Appendix F29

McCauley 2011

Woodside Kimberley Sea Noise Logger Program, Sept-2006 to June-2009: Whales, Fish and Man-made Noise

BROWSE FLNG DEVELOPMENT
Draft Environmental Impact Statement

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WOODSIDE KIMBERLEY SEA NOISE LOGGER PROGRAM, SEPTEMBER 2006 TO JUNE 2009: WHALES, FISH AND MAN MADE NOISE

By:

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For - Woodside Energy

PROJECT CMST 861
REPORT R2010-50_3

1. Executive summary

Twenty four deployments of CMST-DSTO sea noise loggers have been made in and around Scott Reef since Sep-2006 at 23 sites. Nineteen recordings were made in or around Scott Reef and four near-shore. Seventeen loggers have been recovered with the whale data in this document analysed to Jun-2009 from 12 sets and the fish chorus data analysed to Jun-2010. One noise logger was lost, and three are in the water and due for recovery in May-2011. The noise loggers typically sampled 200 s every 15 minutes at 6 kHz sample rate. In and around Scott Reef five regions have been sampled, 24 km SE of Scott Reef (Scott South), 17 km NE of the reef (Scott North), 31 km east of the reef (still in the water) and four locations inside the lagoon, two on the western lagoon side with a listening aspect to open water to the west (Scott West) and two located in the lagoon centre or near the southern lagoon, northern rim (Scott East). Amongst other sources, the noise loggers have detected: humpback whales; minke whales of the Antarctic and dwarf sub-species; pygmy blue whales; Bryde's whales; several regular daily fish choruses; unknown sources of great whales and fish; vessel traffic; noise associated with exploration drilling; seismic survey noise including the *Maxima*, *Endurance*, *Gigas*, *Vulcan* and *Canis* surveys; and what was believed to be illegal dynamite fishing inside Scott Reef.

All great whale sources were present over July to October each year. In two of three years sampled a sizeable pulse of south bound pygmy blue whales were detected over October to January. Bryde's whales were present in low numbers year round. Vessel and seismic survey activity feature prominently in all recordings, dominating the sea noise spectra below a few hundred Hz for long periods, particularly in late 2007 and early 2008. The listening ranges of noise loggers has been calculated at typically 50 km for humpbacks and 25-35 km for pygmy blue whales in open water around Scott Reef and 6-18 km for pygmy blue whales detected by loggers set on the Scott lagoon rim.

The peak humpback season around Scott Reef was consistent over three seasons running from late June to early October. The season around Scott Reef with 90% of signals detected was late June / early July to mid September outside Scott Reef and mid August to mid September inside Scott Reef. The outside humpback detection bounds (first and last calls detected) across seasons were 23-Jun to 23-Sep to the SE of Scott Reef and 27-Jul to 14-Oct inside the reef southern lagoon. Humpbacks inside Scott Reef were in low numbers with usually one animal singing and this sporadically. Calling rates were comparatively low inside and around Scott Reef, with a maximum of four singing animals detected at any one time SE of Scott Reef but usually only one singer present. More humpbacks were heard SE of Scott Reef than NE by a factor of six. This and the lower number heard inside Scott Reef than to the SE suggest most humpbacks detected by the Scott South loggers were localised inshore towards the 200 m contour and that Scott Reef was on the periphery of the area in the Kimberly utilised by humpback whales. Humpbacks did use the channel separating the northern and southern Scott reef lagoons. Comparison of humpback whale singing periods along the northern WA coast suggested that many humpbacks do not reach the Kimberley area but rather spend their time further south. The humpback season in the Exmouth area stretches approximately 136 days whereas in the Scott Reef region, some 1200 km further north, it was on average 80 days outside the reef and 34-62 days inside the reef.

Dwarf minke whales calls were commonly heard in sea noise records, often with high numbers of calls (up to 48) per sample although with a median of one or two calls per sample. The season for dwarf minke whales in and around Scott Reef was long, with outside detection bounds across seasons of 13-May to 18-Sep each year (128 days) for the Scott South location. Most calling (90% of) at Scott South occurred over a 44-50 day period ranging from late June to early September. Inside or near to Scott Reef outside call detection bounds ranged from 28-Jun to 25-Aug spanning 58 days. Most dwarf minke calling (90% of) inside Scott Reef occurred over a 30-43 day period.

There was more variability with the time when dwarf minke whales arrived at Scott Reef compared with departing, with animals consistently leaving over 9-18 September. The number of individual dwarf minke callers ranged from normally one animal up to six around Scott Reef. Without correcting for listening area there were 4-8% of dwarf minke detections inside Scott Reef compared with Scott South to the SE. On a regional scale it appears that dwarf minke whales migrate north and south in northern WA, having a long protracted season over late March to late September off the north end of the Monte Bello Islands, and a shorter season over May to mid September at Scott Reef. Like humpbacks, it is probable that not all dwarf minke whales migrate to the Kimberley region.

Antarctic minke whale calls were detected in low numbers at the Scott South location but as of yet little systematic analysis has been carried out. These calls appear seasonal in nature, emulating the pattern seen for dwarf minke whales.

Pygmy blue whales passed through the Scott Reef region usually twice per year, south bound in October to December and potentially into January the following year, with peak passage in November, and north bound over mid April to early August. There was evidence for preferred routes around Scott Reef being used by pygmy blue whales, primarily to the west of the reef. Comparison of swim time for detections between Scott North and South loggers for what where believed to be the same cohorts of whales gave the mean migratory speed as 4.2 kn (7.8 $kmhr^{-1}$). No pygmy blue whales have so far been detected inside the Scott Reef southern lagoon based on the Scott East-1 to East-3 data sets, but pygmy blue whales did visit deep water adjacent the rim of Scott Reef and swam between the channel separating the north and south lagoons. In overlapping loggers set over 2008-2009, approximately half of the pygmy blue whale singing bouts detected by a noise logger listening primarily into open water west of Scott reef were detected a short time before or after by a logger listing only into the channel separating the north and south lagoons. In total 39 bouts of singing were recorded over Sep-2008 to Jun 2009 by the logger listening into open water and 25 by the logger listening into the channel. Of the 25 pygmy blue whale singing bouts detected in the channel 14 were estimated to involve animals swimming with 2 km of the receiver, or in the middle of the channel. The relative abundance of pygmy blue whales passing close to Scott Reef based on the acoustic detections from near the reef, showed a consistently increasing number of animals over the 2007-2009 northbound migratory seasons. In late 2007 the expected south bound pulse of pygmy blue whales did not turn up. Calculation of pygmy blue whale densities off Exmouth and the Scott South and North locations found that: 1) 65% more whales were heard passing Scott North than Scott South in the 2007 north bound pulse; and 2) only between 6-40% of animals passing by Exmouth pass by Scott Reef. The lower numbers of pygmy blue whales recorded off Scott Reef than off Exmouth suggest that only a fraction of animals which pass up and down the WA coast utilise the shelf break further north and that the other animals may move into deeper areas of the Indian Ocean further to the west.

Signals believed produced by Bryde's whales were detected at Scott South and inside or near to, Scott Reef. The animals appear to be present year round in low numbers around Scott Reef, possibly with a peak in calling density in April to May (weak trend) calling profusely, generally as single animals but occasionally with multiple singers. Calling patterns indicate the animals move slowly and may call for long periods, up to almost a day at least. The signals attributed to Bryde's whales have been heard from north of Darwin to off Exmouth with similar patterns and no clear seasonality in presence at any site.

A variety of fish choruses have been recorded, with more chorus types inside than outside Scott Reef and more from a location to the SE of Scott Reef than from a logger to the NE. Fish choruses displayed regular diurnal patterns typically occurring at night with different sources calling at different times, and all having daily, lunar and seasonal patterns, typically with winter lulls. A chorus of nocturnal fishes from inside Scott Reef displayed diurnal calling habits closely coupled to moon phase and was remarkably consistent in timing across seasons. This fish chorus continued its expected pattern after the *Maxima* seismic survey carried out in 2007 inside Scott Reef, into Sep-2009, indicating the seismic survey inside the southern lagoon of Scott Reef did not seem to impact this fish complement over the long trem.

Explosive signals believed produced by illegal dynamite fishing from Indonesian fisherman were common over Jun-2007 to Sep-2007 and also detected in lower numbers in Oct-2008 inside the southern lagoon of Scott Reef. In early 2007 explosive events averaged at one event per day. The daily distribution of signals classified as of explosive origin suggested most events occurred around 11:00 and 16:00 hours. It was probable that in 2007 multiple vessels were engaged in dynamite fishing, although in 2008 the presence was much lower.

Acknowledgments

This project was funded by Woodside Energy through Sinclair Knight Mertz. Numerous staff at Woodside Energy have contributed to the project success and development, their efforts and support over the years are appreciated. Mal Perry, Frank Thomas, Chandra Salgado Kent and Justy Siwabessey of CMST have been instrumental in field work. This document has evolved considerably during the program and has been greatly improved by a series of reviews and suggested formatting changes. The efforts of the reviewers are greatly appreciated.

2. Table of key findings

A table of the key project findings, cross referenced to the appropriate chapter, is given in Table 1

Table 1: Project key findings and text reference.

Category	**Key findings**	**Document reference**
Humpback timing	Visit surrounds of Scott Reef over late June to late September or early October each year, with 90% heard over late June / early July to mid September Visit inside Scott Southern lagoon over late July to early October with 90% heard over mid August to mid September	5.3
Humpback numbers	Low densities around and inside Scott Reef with maximum numbers of tens of animals visiting the waters around Scott Reef and only a handful entering Scott Reef lagoon. The low numbers suggest Scott Reef is on the western periphery of the humpback breeding grounds in the Kimberley Large inter-annual variability in numbers of singing humpbacks detected	5.3.2
Regional humpbacks	Calling patterns along the WA coast suggest only a fraction of humpbacks reaching latitudes 20-21^{o} S migrate into the Kimberley (14-18^{o} S)	5.3.2, 6.1
Antarctic minke	Calls detected in low numbers around Scott Reef over winter periods only	5.4, 6.2
Dwarf minke whales in Scott Reef area	Detected around and near to Scott Reef with normally one animal calling but on occasions up to six Detected outside Scott Reef from mid May to mid September and inside Scott Reef over late June to late August Fewer call detections inside Scott Reef compared with outside in open water (4-8%, not corrected for listening area)	5.5
Dwarf minke in Northern WA	Appear to migrate north to Kimberley, much longer season at latitudes 19-21^{o} S than around Scott Reef (14^{o} S)	5.5, 6.3
Pygmy blue whales around Scott Reef	Measured open water migratory speed at 4.2 kn (7.8 kmhr^{-1}) Pass preferably west of Scott Reef, many pass around Scott, some pass to east of Scott Reef Many detections close to Scott Reef, many detections in channel separating north and south lagoons Concurrence of visual and acoustic detections for visual sightings near Scott Reef Approximately half of the pygmy blue whales passing near to Scott Reef are believed to swim through the channel separating the northern and southern lagoons but few if any venture far into the southern lagoon.	5.6
Pygmy blue whales in northern WA	Pass by Scott Reef over mid April to early August heading north, believed then head into northern Indonesian waters. Pass by Scott Reef over October to December and possibly intro January of the following year, heading south in a short pulse compared with north bound passage Along WA coast only 6-40% of animals which pass by the northern end of the Monte Bello Islands are estimated to pass by Scott Reef, suggesting many animals head west into the Indian Ocean rather than follow the shelf edge	5.6, 6.4

