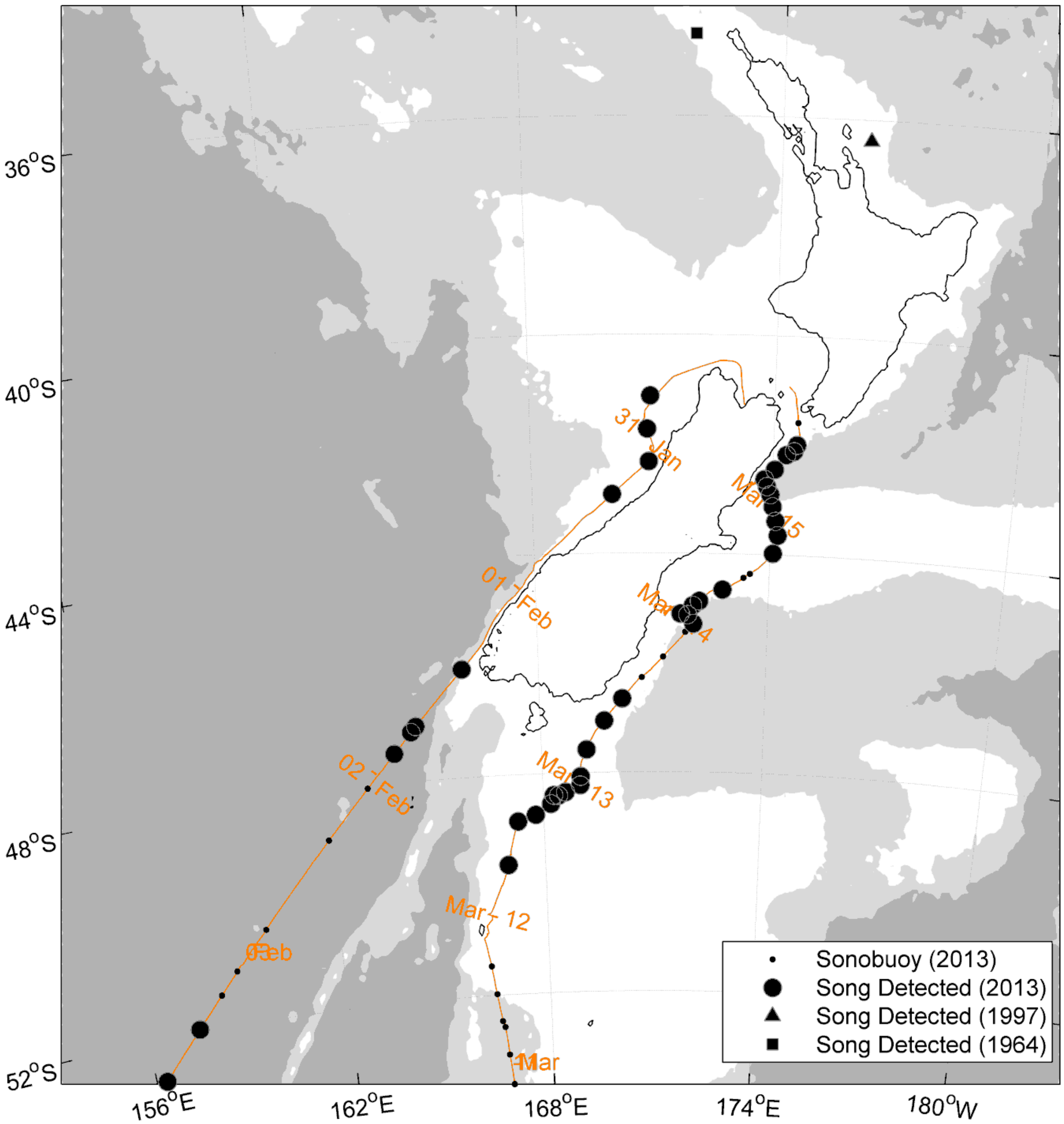

Figure 2 - Geographic distribution of blue whale song described in this study. Dots show the location of sonobuoy deployments from 2013.Circles show the location where calls were detected. The triangle shows the location of recordings made in 1997 (McDonald 2006), and the square shows the approximate location of the calls recorded in 1964 by Kibblewhite (1967). The orange line shows the ships track, and tick marks indicate the start of the day in GMT.

