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Blue whale calling in the Rottnest trench, Western Australia, and low frequency sea noise

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Abstract

Through January-April 2000 research was carried out off the Rottnest trench to search for blue or pygmy blue whales. A consortium of researchers carried out aerial surveys, boat based studies and acoustical measures. Historical records led us to believe that a Western Australian population of pygmy blue whales (*Balaenopteridae musculus brevicauda*, sub species of the true blue whale, *B. m. musculus*) existed, while a preliminary boat survey in 1994 suggested that some of these animals aggregated in the Rottnest trench west of Perth. This was confirmed in the early 2000 observations, in 30 days boat based searching 17 pygmy blue whales were sighted. Five thousand acoustic records were made, almost all of which had blue/pygmy blue whale calling in, some having up to six animals calling at once. Although of a slightly different format, recorded call components were of a similar character to those described from other populations. Also common were impulsive 'clicking' calls which were shorter than the 12-23 s blue whale call components and of low to very low frequency (< 1 Hz to 20 Hz). The literature suggests these are produced by fin whales but none were sighted. The low frequency (< 100 Hz) sea noise spectra from a series of 90 s recordings made every 10 minutes for 33.5 days was dominated was dominated by blue whale calling.

Introduction

In the southern hemisphere two subspecies of blue whale are recognised, the 'true' blue whale (*Balaenoptera musculus intermedia*) and the 'pygmy' blue whale (*Balaenoptera musculus brevicauda).* The 'true' blue whale is the larger of the two and may be found south of the Antarctic convergence zone, particularly along the ice shelf edge feeding on euphausiid krill, whereas the slightly smaller pygmy blue whale is preferentially found further north (Bannister et al 1996). The two subspecies are extremely difficult to discern in the field. Based on recently released Russian whaling data Zemsky and Sazhinov (1994) presented the distribution of pygmy blue whales as being primarily in the Indian Ocean, along the African east coast, throughout the lower part of the Indian Ocean, along the Western Australian coast north to Indonesia, and along the Australian southern coast and east to encompass New Zealand. The migratory patterns and movements of the blue and pygmy blue whale are poorly understood although each are known to undertake extensive migrations between warm water (low latitude) breeding areas and cold water (high latitude) feeding areas (Bannister et al 1996).

These populations were heavily hunted during the whaling decades of the 1950 and 1960's. An international ban on blue whaling was established in 1966 due to alarmingly declining numbers, although it now known that illicit catches of blue whales continued up to the mid 1970's (Bannister et al 1996). The 'true' blue whales were almost driven to extinction during this period. From an estimated pre-whaling population of southern hemisphere 'true' blue whales of around 160,000-240,000 animals, whaling reduced numbers to < 1000 animals, which is still 34 years after the official cessation of whaling, near the estimated current population size of 1000-2000 animals (Bannister and Burton 2000). Pygmy blue whale stocks were less heavily exploited and dropped from an estimated total population size of 12,500-13,000 animals pre-whaling (Zemsky and Sazhinov 1994), with an estimate of the current population at 6000 animals (Bannister et al 1996).

Along the Western Australian coast both true and pygmy blue whales have been sighted and taken. A USSR factory whaling ship captured 269 animals along the coast from Albany to Exmouth in 1965, most of which were believed pygmy blue whales (Bannister and Burton 2000). True and pygmy blue whales were sighted to 45o S of WA in February-March 1993 (Bannister 1993). During a dedicated IWC blue whale cruise in 1994 up to five blue whales per day were sighted off Rottnest Island. Most of these were believed to be pygmy blue whales (Kato et al 1996). What are believed to be pygmy blue whales are regularly sighted off Dunsborough in the states south-west (Bannister and Burton 2000).