Category	Key findings	Document reference
Bryde's whales	Bryde's whale signals detected around and near Scott Reef Usually one singer but occasionally more Singers present all year round, possible weak peak in numbers detected over April to May Singers move slowly, call for long periods (upwards of a day) Bryde's signals commonly detected between waters off Darwin, west and south to Exmouth	5.7, 6.5
Fish activity	Multiple fish choruses detected inside and away from Scott Reef All show daily, lunar and seasonal patterns with winter lulls One chorus type inside Scott Reef, believed due to nocturnal planktivorous foraging fishes, appears systematic across seasons with highest activity over late summer early autumn	5.8
Explosive signals	Signals characteristic of underwater explosives detected widely in 2007 In 2007 signal time distribution peaks around 11:00 or 16:30, with approximately one event per day In 2008-2009 few events detected, mostly in Oct-2008	5.9
Seismic survey signals	Widespread in region, can be a major and persistent contributor to background sea noise levels Seismic signals transmit low frequency energy (< 50 Hz) inside southern lagoon of Scott Reef via coupling through limestone	5.1

Contents

3. Introduction

This document summarises data collected from a series of sea noise logger deployments made in and near Scott Reef over Sep-2006 to Jun-2009. In mid 2006 Woodside Energy contracted the Centre for Marine Science and Technology to deploy sea noise loggers in and around Scott Reef to:

- gain a synopsis of the presence and movements of great whales in the region
- measure and describe ambient sea noise including analysis of fish choruses and vessel activity over the recording period
- measure seismic survey signal transmission from the *Maxima* seismic survey

The sea noise loggers collect samples of ocean noise at frequent intervals over extended time periods. The data collected and logged on board is post-processed to describe vocalisation patterns of biological sources and the noise produced by human activities during the deployment time frame. The loggers are typically deployed to collect data on vocalising great whales such as minke, humpback and blue whales, plus fish sounds. They collect all ocean sounds and have been used at Scott Reef to monitor marine seismic survey signals, noise produced during an exploration drilling program and in 2007 detected widespread illegal dynamite fishing, presumably by Indonesian fisherman, inside Scott Reef.

The Scott Reef noise logger deployment program was extended from that originally planned and is on-going. At the time of writing this report three loggers were in the water and due for recovery in mid 2011. Longer term deployments spanning many years allows a much clearer view of trends in animal movements to be identified, allows more accurate definition of any anomalous events identified and will enable us to track population trends when appropriate analysis techniques are refined.

The analysis presented builds on previous material presented. Included in this report is:

- summary sea noise data for the period Sep-2008 to Jun-2009
- analysis of humpback calling patterns 2006-2009
- analysis of pygmy blue whale calling trends around Scott Reef 2006-2009
- definition of logger listening areas for pygmy blue whales around Scott Reef, which allows comparison of inshore and Scott reef pygmy blue detection rates
- analysis of Bryde's whale visitation near Scott Reef
- analysis of dwarf minke whale visitation near Scott Reef
- analysis for dynamite fishing in Scott Reef Sep-2008 to Jun-2009
- integration of Sep-2008 to Jun 2009 results with 2006-2009 results

The major reports utilising Curtin sea noise logger data are listed in Table 2. This report falls under CMST job number 861. This report analyses two data sets, Scott West-4 and Scott East-4 set inside the Scott Reef lagoon and synthesis their results with previous data. A third logger, Scott South-4 deployed in open water to the SE of Scott Reef was also intended to be analysed here but it had failed due to a damaged hydrophone cable. The analysis carried out here is not complete, more could be carried out (for example little has been done with Antarctic or Bryde's whale data) plus more data is awaiting analysis and to be synthesised with this report.

A glossary has been included at the document end to assist readers with technical matters.

Table 2: Reports utilising long term sea noise logger data sets in or around Scott Reef for Woodside Energy. The final report listed is that presented here. All reports build on each other.

Reference	description
McCauley, R.D. (2008) Sea noise logger deployment 2006-2008 Scott Reef - data summary and February 2008 field report. Prepared for URS / Woodside Energy, CMST R2008-17. 37 pp., 26 Fig.	Summary of data collected to Feb 2008 only
McCauley R.D., Salgado Kent, C.P. (2008) Sea noise logger deployment 2006-2008 Scott Reef – whales, fish and seismic surveys. Prepared for Woodside Energy, CMST R2008-36, 58 pp., 41 Fig.	For data collected to Feb 2008 - analysis of pygmy blue, part of humpback data, fish choruses
McCauley R.D., (2008) Scott Reef sea noise logger recovery, September 2008, and analysis of drilling noise. Prepared for SKM/Woodside Energy, CMST R2008-46, 43 pp. 31 Fig.	Focused on analysis of drilling related noise using Scott East logger
McCauley, R.D., Salgado-Kent, C.P., Archer, M. (2008) Impacts of seismic survey pass-bys on fish and zooplankton, Scott Reef lagoon Western Australia, Full report of Curtin University findings. Prepared for Woodside Energy, CMST R2008-32, 92 pp., 49 Fig.	Used long term sea noise logger at Scott east to look at fish chorus response to *Maxima* seismic program, described results of seismic passbys on fish and zooplankton
McCauley, R.D. (2008) Measurement of air gun signals from Gigas seismic survey, northern lagoon of Scott Reef, Western Australia. Prepared for Sinclair Knight Merz / Woodside Energy, CMST R2008-36, 22 pp., 16 Fig.	Sea noise loggers set inside northern Scott lagoon used to measure transmission of Gigas seismic survey (mid 2008)
McCauley, R.D. (2009). Sea noise logger deployment Scott Reef, 2006-2008 – whales, fish and seismic surveys. Prepared for Woodside Energy, CMST R2009-15, 88 pp., 61 Fig.	Analysis of Scott sea noise loggers for pygmy blue, humpback and minke whales, fish choruses, illegal dynamite fishing and seismic survey signal examples
McCauley, R.D. (2011). Woodside Kimberley sea noise logger program, September 2006 to June 2009: whales, fish and man made noise. CMST R2010-50, 82 pp., 40 Fig.	Focus on Scott Reef detections and listening ranges for pygmy blue whales. Integration of pygmy blue, humpback, Bydes and dwarf minke detections at Scott with period 2006 to Jun 2009.

4. Methods

4.1 Locations of sites

This report summarises sea noise logger deployments around Scott Reef over Sep-2006 to Jun-2009. The location of all Scott Reef noise loggers from which data has been recovered are shown on Figure 1 with the location of the sites sampled inside Scott Reef shown on Figure 2 with the bathymetry. In addition to the recording sets made in and around Scott Reef a sea noise logger was set west of the Lacepede Islands in 2009 and two locations along the Broome Peninsula are being sampled in 2010. Locations sampled under the Woodside Kimberley sea noise program in and around Scott Reef are:

1) A site approximately 24 km to the SE of Scott Reef (termed Scott South) from which four deployment data sets are available (sampling from 24-Sep-2006 to 02-May-2010, 1316 days although significant gaps occurred) with another logger currently deployed here;
2) A site 17 km to the NE of Scott Reef (Scott North) with one logger lost (set in too deep water) and one recovered (data from 14-Jun-2007 to 04-Feb-2008). No logger is currently deployed here;
3) A location on the western edge of the Scott Reef platform in the southern lagoon set so it was close to open water to the west (termed Scott West-1, West-2 and West-3), this site was sampled from 31-May-2007 to 06-Sep-2008. A noise logger was deployed slightly to the east of this site on the opposite side of Sandy Island over Sep-2008 until June-2009 (Scott West-4) to detect any whales traversing the entrance to the channel separating the two Scott Reef

lagoons. This data set is analysed here. This site was re-sampled over 2009 to May-2010. No logger is currently deployed here.

4) A location in the centre of the Scott Southern lagoon (termed Scott East), sampled from 31-May-2007 to 26-Sep-2008 (Scott East-1 to East-3). The Scott East site was moved NW to the edge of the channel separating the northern and southern lagoons in 2008 to detect any whales traversing the channel. Two noise loggers have been recovered from this site (Scott East-4 & East-5) and another logger is in the water. This report analyses data from Scott East-4;
5) A site to the east of Scott Reef in deep water (Scott Deep-East-1) sampled from May to Dec 2010 (logger currently in the water).

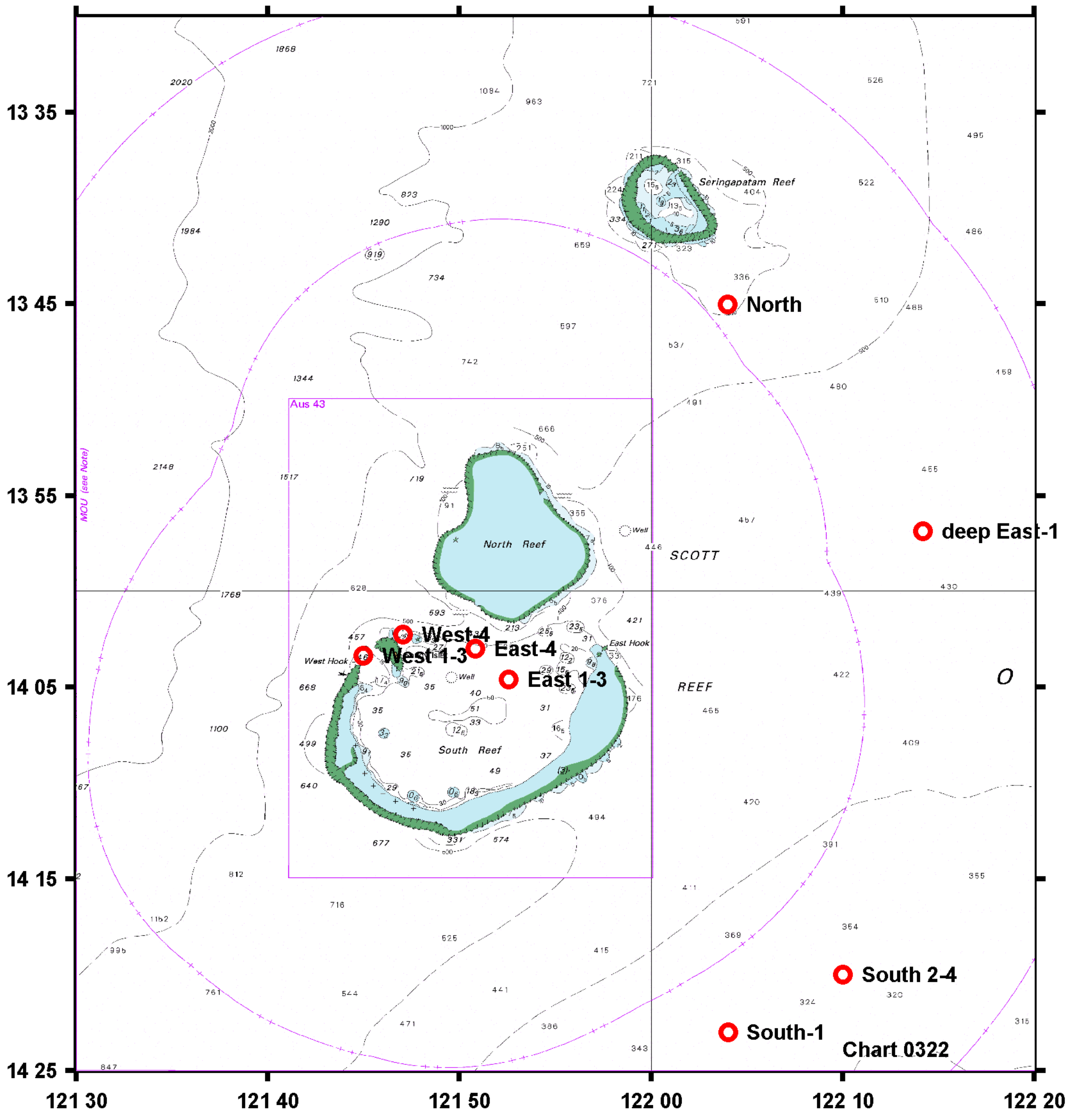

Figure 1: Location of sea noise logger moorings set for Woodside Energy in and around Scott Reef. Noise loggers are currently in the water at the location to the SE of Scott Reef (south 2-4 location), inside the southern lagoon (at Scott East-4 location), and at the deep East-1 site. This report adds data from Scott West-4 and Scott East-4 to existing data.