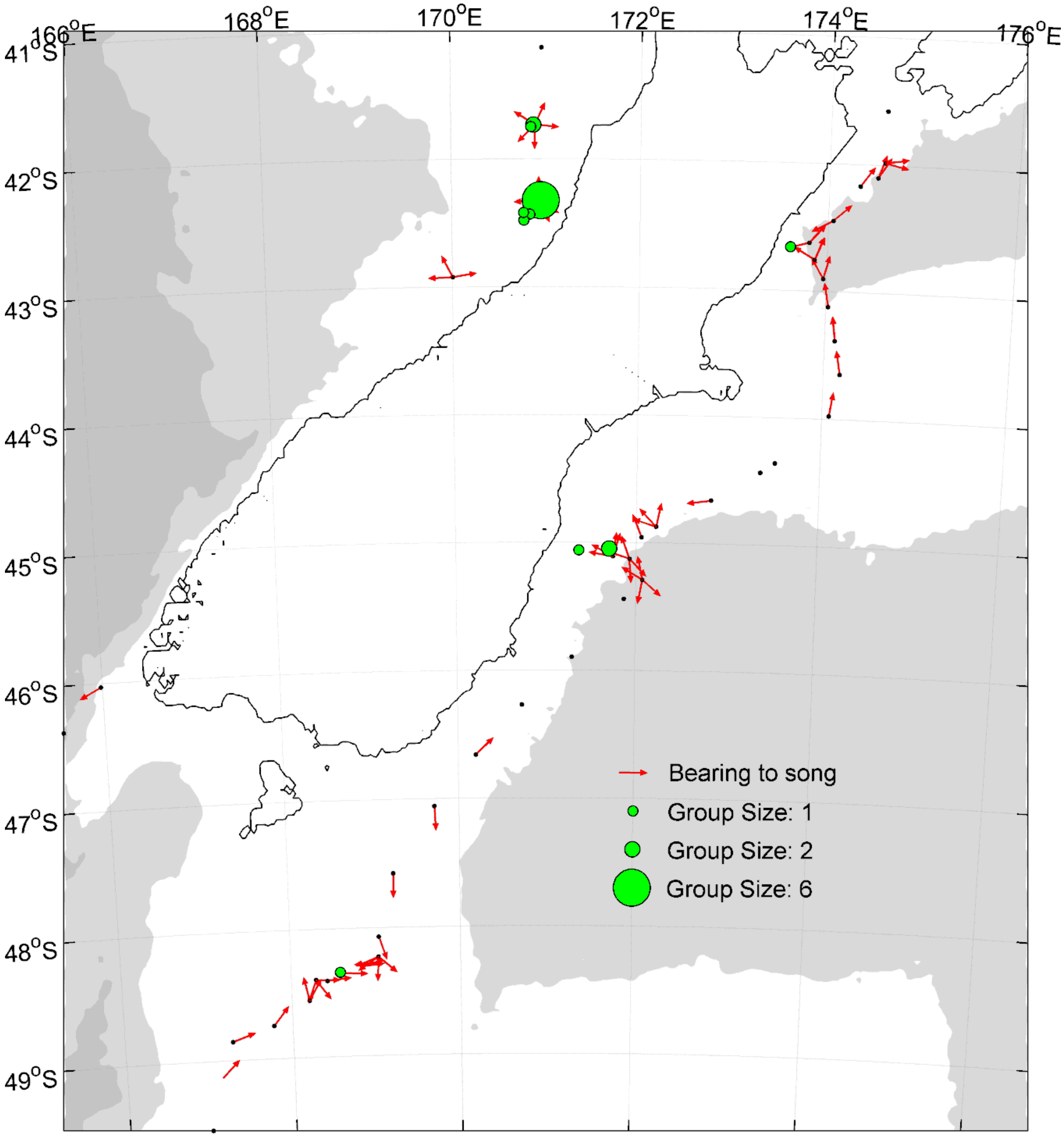

Figure 3 - Visual and acoustic locations of blue whales during the 2013 transit. Dots show location of listening stations, while red arrows indicate the mean direction of clusters of blue whale 'song' vocalisations. Visual sightings of blue whales are indicated by green circles

Acoustic tracking and targeting

A total of 1617 blue whale vocalisations were analysed for directionality in real-time during the transits. Peaks in the BDF of each sonobuoy are plotted to show a summary of these 1617 bearings to blue whales (Figure 3). In general, the received levels of vocalisations showed inverse correlation with distance from a group of whales.