Given the historical records, the observations of blue whales off Perth in 1994, and the dearth of information on true and pygmy blue whales, a consortium of WA researchers carried out concurrent aerial surveys, boat based observations and acoustic surveys to study blue whales west of Rottnest Island. The aerial surveys began in January 1999 and were to be carried out on a monthly basis until mid 2000. Weather and aircraft availability restricted the number of successful flights. Over the period January-1999 to February-2000 eight flights were carried out during which 16 blue whales were sighted (Bannister and Burton 2000). Boat based observations in the region of the Rottnest trench were carried out through January-March 2000. In 30 days of searching 17 blue whales were sighted (Curt Jenner, pers. comm.). Concurrently with the boat based observations, acoustic records were made. Blue whales are known to produce intense low frequency signals (eg. Cummings and Thompson 1971). Several workers have used these signals to track animals using arrays and to gain insight into the animals underwater behaviour (eg. D'Spain et al 1995; McDonald et al 1995; Stafford et al 1998; Thode et al 2000). In this project the acoustic monitoring work was attempted primarily as a censusing technique, that is to determine if the animals were present, approximately how many calling animals were present at any given time within some range of the hydrophone, and how these characters varied with time. As it transpired the results offered all this information not only for blue whales but also for other baleen whale species. Additionally the recordings, particularly those from a bottom mounted receiver deployed over a 34 day period, provided a rich source of information on the behaviour of several baleen whale species in the area, as well as physical sea noise sources. There were many instances where calling blue and other baleen whale species passed within 500 m of the recording gear, providing some extremely high signal to noise ratio signals.

The following discussion presents a short summary of several of the call types recorded. At the date of writing this document only a small fraction of the data available had been analysed.

Methods

The study site was located in the region of the Rottnest trench, an indentation in the continental shelf which begins approximately 22 km WNW of the western end of Rottnest Island. The shelf slope in the trench region drops steeply to 1000 m depth. The general location of the study site is shown on Figure 1.

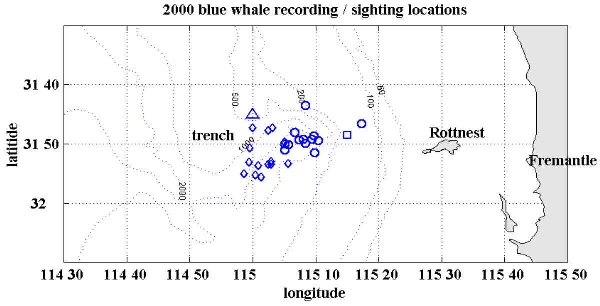

Figure 1: Location of the Rottnest trench region, west of Rottnest Island Western Australia. Recording locations are shown by the circles (drifting gear), square (inshore moored gear sampling over three days) and large triangle (moored gear sampling over 33.5 days). Whale sightings from the boat observations are shown by the diamond symbols. Depths in metres.

The deep and indented nature of the trench can be seen on Figure 2. Along the Western Australian continental shelf between the 100-500 m depth contours, flows the Leeuwin current, a southerly current of warm tropical water approximately 50-200 m deep. Over the study period of early January to April 2000, the Leeuwin current was particularly strong, with current speeds estimated at up to1.5 knot (0.75 ms-1) based on observations of moorings and drift rates. The sharp indentation of the trench lying across the path of the Leeuwin current may be expected to give rise to complex oceanographic conditions in the area.

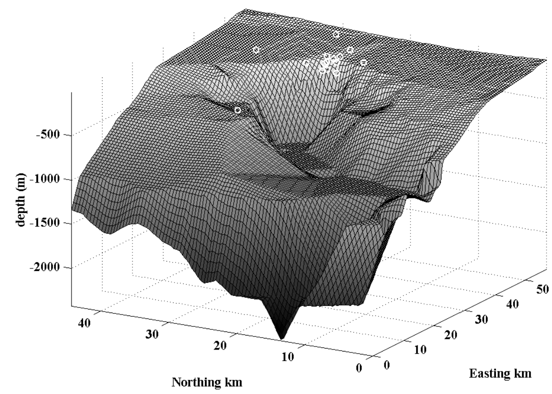

Figure 2: Surface representation of the trench bathymetry, showing the location of recording sites (white circles). The image is looking NE into the trench from the western side.

Acoustic recordings were made with a drifting package (13 sets, shown as circles on Figure 1) or using moored equipment (two sets, shown by square and triangle on Figure 1). The drifting package used a Massa TR1025C hydrophone suspended from a housing containing a purpose built pre-amplifier (40 dB gain) and Sony TCD D-8 digital tape deck operated at 32 kHz sample rate to give 4 hour recordings per tape. System response was linear from 20 Hz to 14.5 kHz. To reduce surge from the surface gear and flow noise from cable strum, the hydrophone cable was spirally wrapped with twine and suspended on rubber strops from the housing while the housing was suspended from a rope weighted and buoyed to create a substantial catenary. A depth meter attached to the housing was used to log the housing, and hence hydrophone, depth. Under most conditions the hydrophone was at 40 m depth. Drifting sets were made during daytime, concurrent with the boat based observations.