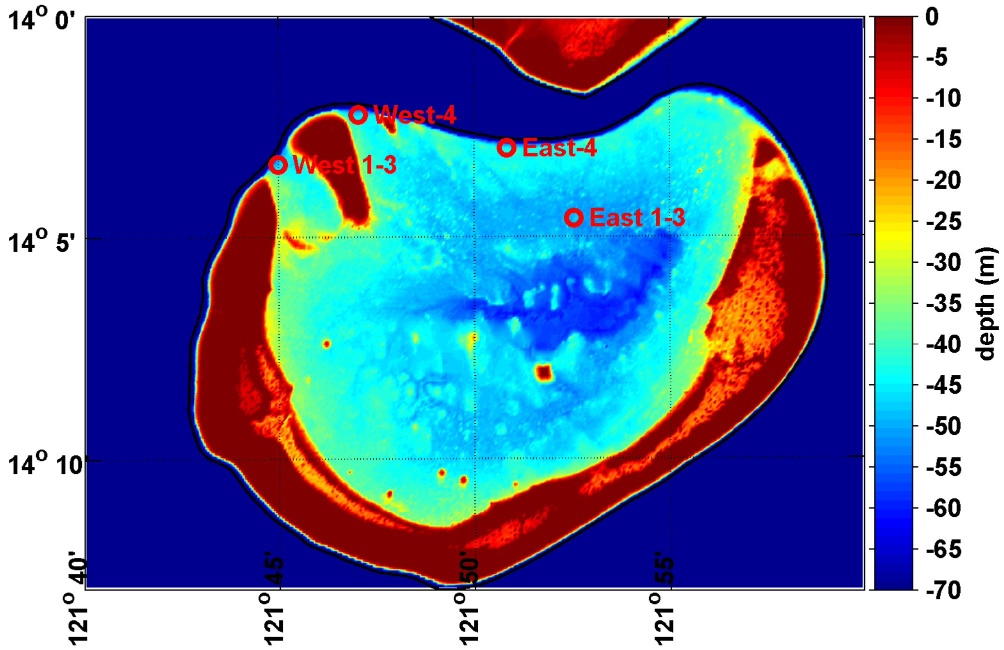

Figure 2: Location of noise loggers set inside Scott Reef and reef bathymetry with the scale clipped at 70 m depth..

The Kimberley noise logger program was expanded in 2009 to begin covering inshore areas. In 2010 the spatial scale was further expanded to include the Broome Peninsula. Sites towards the Kimberley coast sampled to date include:

6) West of Lacepede Island, sampled over Aug-2009 until Oct-2009. No logger is currently at this site;
7) West of Pender Bay, in water from May-2010
8) West of James Price Point, two loggers on one mooring deployed here from May-2010, one logger recovered and replaced in Jul-2010, two loggers currently in the water.

In addition the Western Australian State Government has funded inshore sea noise data collection, off Gourdon Bay in 2008 and off James Price Point in 2009. Locations of all sites sampled are shown on Figure 3. Several sites sampled under different funding sources are also shown on Figure 3.

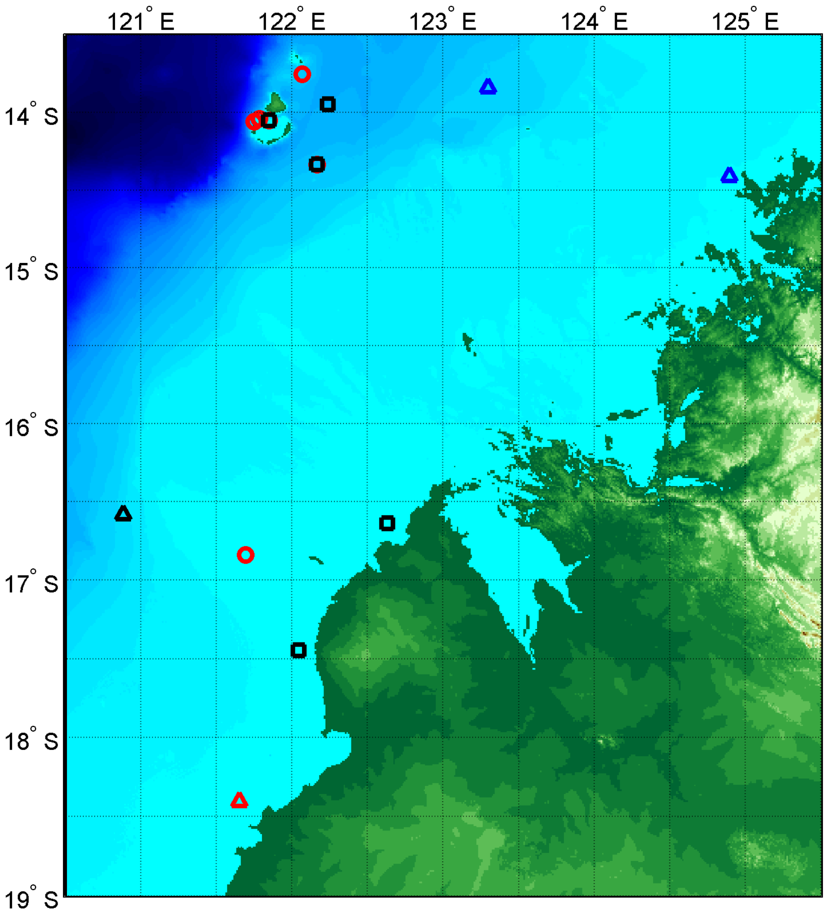

Figure 3: Location of all sites sampled with sea noise loggers since 2003 in the Kimberley (some spot or overnight samples nearshore have been made back to 1992). The black squares are Woodside loggers currently in the water; the red circles are previously sampled Woodside sites; the northern blue triangles were sampled 2006-2008; the black triangle was a DSTO site sampled 2003; and the red triangle was off Gourdon Bay in 2008 (the WA Government),

4.2 Recordings made

The sea noise logger sets, their recording numbers (a Curtin number is assigned to each deployment), locations, water depth at hydrophone (all loggers set on the seabed) and good samples collected are listed on Table 3 for all noise loggers set in the sea noise program. The sampling regimes of sample rates, filters, programmable gains, duty cycle, logger electronics and hydrophones for all noise loggers are given in Table 4. Note that the sampling durations listed in Table 4 are that specified, the logger electronics typically allows an extra five s of sampling to allow for the electronics to stabilise at the recording start and to initialise the file closing process at its end. Thus actual sample durations are around 5 s longer.

To date 24 sea noise loggers have been deployed at 23 sites (one site has two noise loggers deployed). Of these 24 noise loggers: six are still in the water; one was lost (North-1); one was recovered but returned no data (Scott South-4, damaged hydrophone cable before or during deployment); four had partially good data (ie data was good for ½ to 2/3 deployment period) then had partially compromised data in the low frequencies due to a faulty underwater connector type; one had its hydrophone cable bitten through during a deployment; and 11 had excellent data. This report includes 12 data sets, with five data sets awaiting analysis post this report (four under one contract, one to be included with the analysis of gear to be recovered). It was intended to analyse

Scott South-4 in this report but the recording set returned no data (damaged hydrophone cable before deployment).

The deployment sets 2734, 2792, 2873 and 2883 suffered a technical problem where water began to enter the bulkhead connector which connected the hydrophone to the electronics through the housing end-cap. While the quantity of water was small and of no significance to the logger electronics or battery, it was sufficient to cause corrosion in the wires leading to the pre-amplifier (the water fed down the inside of the wires). For the HTI U90 hydrophones used (but not Massa TR1025-C hydrophones, as they are of higher capacitance) this had the effect of altering the hydrophone electrical properties ‘seen’ by the pre-amplifier which lowered the system gain and altered its frequency response. This meant that at some point during the deployment the low frequency response of the system began to degrade, with the frequency at which this occurred gradually creeping upwards with time as the corrosion in the wires increased. To remove this problem we firstly shifted the underwater connector type to a more expensive connector but on testing found similar problems occurred, the issue being that it seems all underwater connectors have a finite number of insertions before they fail somehow. We have now modified our housing design and have shifted all noise loggers to use a through bulkhead connector where the hydrophone is permanently attached to the noise logger end cap and there is no mate-able connector.

The Scott West-2 set (2757 and 2758) had a shark bite through the hydrophone cable 49 days into the deployment (the teeth marks were evident) thus failed from here on.

Table 3: Summary of sea noise recordings made at Scott Reef and the Kimberley. Locations use WGS84 datum. Data sets in normal fonts have been analysed, those highlighted in bold are analysed here and synthesised with all data sets, those in italics are awaiting analysis under separate contracts or in the water. The start/end dates and days are given for the full period in the water with the period of linear calibration given at the Lacepede site followed by the period in-water. The field *Good Recordings* has sample numbers with full calibration

and where applicable, in brackets maximum sample numbers with part calibration.