Measurement of calls and comparison with old recordings

A total of 14.5 hours of recordings of high enough quality for measurements of calls of New Zealand blue whales were made during the 2013 voyage. These recordings were made on three separate occasions, two of which were recordings of solitary individuals while the third was of at least two singing whales.

The blue whale song recorded in 2013 and 1997 consisted of a four-unit call (as described in detail by McDonald (2006)), while the recording from 1964 contained the last three units of the 1997/2013 calls followed by an additional unit E that was not found in the later recordings (Figure 1). In the 2013 recordings, the four different vocalisation units associated with New Zealand blue whales comprised two different call variants. Call variant one was the same as that described by McDonald (2006) and consisted of each of the four units in sequence (*ie* ABCD; Figure 1), while call type two consisted of only the last two units from call type one (*ie* CDCDCD; Figure 4). Call type one was recorded on most occasions, while call type two was recorded only once on the western coast of the South Island. In order to give qualitatively similar units the same names, we named the four units comprising calls from 1964 as BCDE.

Variation in the SNR throughout the recordings, as well as variation in the relative amplitude of units, resulted in differences in the number of measurements that were made among units, intervals, and calls. Frequency and pulse repetition rate characteristics were made only from calls that had high SNR (2013: n=31, 1997: n=41). The lower relative amplitude of the A unit, however, resulted in only six measurements of pulse repetition rate from 2013 recordings.

The duration of units A and B appeared to increase as a function of time, while the duration of units C and D appeared stable (Figure 5a). Simple linear regression of frequency over year revealed a decrease in peak-frequency as a function of time for all units (Figure 5b). Unit B showed a decrease of approximately 0.14 Hz/year, while both units C and D showed a linear decrease of approximately 0.16 Hz/year. In addition to a decline in peak-frequency units A, B, and C also showed a decline in pulse rate. However, it appears that simple linear regression may only describe the decline in pulse rate for unit C (Figure 5c). Mean values and standard deviation of all measurements can be found in Tables 1, 2, and 3.