A moored system was set at the head of the trench (eastern trench end, square symbol, Figure 1) in 160 m water. This comprised the same hydrophone and electronics as the drifting system, but with the tape deck operated by timer on a 3 minute sample time every 44 minutes. The gear was suspended from the mooring surface floats. Sixty samples were collected over a two day period (10-12 January).

A second moored system comprising a deepwater housing (the 'bluey' logger) was set on the bottom in 450 m of water on the northern trench edge (large triangle symbol, Figure 1) through 7-March to 10-April. This system comprised a General Instruments C-32 hydrophone connected to custom built electronics comprising an A-D converter and microprocessor controlled sampling and storage system (10 kHz sample rate, 90 s samples every 10 minutes, 9.1 GByte SCSII storage disk). The frequency response of this system was calibrated from < 1 Hz to 3.5 kHz. This system retrieved 4827 samples.

Continuous sections of sea noise from the DAT tape decks was digitised at 651 Hz using a calibrated DataPhysics DP430 spectral analyser card installed in a 166 MHz PC. The digital data from the 'bluey' logger was transferred to an IDE disk on a PC. All data analysis was then carried out in the Matlab environment.

Salinity, temperature and depth profiles were taken opportunistically with a Marimatech HMS 1820 CTD profiler. The Leeuwin current was a consistent feature throughout January to April. Most CTD profiles showed a warm body of water at 21-22.5o C from the surface down to 50-100 m where a sharp thermocline existed. Water temperatures dropped steadily below this depth with one record showing10o C water at 300 m depth but most settling between 13-19o C. On the last sample taken on the 10-April at the bluey logger site (square Figure 1) the Leeuwin current extended to 200 m depth below which the temperature steadily dropped. All sound speed profiles showed a sound speed maximum at the base of the Leeuwin current of 1530-1532 ms-1.

At the time of writing this document only a preliminary analysis of the data had been completed.

Results

Call types - 'blue' whale calls

The most common low frequency call observed with typical 'blue' whale characteristics (based on literature comparisons), was a sequence of three long tonal signals. The first signal type (referred to here as a type I) comprised an almost constant tone centred near 21-22 Hz and lasting for 22 s. This was followed 5-10 s later by a frequency sweep (type II), this beginning near 20 Hz, increasing to 21 Hz over 2-3 s then slowly increasing to approximately 26 Hz over a further 20 s period. The type III component then followed approximately 23 s later. This component was again an almost constant tone, centred near 18.5-19 Hz An example of a sequence of the three components (to make a single 'call'), taken with the drifting gear on the 29-January is shown on Figure 3. Each component has strong associated harmonics. This call type is similar, although not exactly the same, to spectrograms displayed by Cummings and Thompson (1971) from blue whale calls recorded off Chile in 1970.

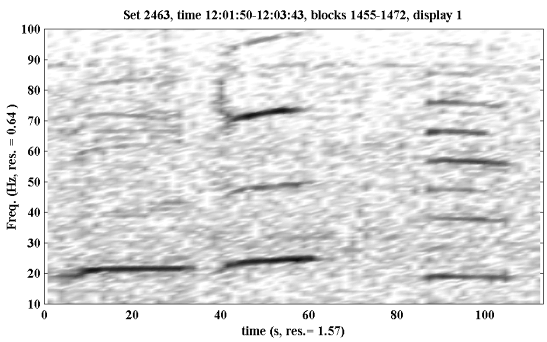

Figure 3: Spectrogram of the three components (I, II, III) believed attributable to pygmy blue whales.

The three call components were remarkably stereotyped in individual structure and in the timing between adjacent components. The distribution of the spectral peak frequency of 87 call components (recorded across a 24 hour sequence) determined from FFT averages at a resolution of 0.0763 Hz over the full duration of each component, is shown on Figure 4. The type III component was centred almost exclusively near 19 Hz, the type I component varied over approximately a 1 Hz band centred near 21.2 Hz, and the type II component varied in dominant frequency which reflected its frequency sweep nature.

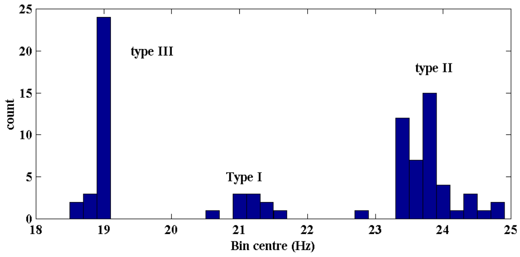

Figure 4: Distribution of the frequencies of the spectral peak for each call type, as determined by averaging the frequency content over each call duration (FFT's taken with a 0.0763 Hz resolution two averages per component, distribution shown with a 0.2 Hz bin width).