Set	**Curtin # / sample rate (Hz)**	**Latitude (S)**	**Longitude (E)**	**D. m**	**Start / end good data** **(days recorded) / part calibration times**	**Good recordings**
*South-1	2734 6 kHz	14° 23.016’	122° 04.006’	350	05-Sep-06 to 30-Apr-07 (236.8)	1 – 22681
South-2	2761 6 kHz	14° 20.001’	122° 10.001’	358	14-Jun-07 to 03-Feb-08 (233.6)	4 – 22430
South-3	2793 6 kHz	14° 19.926	122° 09.994	358	03-Feb-08 to 27-Sep-08 (237.1)	207 – 22966
@South-4	2816 6 kHz	14° 19.772’	122° 10.000’	358	Failed from damaged hydrophone cable	failed
South-5	*2871 6 kHz*	*14° 20.110’*	*122° 09.942’*	*336*	*11-Aug-2009 to 02-May-2010 (263.4)*	*1-25078*
South-6	*6 kHz*	*14° 20.133’*	*122° 10.015’*	*330*	*In water, recovery Nov-2010*	
North-1	6 kHz	13° 45.873'	121° 57.222'	570	Not recovered – lost	lost
North-2	2762 6 kHz	13° 45.003'	122° 4.000'		14-Jun-07 to 04-Feb-08 (234.8)	2 – 22410
East-1	2740 6 kHz 2741 2.5 kHz	14° 4.585’	121° 52.549’	48	14-Jun-07 to 12-Sep-07 (89.8)	6 – 8626
East-2	2759 6 kHz 2760 2.5 kHz	14° 4.577’	121° 52.549’	48	19-Sep-07 to 18-Jan-08 (121.1)	4 – 11499
East-3	2791 6 kHz	14° 04.58’	121° 52.54’	48	05-Feb-08 to 28-Sep-08 (236.5)	213 – 23007
East-4	**2817** **6 kHz**	**14° 03.041’**	**121°50.856**	**48**	**28-Sep-2008 to 09-Jun-2009 (254.1)**	**60 - 24390**
East-5	***2872 6 kHz***	***14° 03.09’***	***121° 50.825’***	***48***	***12-Aug-2009 to 02-May-2010 (263.2)***	***52-25321***
East-6	*6 kHz*	*14° 03.069’*	*121° 50.971’*		*In water, recovery Nov-2010*	
West-1	2735 6 kHz 2744 2.5 kHz	14° 3.366'	121° 44.981'	48	14-Jun-07 to 12-Sep-07 (89.9)	3 - 8637
**West-2	2757 6 kHz 2758 2.5 kHz	14° 3.378’	121° 45.000’	48	20-Sep-07 to 08-Nov-07 (49.2)	16 – 4743
*West-3	2792 6 kHz	14° 03.386’	121° 44.990’	48	05-Feb-08 to 06-Sep-08 (214)	231 - 13200 (20850)
West-4	**2818** **6 kHz**	**14° 02.282**	**121° 47.095**	**48**	**28-Sep-2008 to 09-Jun-2009 (254.4)**	**65 - 24489**
Deep-E-1	*6 kHz*	*13° 56.852’*	*122° 14.196’*	*400*	*In water, recovery Nov-2010*	
**Lacepede*	*2873 6 kHz*	*16° 50.418’*	*121° 41.555’*	*31*	*13-Aug-2009 to 09-Oct-2009 (57.4)* *(09-Oct-2009 to 23-Apr-2010, 196.2)*	*138-5650 (24484)*
Pender		*16° 38.357’*	*122° 37.884’*	*18*	*In water, recovery Nov-2010*	
^JP Pt.	*2883 6 kHz*	*17° 26.740’*	*122° 02.680’*	*19*		
JP Pt..		*17° 26.740’*	*122° 02.680’*	*19*	*In water, recovery Nov-2010*	

***** - the frequency response of this system began to degrade part way through the recording due to a faulty underwater connector.
****** - a shark bit through the hydrophone cable during this sample at day 49 of the recording
@ - this noise logger had a damaged hydrophone cable on recovery, all samples were bad so presumably the cable was damaged during deployment
^ - this data set had a faulty hydrophone underwater connector which altered the system response. The unit was replaced part way through its nominal recording period. A calibration curve was made before the logger was deployed thus the data recovered is useable.

Table 4: Sampling regimes and hardware for each logger from which data has been recovered or which is in the water. The gain is the logger programmable gain, a further 20 dB gain was applied by the pre-amplifier. Gear in the water is highlighted in bold.

Site	Set	Gain (dB)	Sample rate / anti-aliasing filter (kHz)	Duty cycle	Logger	Hydrophone
South-1	2734	20	6 / 2.8	200 s every 900 s	Resign	Massa TR1025-C # 494
South-2	2761	20	6 / 2.8	200 s every 900 s	Signal	HTIU90 011
South-3	2793	20	6 / 2.8	200 s every 900 s	Recycle	HTIU90 006
South-4	2816	20	6 / 2.8	200 s every 900 s	Gareth	*HTIU90 003
South-5	2871	20	6 / 2.8	200 s every 900 s	E13 / H34X	Massa TR1025-C # 498
South-6		**20**	**6 / 2.8**	**200 s every 900 s**	**E13**	**Massa TR1025-C # 498**
North-2	2762	20	6 / 2.8	200 s every 900 s	Silicon	HTIU90 003
East-1	2740 2741	20 0	6 / 2.8 2.5 / 1.1	200 s every 900 s 300 s every 900 s	Reynold	GEC SH101X 083
East-2	2759 2760	20 0	6 / 2.8 2.5 / 1.1	200 s every 900 s 300 s every 900 s	Revelrey	GEC SH101X 083
East-3	2791	20	6 / 2.8	200 s every 900 s	Redo	HTIU90 010
East-4	2817	20	6 / 2.8	200 s every 900 s	Tristian	Massa TR1025-C # 494
East-5	2872	20	6 / 2.8	200 s every 900	14 / H33X	Massa TR1025-C # 499
East-6		**20**	**6 / 2.8**	**200 s every 900**	**14 / H33X**	**Massa TR1025-C # 499**
West-1	2735 2744	20 0	6 / 2.8 2.5 / 1.1	200 s every 900 s 300 s every 900 s	Revelrey	GEC SH101X 081
West-2	2757 2758	20 0	6 / 2.8 2.5 / 1.1	200 s every 900 s 300 s every 900 s	Reynold	GEC SH101X 081
West-3	2792	20	6 / 2.8	200 s every 900	Revenge	HTIU90 002
West-4	2818	20	6 / 2.8	200 s every 900	Galahad	Massa TR1025-C # 467
Lac. -1	2873	20	6 / 2.8	200 s every 900	Gawain	Massa TR1025-C # 494
Deep-East-1		**20**	**6 / 2.8**	**200 s every 900**	**Percival**	**Massa TR1025-C # 495**
Pender Bay		**20**	**6 / 2.8**	**200 s every 900**	**Resign**	**HTIU90 006**
JPP-1		**20**	**6 / 2.8**	**200 s every 900**	**Recycle**	**HTIU90 015**
JPP-2	2883	20	6 / 2.8	200 s every 900	Gawain	Massa TR1025-C # 494
JPP-3		**20**	**6 / 2.8**	**200 s every 900**	**Lancelot**	**HTIU90 033 – from 02-07-2010**

All noise loggers were calibrated before deployment by inputting white noise of known level through the bulkhead connector. This gave the system gain with frequency, with the system response for the sets Scott East-2 (2817) and Scott West-4 (2818) analysed here shown on Figure 4. The logger electronics deliberately apply a low frequency rolloff below 8 Hz to flatten the naturally high sea noise levels and so increase the loggers input dynamic range (ie. low frequencies are less likely to saturate). This rolloff was corrected in post-processing. The loggers were calibrated from 1 Hz to the anti-aliasing filter setting using the system gain curves and the hydrophone sensitivity.

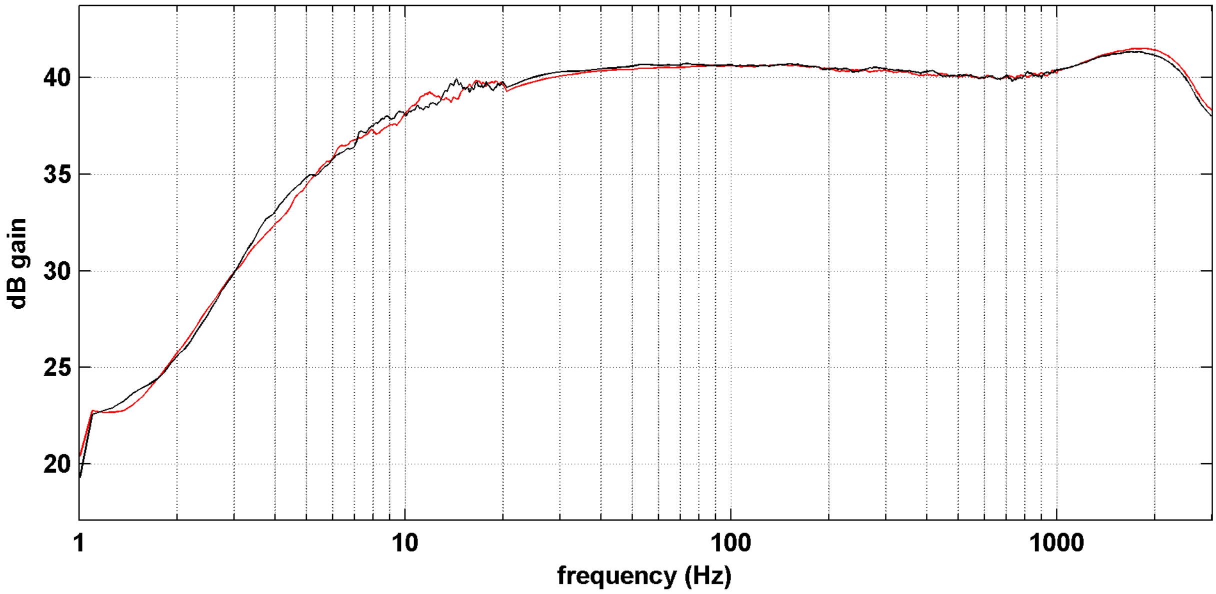

Figure 4: Set of system gain curve for the sets 2817 (East-4, red curve) and 2818 (West-4 black curve).

All loggers were time synchronised to GPS transmitted UTC time before deployment and the clock drift read after deployment, with estimated clock accuracies at any point in time of the order of ± 250 ms. The logger clocks jump when going in and out the water due to the sharp temperature change thus the drift determined from the GPS synchronisations is not completely linear between the time synchronisations.

4.3 Time frame of recordings

The time frame of recordings is shown on Figure 5. This figure includes overlapping loggers set near Browse Island (142 km ENE of Scott Reef), along the Kimberly coast off the Maret Islands and off Gourdon Bay on the Kimberley coast.

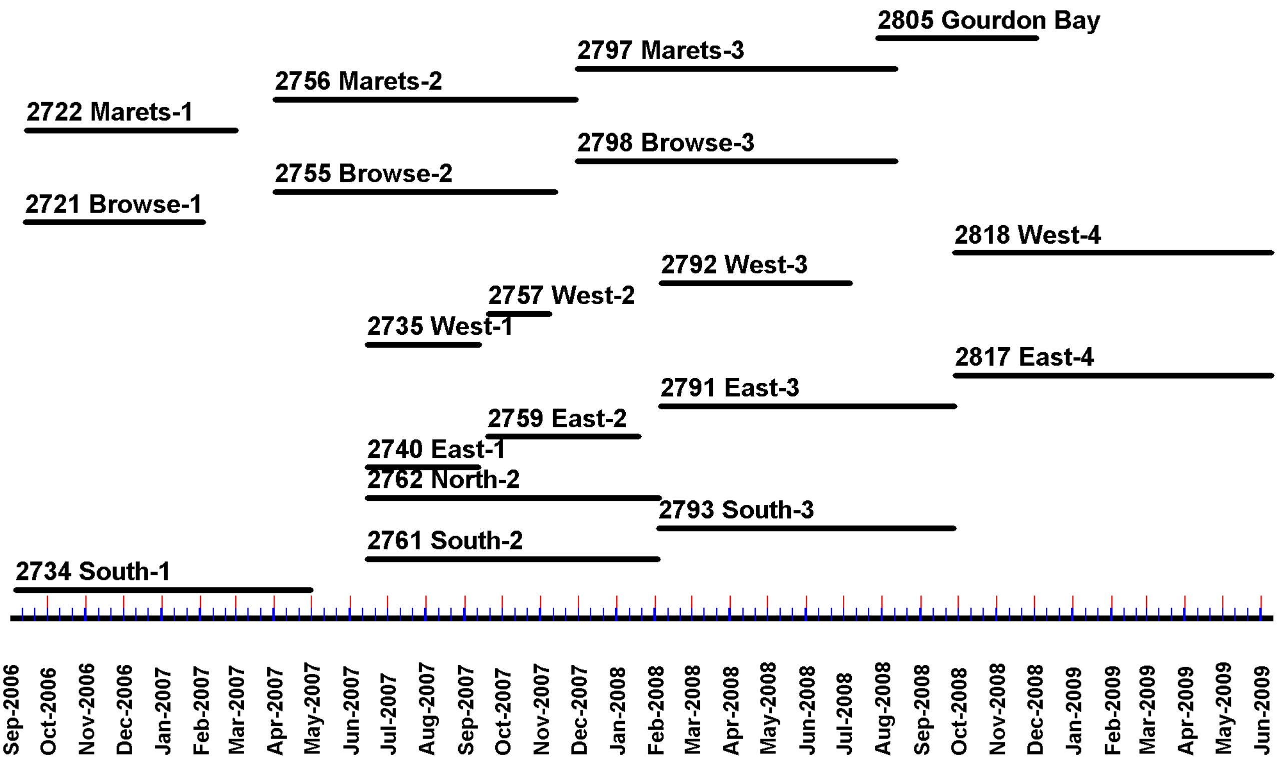

Figure 5: Time frame of all Woodside Kimberley noise loggers to mid 2009 plus: one site set 142 km to the ENE of Scott Reef (Browse); one site along the Kimberley coast; and one site off Gourdon Bay south of Broome. Ticks are shown by month and in 10 day increments within a month.