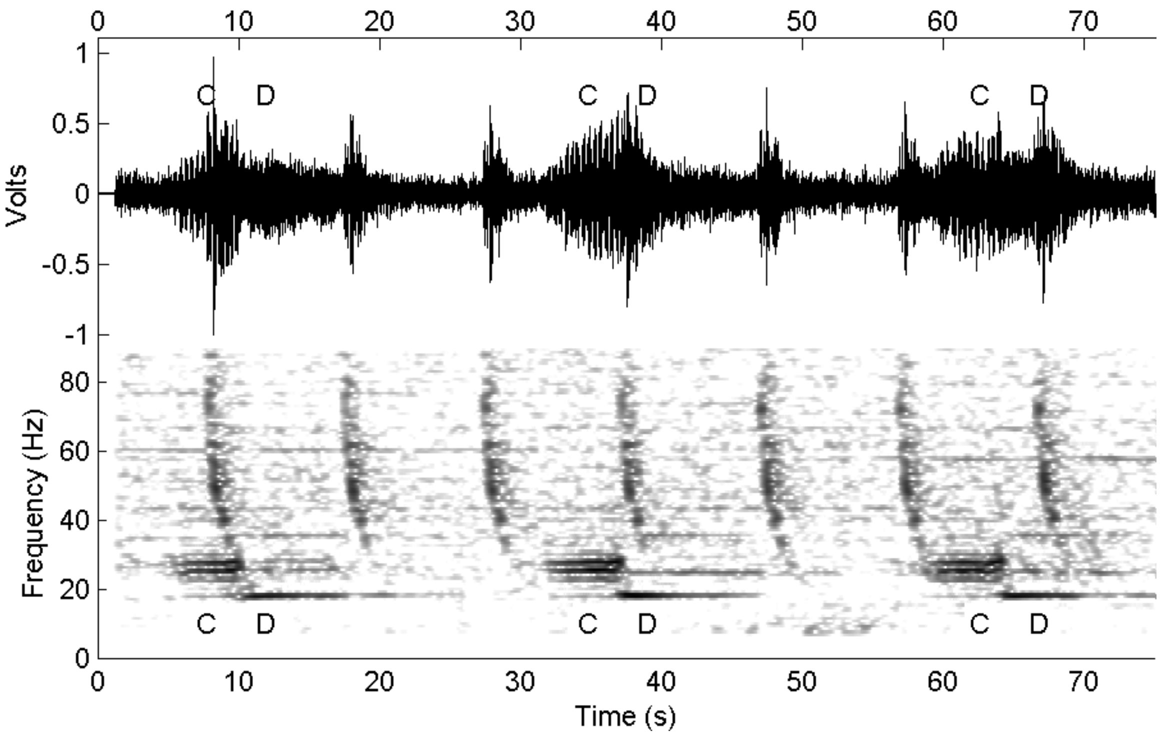

Figure 4 - Top: Pressure waveform of two-unit call produced by New Zealand blue whales. Bottom: Spectrogram of blue whale sounds. Spectrogram parameters: 200 Hz sample rate, 512 point FFT with Hamming window, 93.75% overlap. Note: the slightly downswept pulses that repeat every 10 s are from seismic airguns rather than blue whales.

DISCUSSION

Visual observations and acoustic recording and tracking

We have presented the first recordings of the New Zealand song type with concurrent visual confirmation that these songs were produced by blue whales. Acoustically derived bearings from directional sonobuoys unambiguously pointed to these whales as the source of these calls, confirming hypotheses regarding the origin of these sounds (Kibblewhite 1967; McDonald 2006; McDonald *et al* 2006). Furthermore, acoustically-derived bearings from these sounds led us to encounters with these animals from initial detections that were tens to hundreds of kilometres away (Figure 3).

New Zealand blue whale calls were detected all around the South Island of New Zealand and as far south as 53°S latitude. However, bearings from vocalisations received at 53°S pointed back to the north, potentially indicating that these detections may be beyond the actual southern limit of distribution of this population during this time of year. On the basis of a single return transit and a typical detection range of approximately 60 nmi, our results would be consistent with a lower latitude distribution of around 52°S. In New Zealand waters, a compilation of incidental visual sightings (as well as strandings) demonstrate blue whales have a broad distribution throughout the region, with two areas of apparent concentration in coastal waters of the North Island (Torres 2013).

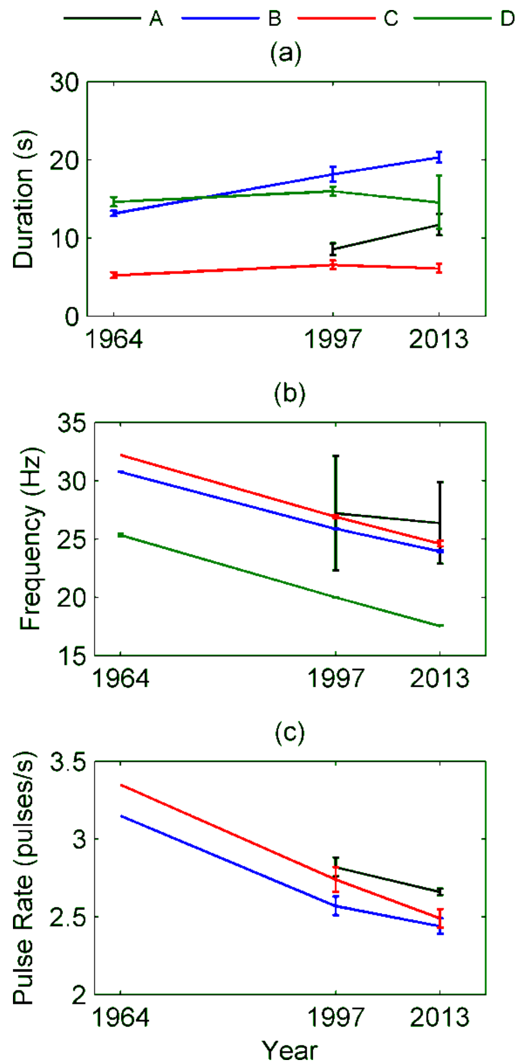

Figure 5– (a) Duration of vocalisation units from New Zealand blue whale calls as a function of time. (b) peak-frequency of vocalisation units from New Zealand blue whale calls. (c) Pulse rate of vocalisation units from New Zealand blue whale calls. In all cases lines connect mean values for each year and error bars show standard deviations. Black represents unit A; blue represents unit B; red represents unit C, and green represents unit D.