The precise tonal nature of the type I & II components was emphasised in several recordings in which amplitude modulation of the carrier tone can be discerned in spectrogram plots. An example of this can be seen on Figure 5 where a type III and type I components (separate calls) display strong sidebands which shift frequency with time.

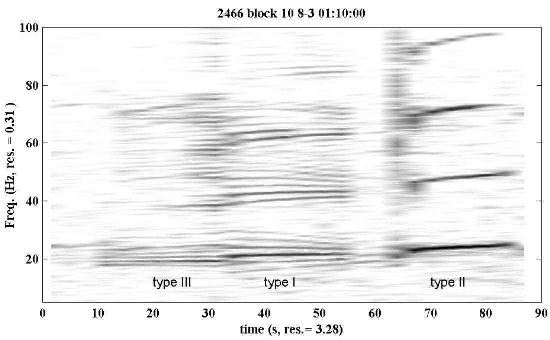

Figure 5: Spectrogram of three blue whale components (two separate calls) with the type I and III components displaying sidebands associated with amplitude modulation of the carrier tone.

For the same call, the three components consistently had different received levels. Based on matched components from the same call and using the mean squared pressure over the component duration, then the type II component was 3-10 dB higher in received level than the type I component and 0.4-3 dB higher than the type III component. This implies differences in source levels for each component. The nature of received calls emphasised this, for very long range calls, or those with low signal to noise ratios (SNR), it was always the type II component which showed up best. For the deep water moored hydrophone (bluey logger at 450 m depth) low SNR signals displayed the 20-26 Hz type II fundamental and the harmonics. For the drifted hydrophone (at 40 m depth) the 60-80 Hz harmonic of the type II component showed up best in spectrograms, with often the fundamental frequencies lost.

Given the precise tonal character of the calls then the possibility of using spectrogram cross correlation techniques to automate call identification seemed attractive (eg as described by Mellinger and Clark, 2000 for bowhead calls). Correlation techniques were thus developed using high SNR ratio components to set up kernels and correlating these against measured spectrograms after normalising the test signal to the total energy in the kernel. This was done at 1.22 Hz and 0.3 Hz spectrogram resolution. Although this method gave excellent discrimination for recordings with single calls, the presence of a large number of overlapping calls in some sequences greatly reduced the techniques sensitivity. In some of the 90 s sequences recorded from the bluey logger there were up to six different calling animals, with 3-4 of these at similar SNR. The ability of the spectrogram cross-correlation techniques to discriminate overlapping call components has so far been poor. Further techniques to enhance this discrimination are being pursued.

Call types - 'clicking'

A second call type commonly observed was 20 Hz 'clicks'. An example of several click waveforms is shown in Figure 6. These were common, occurred in bouts of several hours and were often recorded at very high levels (up to 146 dB re 1µPa peak-peak). They display several multipath reflections, from which it should be possible to estimate range and depth using an extension of the method described in Cato (1998). For example the middle call of Figure 6 was estimated to be at a depth of 286 m, and 1987 m from the hydrophone using a surface reflected time relative to the direct arrival of 82 ms and a bottom-surface reflected time of 169 ms relative to the direct arrival time.

During clicking bouts signals were received with a wide range of levels and separate clicks had different patterns of multipath arrivals. This indicated that several sources were active and responsible for the click bouts. Previous workers have attributed calls similar to these as being produced by fin whales (Watkins 1981). No fin whales were sighted in the area during the study period by the aerial surveys or from the boat searching, although fin and Brydes whales are known be found along the WA coast.

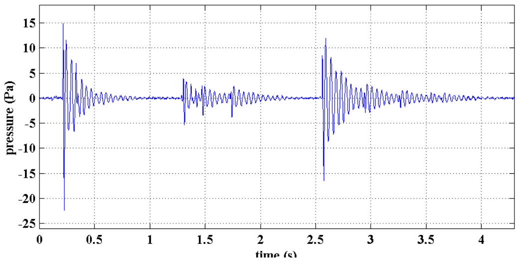

Figure 6: Example waveforms of 20 Hz clicks recorded.

Calling through time:

The 'blue' whale calls were evident all through the sample period of from 10-January to 10-April 2000. They were not sighted by the aerial or boat based surveys until early February. The maximum group size of blue whales sighted in the aerial surveys was two, and in the boat based surveys was four. To date only a 24 hour sequence of the bluey data has been analysed for the number of callers in each sample. From this analysis the number of calling animals in a 90 s sample ranged from zero to six, to give a mean number of two calling animals. The samples with no calling often correlated with nearby boat noise, as did a fourth call type (not described here).