4.4 Comparative regional scale recording sets

The Scott Reef noise logger data set has been combined with regional scale acoustic data sets derived from sea noise loggers, to better define seasonal whale movement patterns and allow for comparisons of fish chorus activity. The locations of sites on the North West Shelf into the Kimberley for which such data sets are currently available is shown on Figure 6. The time frames of these deployments are given in the caption of Figure 6. Currently Kimberley loggers are set around Scott Reef, these due for recovery in late 2010 and along the Broome Peninsula (due for recovery in late Nove-2010). In addition to the sites shown on Figure 6 historical data sets are available along the Kimberley coast from Broome northwards, made in 1992 (overnight or several day sets made with tape deck systems).

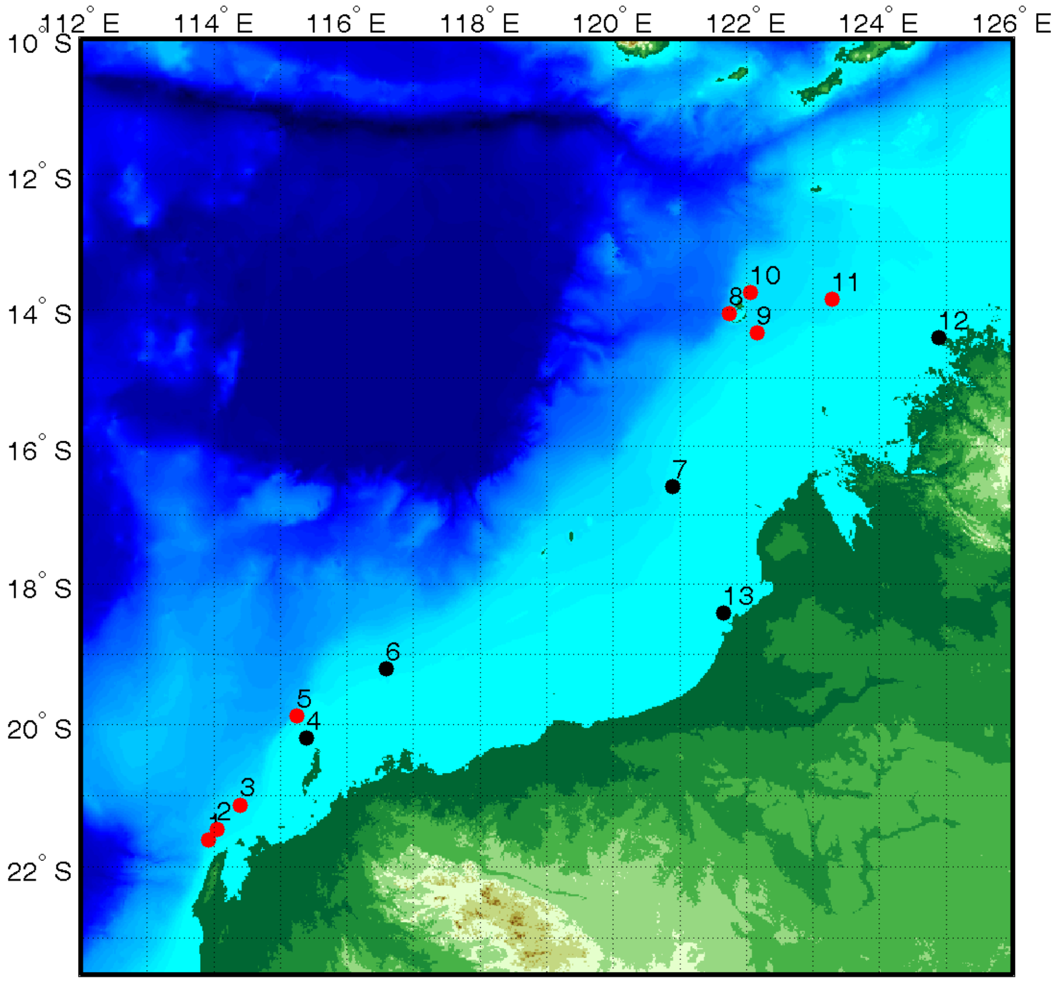

Figure 6: Locations of most sea noise data sets (long term deployments) in hand for the North West Shelf and Kimberley region of northern WA for which good samples have been made (sites with logger lost or data no good, not shown). Sampled sites are colour coded as those which have detected pygmy blue whales (red) and those which have not (black). Humpback whales have been detected at all sites. The sites are numbered as: 1) Exmouth 2000; 2) Exmouth 2004-2005, (Woodside); 3) Exmouth 2005; 4) immediate north end of Monte Bello Islands; 5) north of Monte Bello Islands Pluto field (Dec-2005 to Nov-2006, Woodside); 6) NE of Monte Bello Islands on the NW Shelf, Jun-2006 to Sep-2006; 7) NW of Broome, Defence (Mar-2003 to Aug-2003, DSTO); 8-10) the Scott Reef sites (2006-2008 reported here); 11) site east of Scott Reef and closest to Browse Island set in 2006-2008; 12) off the Maret Islands (Kimberley coast, 2006-2008); and 13) an inshore site set over late 2008 for humpbacks (DEC, WA Govt. funded). Currently loggers are running at Scott Reef locations 8) and 9) and east of Scott Reef (Woodside), along the Broome peninsula (Woodside); near sites 4) and 5) north of the Monte Bello Islands, off Onslow in 20 m depth, to the SW of Barrow Island in 45 m depth, west of Thevenard Island in 200 m depth (near site 3) and in deep water (950 m) west of Barrow Island.

4.5 Reference systems spatial analysis and acoustic units

All times given in this document are WST unless otherwise indicated. All locations use the WGS84 chart datum. The Eastings and Northings all use reference zone '51 L'. Spatial calculations have been made either using Easting and Northing co-ordinates and assuming a flat earth (short range) or using the Matlab Mapping toolbox and accounting for an elliptical earth. All analysis has been carried out in the Matlab software environment using programs written at CMST.

The acoustic units and their definitions used in this report are described in the glossary.

4.6 Great whale call identification

The noise loggers are particularly powerful at discriminating time-series patterns in whale visitations and fish activity via monitoring their respective calling behaviour. For whale censusing the ideal outcome from the passive acoustics is to be able to gain an accurate measure of the number of individual whales of a given species calling at an instantaneous point in time, or for practical purposes here, within each 200 s sample. These counts then give a relative abundance estimate for the source. Obtaining counts of individual whales calling per sample requires passing a search algorithm tailored for the call type across each data set. The entire data set is too large to manually search. Building search algorithms is difficult and time consuming due to a variety of complicating factors. Given these confounding factors which confuse the search algorithms, then their outputs are generally best manually cross checked, or their accuracy determined against a manually checked batch. We have developed an efficient means of cross checking search algorithm outputs, which: 1) checks the search algorithm output and only displays spectrograms not previously checked; 2) once all search output algorithm outputs are checked, then brackets the confirmed detections by five samples (can be another value) and displays these for checking; 3) iterates the bracketing process until no new samples are returned. Various search techniques have been utilised here, the technique used depending on the call type and the type of background noise across the frequency of interest (with background noise anything other than the call one is searching for). Not all search algorithms were fully cross checked in this report. The status of whale searching, algorithm output cross checking and the metric output for all Scott Reef data sets currently available is given in Table 5. Note that at this stage an algorithm to search for Antarctic minke whale calls has not been developed so the presence of these calls was noted during manual searching for other species.

Note that for pygmy blue and humpback whales the unit given by the searching process is the number of instantaneously calling individual whales. Assuming that the proportion of whales calling within a population is constant (ie for example only mature male humpbacks sing) then this measure is a robust relative abundance estimate when averaged across a season. When comparing this metric between different times and locations we assume that the proportion of the population calling is constant in time and space, with the measure independent of call rate (calls per individual per time period), since this is accounted for in the unit derivation.

For dwarf minke whales a measure of the minimum time period between calls for an individual whale has been calculated from the search algorithm output and this used to establish the number of instantaneously calling individuals. The search technique used for dwarf minke whale calls has not been thoroughly checked for this report, and the technique of converting recognised dwarf minke calls into the number of instantaneous calling whales can currently only be done with the search algorithm output, since for each call the detection time within a sample is required.

For Bryde’s whales the minimum time between successive calls from the same individual has not been determined, thus the measure of individuals calling at any point in time cannot be given. Thus for Bryde’s whales a measure of the number of calls per 200 s is given as the call metric. This can be used as a relative abundance estimate if we assume that the population maintain a mean call rate, that a constant proportion of the population in the area call and that this proportion does not change with time and space.

Table 5: Status of whale searching for this report. The locations are **S** = Scott South, **E** = Scott East, **W** = Scott West and **N** = Scott North. Abbreviations are: **Alg** = search algorithm run (**Y / N**); **Man** = if search algorithm output manually checked (**Y / N** or **P** = partly); **Metric** - the measure of whales with: **#I** = count of individual whales calling at a point in time or **C/200 s** being the number of calls per 200 s; **ND** = not detected.

Location	**Pygmy Blue**			**Humpback**			**Bryde's**			**Dwarf Minke**		
	Alg	**Man**	**Metric**	**Alg**	**Man**	**Metric**	**Alg**	**Man**	**Metric**	**Alg**	**Man**	**Metric**
S-1 2734	Y	Y	# I	Y	Y	# I	Y	N	C/200 s	Y	P	C/200 s & # I
S-2 2761	Y	Y	# I	Y	Y	# I	Y	N	C/200 s	Y	P	C/200 s & # I
S-3 2793	Y	Y	# I	Y	Y	# I	Y	P	C/200 s	Y	P	C/200 s & # I
N-2 2762	Y	Y	# I	Y	Y	# I						
E-1 2740		Y	ND	Y	Y	# I				Y	P	C/200 s & # I
E-2 2759		Y	ND							Y	P	C/200 s & # I
E-3 2791		Y	ND	Y	Y	# I				Y	P	C/200 s & # I
E-4 2817	N	Y	# I	N	Y	# I	Y	Y	C/200 s	Y	Y	C/200 s & # I
W-1 2735	Y	Y	# I	Y	Y	# I						
W-2 2757	Y	Y	# I									
W-3 2792	Y	Y	# I									
W-4 2818	Y	Y	# I	N	Y	# I	Y	Y	C/200 s	Y	Y	C/200 s & # I

4.7 Noise logger listening ranges

Noise logger listening ranges were calculated to define the detection area of a noise logger. In this report listening ranges are calculated for a single background noise level only, with the background noise level chosen typical of that receiver location over the period of interest and spanning the frequency band of the signal for which the listening range is calculated. In future reports the background noise level for each sample will be taken into consideration when calculating listening areas.