The 2013 acoustic detections provide updated information on the geographic distribution of this 'acoustic population' of blue whales. The long range over which these sounds were detected indicates that these acoustic methods may represent a particularly efficient means to examine the spatial distribution and abundance of this population. Furthermore, as a novel method to find individuals of this (infrequently sighted and poorly known) population it would greatly enhance the efficiency of any potential future in-depth studies. The fact that a substantial number of detailed acoustic recordings, identification photographs (Olson *et al* 2013), and behavioural observations were successfully obtained opportunistically at several, widely separated, geographic locations during the transit to and from the Antarctic, further highlights the value and utility of these acoustic methods.

Measurement of calls and comparison with old recordings

Visual inspection of the spectrograms of calls with high signal-to-noise ratio reveal that these sounds appear, at least qualitatively, to be the same calls as recorded by Kibblewhite *et al* (1967) and McDonald (2006). However, close analysis of digitised recordings made in 1964 by Kibblewhite *et al* (1967) reveal what may be an additional unit on the end of the call, as well as ambiguity about whether the modern-day unit A was present in the historic calls.

Ambiguity regarding the number of units from the calls recorded in 1964 arises due to relatively low signal-to-noise ratio of the original recordings. Inspection of unit E from a digitised copy of the original recording reveals that this unit has a relatively low peak amplitude, approximately -15 dB with respect to the loudest unit, unit D. Furthermore, the peak-frequency of 16 Hz appears to be one of the lowest peak-frequencies observed in any blue whale population. This likely explains why neither Kibblewhite *et al* (1967) nor McDonald (2006) include unit E in their description of the calls. However, the consistent inter-unit interval DE and slightly longer call repetition rate of the calls from 1964 suggests that these units may indeed be part of the call. By analysing only calls with high signal-to-noise ratio from 1997 and 2013, we can however confirm that blue whales calls recorded in these years did not contain this unit E, thus highlighting changes in this song that are more overt than a subtle decline in tonal frequency.

Similarly, in recordings from 2013 we observed that unit A also has a relatively low amplitude compared to the other extant units. In these recordings, we found the peak amplitude of unit A was regularly 20 dB below that of unit D. If we assume the relative amplitude of the units has remained stable, then even if unit A was produced by the whales in 1964, it would have been below the noise floor of the available recordings. Thus, without additional historic recordings we cannot say whether or not unit A was part of New Zealand blue whale calls in 1964, or whether unit A was introduced only after the cessation of the production of unit E.

Quantitative comparison of each call unit over time revealed differences in the durations, peak-frequencies, and pulse rates of some units. The observed decline in tonal frequency is in accord with previous observations (McDonald *et al* 2009), while the changes in duration and pulse rate represent new observations that have become available due to the recent opportunistic recordings from the transit of the Antarctic Blue Whale Voyage. In addition to the qualitative observations above, these quantitative observations may form a basis for further investigation of the evolution of blue whale song in New Zealand waters.

Understanding the evolution of blue whale song may provide insight into song function as well as the hypothesised relationship between blue whale song and population structure (McDonald 2006). However, quantification of both historic and present day song of other populations of blue whales, as well as collection of photographic identification and genetic samples of blue whales around New Zealand, are likely to be required in order to further investigate questions of population structure and distribution.

WORK-IN-PROGRESS

Accurate locations of visual detections of blue whales, relative to the ships position, were obtained during approach and opportunistic photo identification attempts using a system involving combined binoculars, video camera and still camera (as described in Leaper and Gordon 2001).To measure the distance of the whale from the ship, still images captured from the video were used to measure the angle of dip from the horizon to the whale, and images from a downward pointing still camera to obtain bearings relative to the heading of the ship. Analysis of these video tracking data are underway and, the results of this, when combined with the GPS location of the ship will yield accurate positions of whales as well as more detailed information regarding the behaviour of whales.

Comparison of acoustic and visually observed behaviours is also potentially possible as, on several occasions, concurrent video tracking and acoustic recordings were obtained. Analysis of this simultaneous video and acoustic data, when combined with CTD data collected during the voyage, may additionally yield estimates of source levels of blue whale calls.

Furthermore, during the 2013 voyage there were 14 photographic identifications of blue whales obtained around New Zealand (Olson *et al* 2013). For several of these individual identifications, the singing whale could be unambiguously acoustically identified, thus potentially enabling a comparison of call properties among different individuals recorded in the same year. All identification photographs will be submitted to the southern hemisphere blue whale catalog (Galletti Vernazzani and Olson 2012).

In this manuscript we have analysed all of the high quality recordings made during 2013, eight hours of recording from 1997, and five calls from 1964. The large number of calls measured in 2013 should allow a statistical analysis among measurements and provide further detail on the changes of calls over time.