It is not known what proportion of any group of blue whales call, but estimates could range from as low as 10% (as per humpback calling, Doug Cato pers. comm) to close to 100%. Drifting recordings were made in the vicinity of blue whales. Not all of these recordings had nearby animals calling, hence we would expect it unlikely that all animals present in an area would be calling at any given time. Thus simply assuming a 50% call rate, the bluey logger hydrophone results for the 24 hour period suggest that a mean of four, possibly ranging up to 12, animals may have been within some range from the hydrophone at any given time. Although the range brackets have not yet been calculated, a crude estimate of the outside detection range is approximately 10-15 km (based on an estimated mean squared pressure source level of blue whale calls at 180 dB re 1μPa, the minimum received signal level of close to 100 dB re 1μPa, and spherical spreading).

To give a display of the presence of blue whales through time, the power spectral density of each 90 s sample from the bluey logger (10 minute sample separation) was determined at a 1.22 Hz resolution using 219 averages (hanning window) per 90 s, and has been displayed with time on Figure 7 for the week 8-15 March. The presence of blue whales is indicated by the banding at 18-25 Hz, while the 'clicking' displayed above shows up as the intense narrow vertical stripes. It can be seen that the two call types dominate the sea noise spectra over this period. The bluey logger ran for almost five weeks. Although the degree of calling tapered slightly towards April, the sea noise spectra over the 18-80 Hz band was still dominated by blue whale calling and the clicking at the end of the sampling period.

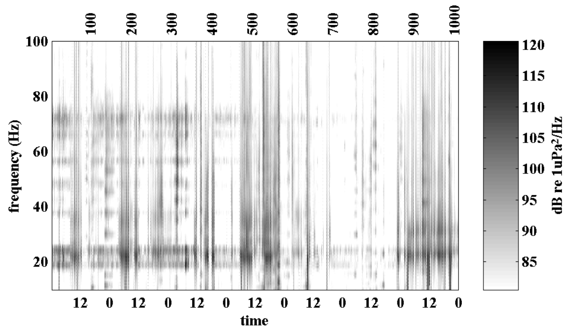

Figure 7: Power spectral density with time over the frequency band 10-100 Hz for the first week of deployment of the bluey logger. Blue whales were evident as the horizontal banding at 18-20 Hz and the narrow vertical stripes indicate the presence of the 'clicking' calls. See text for FFT parameters. Upper scale is sample number.

Discussion

Blue whale calling and a 20 Hz clicking call were found to predominate in sea noise records made over January to April 2000 in the Rottnest trench west of Perth. Up to six blue whales were evident at a given time in some records. The blue whale calls were made up of three, highly stereotyped components. The first and third components were very sharp tones, while the second was a slowly rising-frequency signal. Each component displayed strong harmonics. The three components had different source levels, with local sound propagation conditions determining the received signal character.

Time averaged sea noise spectra over the band 18-80 Hz was dominated by the two call types. From recordings in the deep sound channel off Cape Leeuwin made over three weeks in June-July 1998 Penrose et al (1998) determined that there was an increase in ambient sea noise across the band 20-80 Hz which could not be attributed to the local wind field. This suggested that a source other than wind was setting sea noise levels across this band. No easily discernible blue whale calls were found in the Penrose et al data set. The measurements described here show a similar increase in sea noise across the same frequency band which is definitively attributable to blue and other baleen whales. It may have been that the measurements over this frequency band made by Penrose et al were also dominated by baleen whales, which because of coupling into the deep sound channel meant that the calls emanated from great distances and so were not easily identifiable. Some workers in the northern hemisphere have attributed similar increases across a similar frequency band to shipping noise.

The fact that blue whales seem to aggregate in the Rottnest trench has now been confirmed. Just why the animals aggregate their is not yet clear. The complex oceanographic conditions set up by the trench crossing the path of the southerly travelling Leeuwin current, and the strong offshore winds experienced in summers may result in localised upwellings around the trench. This would enhance plankton productivity and possibly result in the formation of dense macro-zooplankton aggregations, such as euphausiid krill swarms. Such swarms would maintain the attention of many species of large baleen whales. Further studies in 2000-2001 are proposed to elaborate this and other questions whilst the current data set is still under perusal.

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