The noise logger listening area at a site is species specific, dictated by the frequency range of the call and the average call source level (energy radiated at an equivalent of 1 m range). The listening ranges have been calculated by:

- Deciding on the frequency span of the call and dividing this into a number of discrete frequencies spanning the main energy output of the call (since sound transmission modelling runs at discrete frequencies);
- Obtaining representative call source levels, usually from the literature. For pygmy blue whale calls different frequency components of a call have been allocated different source levels, based on previously measured call received levels.

- Obtaining representative caller source depths (the modelling requires a source depth and this depth may be critical in lateral sound transmission). The modelling carried out here assumes a range of caller source depths based on the literature.
- Defining the bathymetry paths on radial headings run from the receiver location. The sound transmission models are then run along each heading.
- Defining the seabed geo-acoustic properties and the water column sound speed profile along each heading. These have been assumed to be constant along each heading from the source.
- Running a sound transmission model set up for each frequency and environment along each heading. This is done using the theory of reciprocity where the calculations are made with the source at the receiver location (hydrophone) and the receiver in the water column (where the real-source would be). The model runs allow the full water column sound field to be calculated (usually around a one m vertical step) out to the range limit set (range resolutions of 25-200 m depending on the case). Using reciprocity a selection of source depths can then be chosen and the modelled source-receiver orientation switched with the real source-receiver orientation so that the real-receiver becomes the hydrophone location and the real-source is in the water column.
- Along each heading the sound transmission modelling output is then averaged across the frequency span of the call and the assumed source depths, to give an energy loss for the call with range from the receiver.
- The call source level then has the averaged sound transmission loss subtracted to give the estimated received level at the hydrophone, with range from the source.
- This curve of estimated received call level with range is then smoothed using a probability approach outlined in McCauley et al (2001).
- The curve is run down to the ambient noise level in the frequency band of the call, to determine the outside call detection range. This step is determining the outside range signals are detected at by the noise logger given the prevailing noise conditions. The ambient noise conditions may be set slightly higher than as measured if the appropriate search algorithm does not detect calls down to the background noise state (some of the algorithms have a threshold the signal must exceed before the detection threshold is tripped)
- The call outside detection range for the defined conditions are interpolated between headings around the receiver to give a polygon of call listening area.
- Where appropriate the influence of any blocking bathymetry is calculated and sections with shallow bathymetry are removed from the listening area polygon. The depth profiles along a series of closely spaced headings around the receiver are retrieved from a bathymetry atlas for the area and ranges at which the seafloor becomes too shallow for a whale to be in, are tagged. The polygon around the receiver location is then adjusted to the range limited locations along each heading.

The details for each species are listed in the results. For pygmy blue whales several listening ranges have been calculated, for different frequency components of the call and for different source levels.

5. Results

Results are presented as: a) a general summary of the recording period Sep-2008 to Jun-2009; b) the estimates of logger listening ranges; c) results for whale species studied in the order humpbacks, dwarf minke whales, Antarctic minke whales, pygmy blue whales and Bryde's whales; d) measurements of fish choruses; and e) identification of probable underwater explosive events from within Scott Reef. Previous reports have dealt with vessel noise related to drilling (McCauley (2008) and the Maxima seismic survey noise (McCauley et al 2008). See Table 2 for a summary of reports produced during this program.

While the primary emphasis of this report is whale presence, notably pygmy blue whales in the vicinity of Scott Reef, there is a great deal of other information inherent in the sea noise data sets. The fish chorus data is analysed as the different choruses reflect the behaviour of large numbers of fish over long time frames. The seasonality in fish choruses reflect secondary productivity, either by fish calling as part of their foraging behaviour or productivity being a key driver of reproductive output which is reflected in reproductive related fish calling. The fish chorus believed produced by nocturnal planktivorous fishes and analysed within Scott Reef below, is believed to reflect local secondary productivity. By tracking these fish choruses over long time frames we can get a potential proxy for the reef system health, changes in this and of inter-annual shifts in secondary productivity.

To date most of the seismic survey signals received by the noise loggers have not been analysed. Since preparing this report the author has obtained the navigation data for several large seismic surveys run in the region in 2007-2009 and intends to analyse these signals at some point. There have and continue to be, large numbers of different seismic surveys run in deep water in north Western Australia. Many of these air gun signals arrive at the various noise loggers. This data can be analysed for: transmission of different seismic sources in the area; and the long term contribution of seismic surveys to the ambient noise of the area.

Each of the sections in the results is preceded with a short description of what has been added or altered from previous, in the analysis carried out for this report.

5.1 Data summary

To facilitate a visual inspection of the data for time-series trends, results are presented as 50 day summary plots for the data sets analysed in this report, Scott East-4 (2817) and Scott West-4 (2818). Different noise sources which occurred across the period Sep-2008 to Jun-2009 are highlighted and their contributions to the ambient noise regime of the area can be seen in the plots presented in this section.

These 50 day plots are made by taking the time averaged power spectra of each sample at four frequency resolutions, averaging each of these across 10 samples (150 minutes of elapsed time), and stacking a combination of the averaged four frequency resolutions through time on a colour plot. The figures are displayed with a logarithmic frequency scale from 10 Hz to 2800 Hz (the upper calibrated limit of the recording system) and a fixed colour scale with bounds from 55 to 100 dB re 1 $\mu Pa^2/Hz$ respectively. The colour scale bounds are fixed to standardise the plots and optimise the colour dynamic range (so highlighting the natural fish chorus levels which tend to be lost if the full recording dynamic range is used). By using a fixed colour scale, levels which fall below or above the bounds are set at the respective bound-colour. These figures show broad scale temporal patterns only and because of the averaging involved (within a sample and across the 10 consecutive averaged samples) can miss or not display well, signals which are short in relation to the sample length, such as humpback signals. The plots tend to highlight signal types which are either intense and / or which persist across the 200 s sample length either through a long signal duration (ie. pygmy blue or Bryde’s whale and vessel noise) or involve multiple signals within a sample (such as fish chorusing activity or air guns).

A series of these stacked sea noise spectra with corresponding time periods for Scott East-4 and West-4 overlain are shown on Figure 7 to Figure 11. These figures show the samples numbers (top axis), moon phase (full or new moon) and date. The respective figures and highlights evident on each one are:

- Figure 7, 29-Sep-2008 to 17-Nov-2008 - Air gun signals, vessel noise, fish choruses, fish calling and pygmy blue whales – Low level air gun signals were evident at the Scott East site but not Scott West site. Vessel noise from a rig tender associated with drilling outside of Scott Reef was prevalent at the Scott East site over November 2008 to January 2009. Fish choruses were common and show the daily and lunar patterns. One fish chorus type dominated at the Scott East site while this and a second chorus type were present at the Scott West site. Pygmy blue whales were prevalent at the Scott West site but while present, do not show on these plots at the Scott East site.
- Figure 8 – 18-Nov-2008 to 06-Jan-2009 - Fish choruses and daytime fish calling, vessel noise – The air gun signals disappeared from the Scott East site, but vessel activity stayed. Strong tones associated with vessels appeared at the Scott East site. The Scott West site was dominated by fish calling. Pygmy blue whales were present at Scott East-4 and West-4 but the calling was either too distant or infrequent to show on these plots.
- Figure 9 - 07-Jan-2009 to 25-Feb-2009 - Fish choruses and daytime fish calling, vessel noise – Vessel noise remained persistent throughout this period at the Scott East site. The fish choruses at Scott East begin to show clear increases in level around the new moon period.
- Figure 10 - 26-Feb-2009 to 16-Apr-2009 – Fish choruses and daytime fish calling, Bryde’s whales – Brydes whales were present at the Scott East and West sites. The vessel noise has largely gone from Scott East-4 and was not present at Scott West-4.
- Figure 11 - 17-Apr-2009 to 05-Jun-2009 - Fish choruses and daytime fish calling, Bryde’s whale signals were prevalent at the Scott West site and present to a lesser degree at the Scott East site. Again little vessel noise was present and no seismic survey activity was obvious.

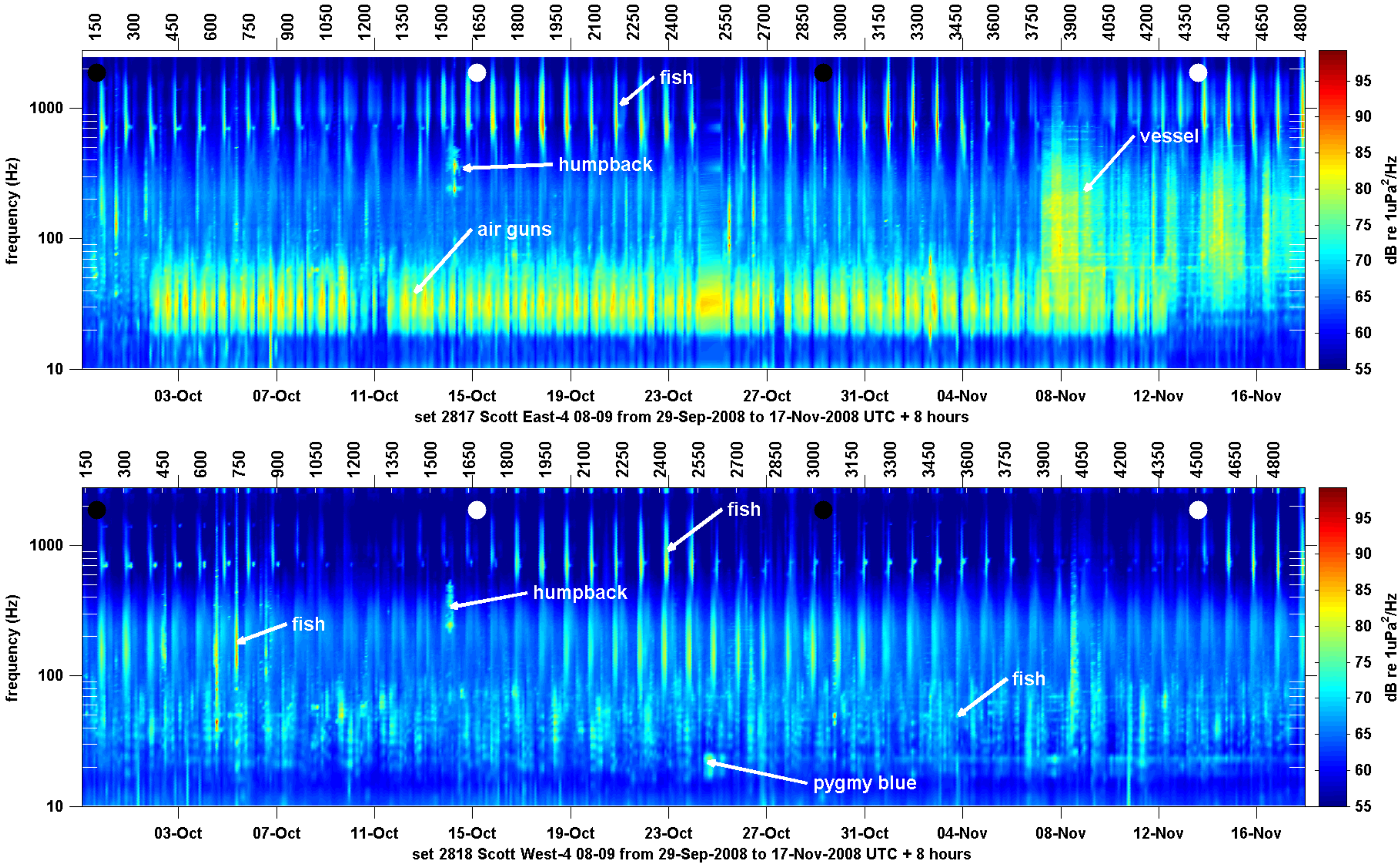

Figure 7: Stacked sea noise spectra from Scott East-4 (top) and West-4 (bottom) for 29-Sep-2008 to 17-Nov-2008. Dark circles are times of new moon, light circles, full moon.