The relative scarcity of New Zealand blue whale song at the Hauraki Gulf site in 1997 (four encounters during a year of near continuous recording) suggests these whales are either much more common off the South Island of New Zealand, or the density of the whales has increased around New Zealand since

1997. Further compilation of sighting data and acoustic recordings may provide insight as to any seasonal migrations of this blue whale population and any long term changes in apparent density.

Finally, noise from distant seismic surveys was present throughout the recordings made on the west coast of the South Island. High noise levels from seismic surveys have been shown to alter the properties of 20 Hz fin whale calls (Castellote *et al* 2012). Further analysis of our acoustic data is required to investigate if there were any differences between blue whale calls with and without the presence of seismic airgun noise. However, because our data were collected opportunistically, such analysis is perhaps unlikely to yield conclusive answers.

CONCLUSIONS

We have confirmed the hypothesis that the unique series of pulsed and tonal sounds described by Kibblewhite *et al* (1967) and McDonald (2006) are produced by blue whales in the New Zealand region. Furthermore, evidence suggests this acoustic population of blue whales can be found all around New Zealand and at least as far south as 52°S in the Southern Ocean. We have confirmed a steady tonal decrease in peak-frequency first observed by McDonald *et al* (2009) and have further quantified changes in the duration and pulse rate of the units of these calls, thus more completely describing the evolution of this variety of blue whale song over a span of 50 years. Lastly, we have demonstrated a very successful, efficient acoustic method for long-range detection and localisation of blue whales that could greatly facilitate future research on the distribution, abundance, and behaviour of this poorly known population of blue whales in New Zealand waters.

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TABLES

Table 1- Duration measurements of units, intervals, and four-part calls of New Zealand blue whales. All measurements except call interval are of the form mean ± standard deviation in seconds with sample size in parenthesis. Inter-call interval is the median value with sample size in parenthesis.

Year	A	B	C	D	E	A-B interval	B-C interval	D-E interval	Inter-call interval
2013	11.72 ± 1.36 (84)	20.33 ± 0.66 (186)	6.12 ± 0.52 (164)	14.56 ± 3.40 (162)	-	7.53 ± 1.18 (84)	7.40 ± 0.55 (164)	-	132.62 (180)
1997	8.57 ± 0.75 (45)	18.17 ± 0.94 (168)	6.59 ± 0.53 (145)	16.02 ± 0.57 (145)	-	5.68 ± 0.53 (45)	5.30 ± 0.63 (145	-	115.44 (167)
1964	-	13.15± 0.36 (5)	5.24 ± 0.36 (5)	14.64 ± 0.59 (5)	13.38± 0.36 (2)	-	5.95 ± 0.59 (5)	13.83 ± 0.97 (2)	-153.82 (2)

Table 2- Mean peak-frequency measurements of units of New Zealand blue whale calls. Units for all measurements are Hz, and measurements are of the form mean ± standard deviation.

	A		B	C	D			E
Year	**Peak Freq. Start**	**Peak Freq. End**	**Peak Freq.**	**Peak Freq.**	**Fund Freq**	**Peak Freq. Start**	**Peak Freq. End**	**Peak Freq.**
2013 (n=31)	26.36±3.50	20.72±2.77	23.93±0.09	24.60±0.24	17.55±0.01	17.53±0.13	18.88±0.57	-
1997 (n=41)	27.20 ± 4.90	22.33 ± 4.35	25.87 ± 0.02	26.90 ± 0.14	20.00 ± 0.00	20.00±0.00	20.82 ± 0.15	-
1964	-	-	30.75 ± 0.01 (5)	32.22 ± 0.01 (5)	25.33 ± 0.10 (5)	25.33 ± 0.10 (5)	25.33 ± 0.10 (5)	16.08± 0.10 (2)

Table 3- Mean pulse rate measurements of units of New Zealand blue whale calls. All measurements in pulses/s and are of the form mean ± standard deviation with sample size in parenthesis.

	A	B	C	E
2013	2.66 ± 0.02 (6)	2.44 ±0.05 (31)	2.49 ±0.06 (31)	-
1997	2.82 ± 0.06 (41)	2.57 ± 0.06 (41)	2.74 ± 0.08 (41)	-
1964	-	3.15±0.00 (5)	3.35±0.00 (5)	2.63±0.01 (2)