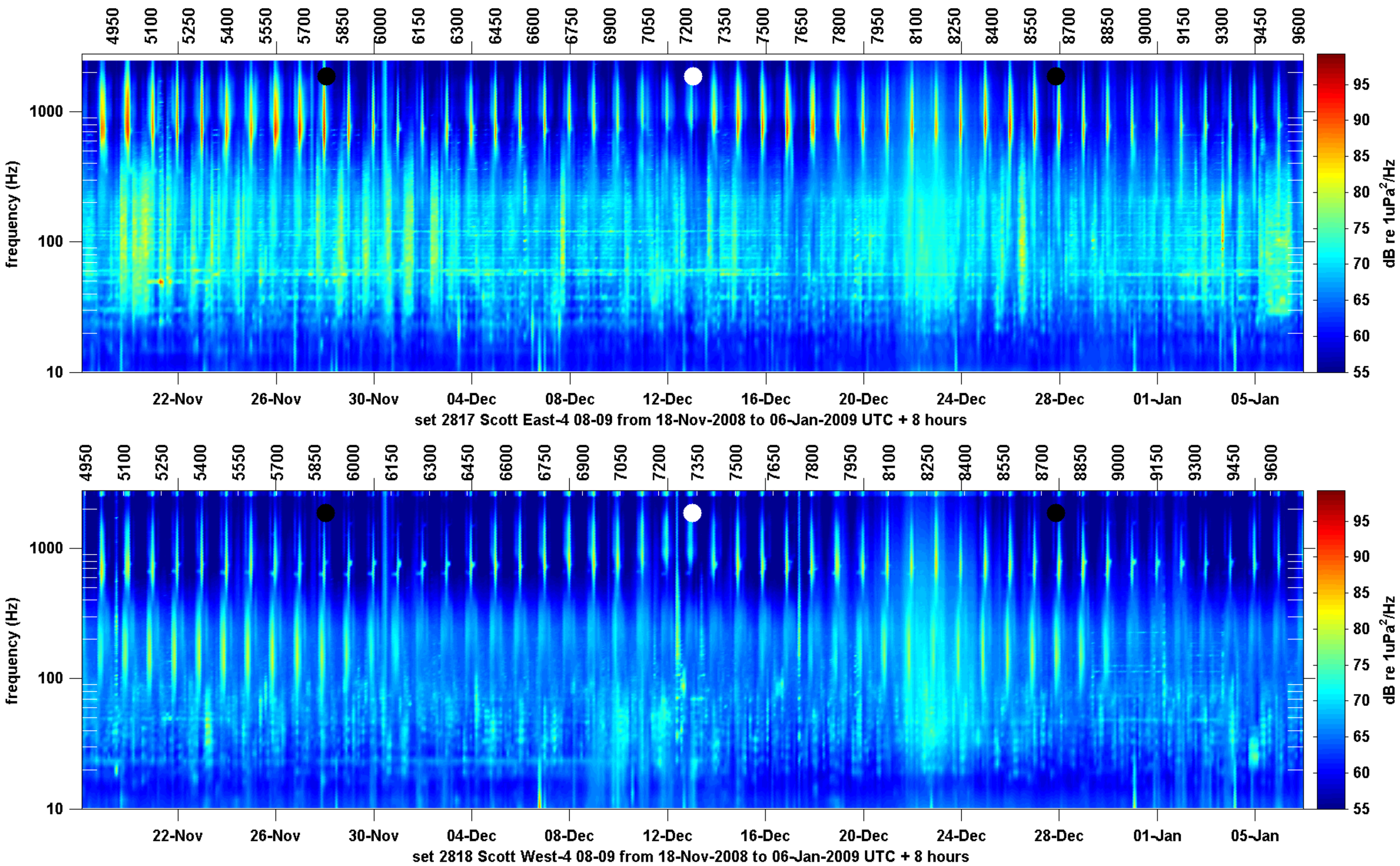

Figure 8: Stacked sea noise spectra from Scott East-4 (top) and West-4 (bottom) for 18-Nov-2008 to 06-Jan-2009. Dark circles are times of new moon, light circles, full moon.

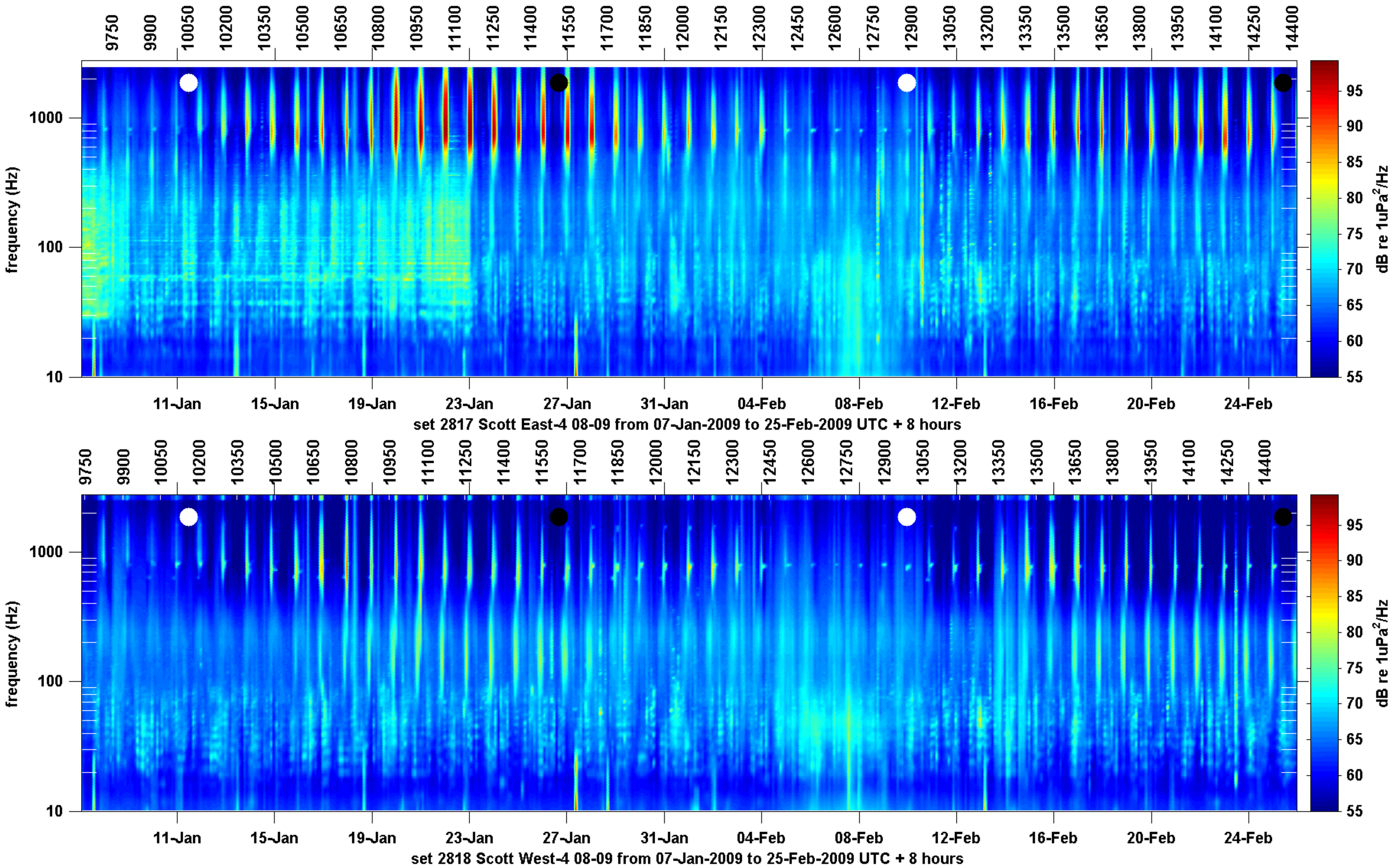

Figure 9: Stacked sea noise spectra from Scott East-4 (top) and West-4 (bottom) for 07-Jan-2009 to 25-Feb-2009. Dark circles are times of new moon, light circles, full moon.

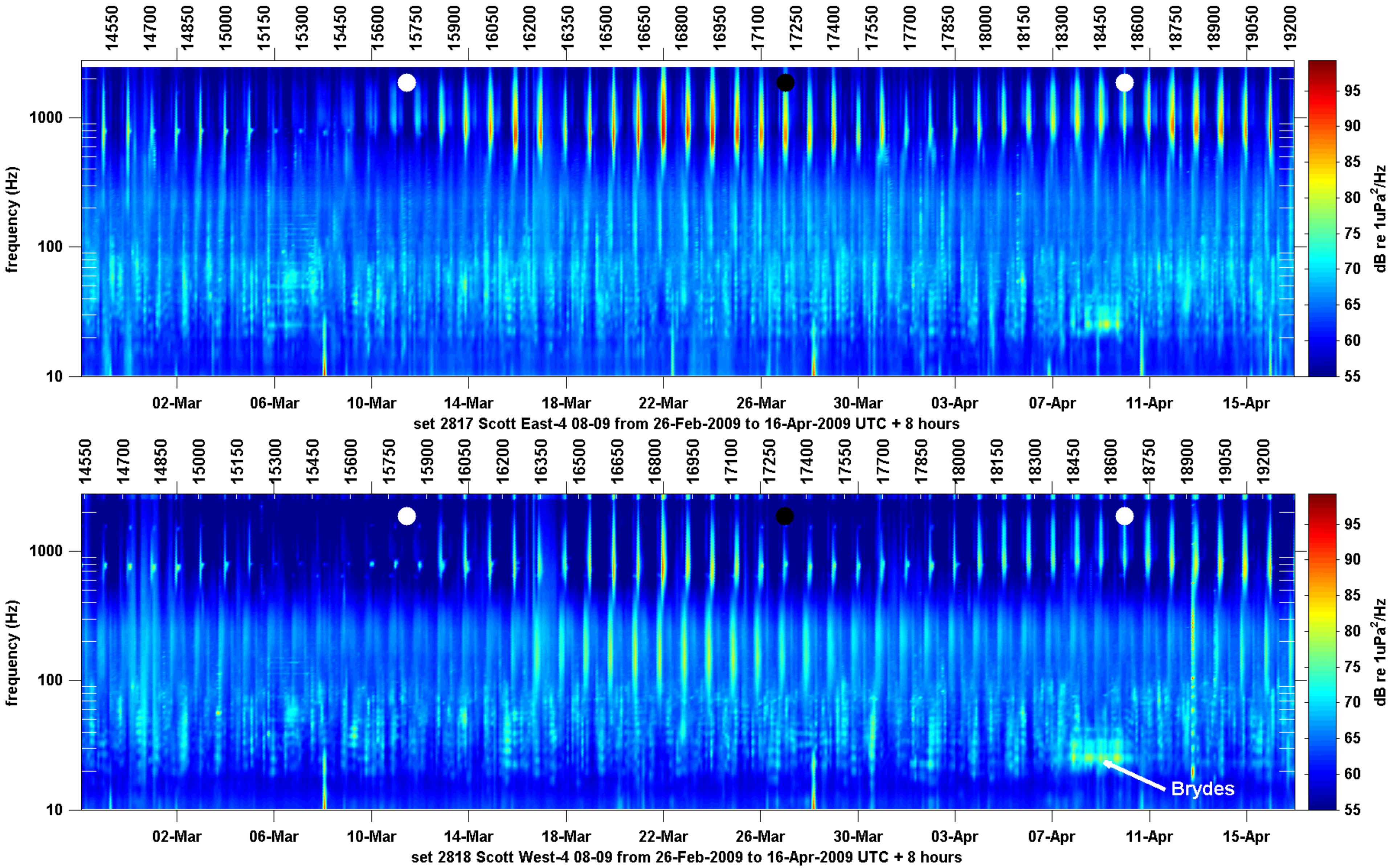

Figure 10: Stacked sea noise spectra from Scott East-4 (top) and West-4 (bottom) for 26-Feb-2009 to 16-Apr-2009. Dark circles are times of new moon, light circles, full moon.

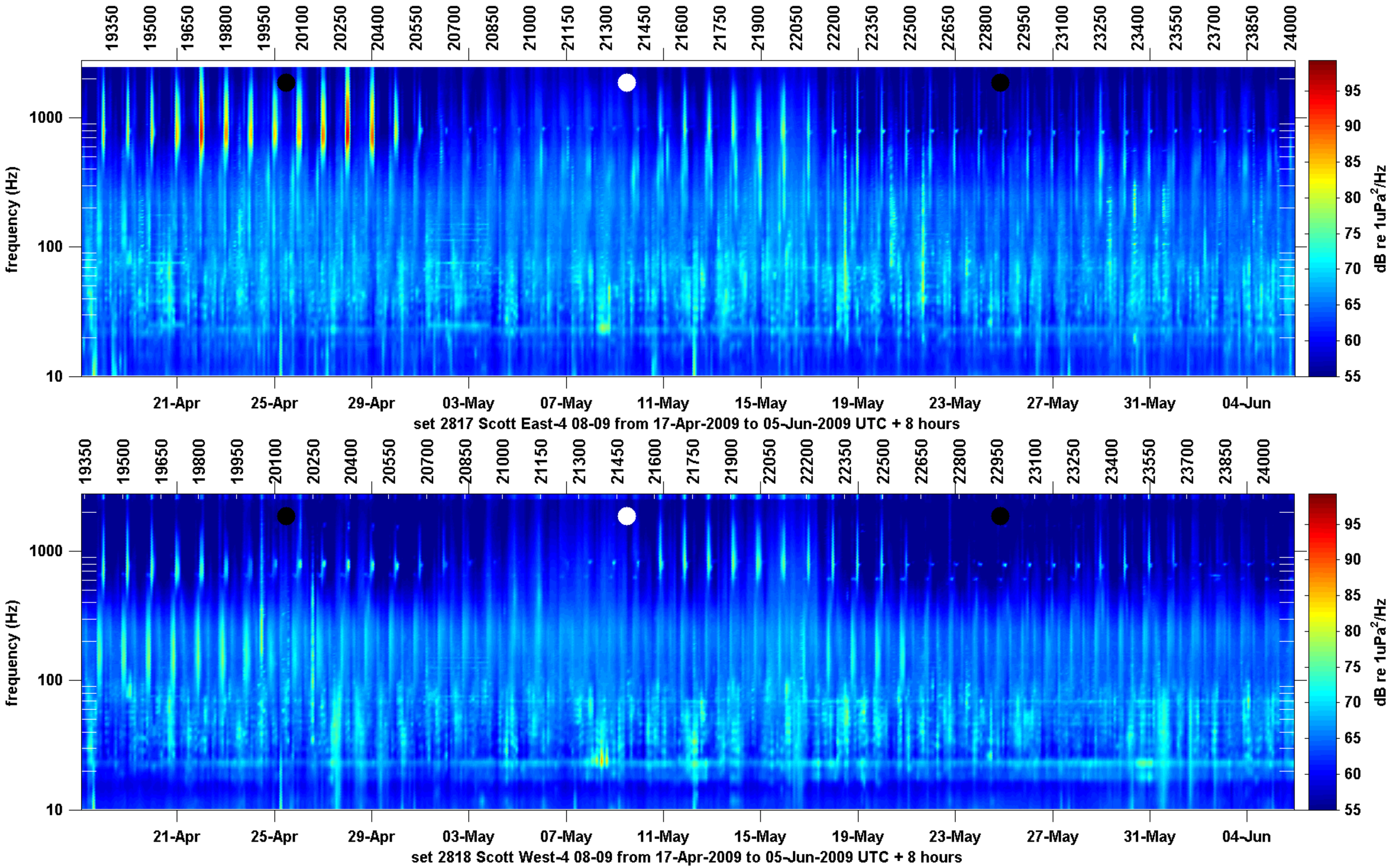

Figure 11: Stacked sea noise spectra from Scott East-4 (top) and West-4 (bottom) for 17-Apr-2009 to 05-Jun-2009. Dark circles are times of new moon, light circles, full moon.

5.2 Logger listening ranges

5.2.1 New data and analysis- logger listening ranges

Humpback and pygmy blue whale listening ranges were previously calculated in McCauley and Salgado Kent (2008) for the open water sites of Scott South and Scott North. The calculations of listening ranges have not been altered although the areas defined have been re-calculated using a spherical earth rather than a flat one, to give slightly different areas.

The detection ranges for pygmy blue whales from the loggers set on the Scott Reef platform have been calculated here. The listening areas of Scott West-1 to West-4, Scott East-1 to Scott East-3 and Scott East-4 (Table 3) were calculated to enable the trends of pygmy blue whale passage in and near Scott Reef to be established.

5.2.2 Humpback and pygmy blue whale listening ranges Scott South and North

The approximate listening range for pygmy blue and humpback whales at the Scott South and Scott North site were calculated along different headings about the receivers using a given background noise level in a previous report on the Scott Reef sea noise loggers (McCauley and Salgado Kent 2008). Details of how this was done are not repeated here, but the estimated detection ranges for pygmy blue whales at Scott South are given in Table 6 and the listening areas for pygmy blue whales and humpbacks from Scott South and Scott North are shown on Figure 12. The Scott South logger had an estimated listening area for humpbacks and pygmy blue whales of 7740 and 2501 km^2 respectively while the similar values for Scott North were 6359 and 2076 km^2. These areas differ slightly from those given in McCauley and Salgado Kent (2008) as they have been re-calculated on the earths surface as opposed to using Easting and Northing co-ordinates and assuming a flat surface.

Table 6: Estimated listening ranges along nine headings from the Scott South site down to an ambient noise of 73.5 dB re 1µPa for pygmy blue whale calls

	15-26 Hz band of most energy		62-75 Hz up-sweep	
heading	Range (km) for SL 183 dB re 1µPa	Range (km) for SL 188 dB re 1µPa	Range (km) for SL 173 dB re 1µPa	Range (km) for SL 178 dB re 1µPa
0	28.3	35.0	23.9	25.9
45	12.0	12.8	21.5	29.1
90	10.7	11.6	21.4	23.3
135	20.0	21.5	22.3	25.2
180	10.7	12.4	27.4	29.4
225	14.4	15.9	24.3	25.2
270	27.6	28.5	24.4	27.5
290	23.3	23.6	27.1	31.9
350	26.5	28.7	31.4	33.8

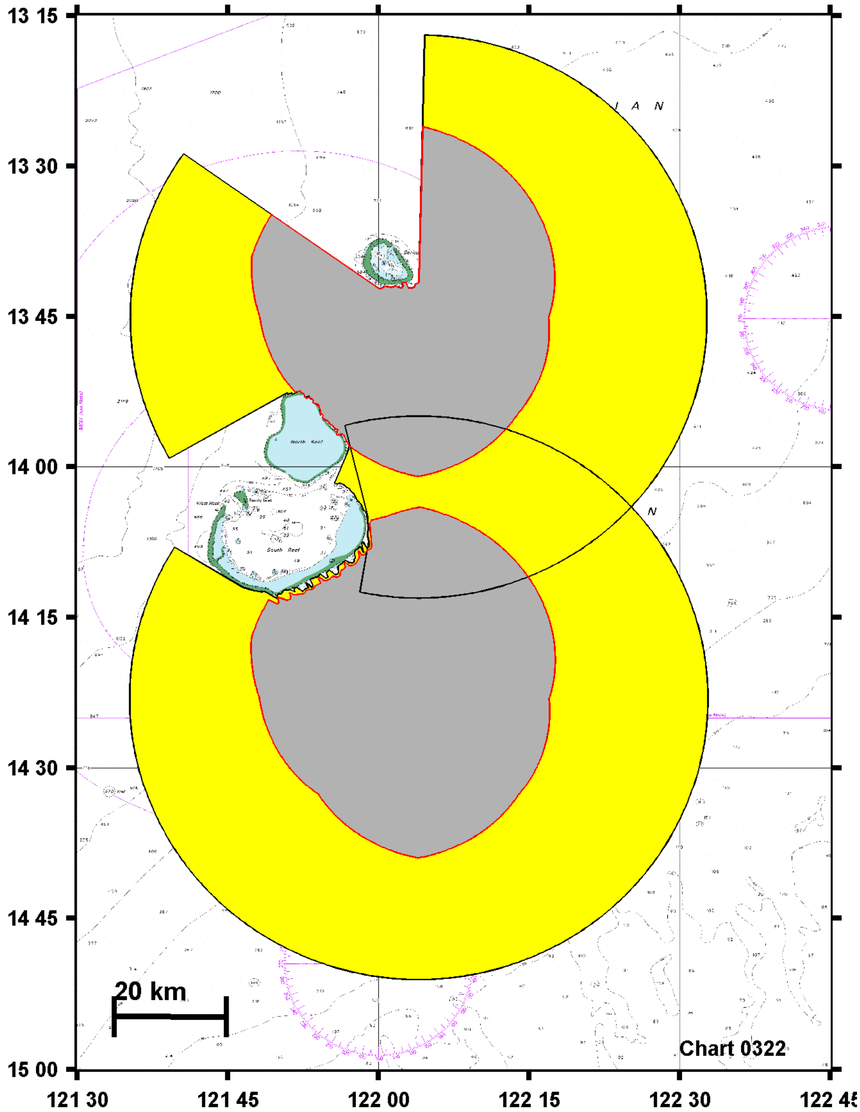

Figure 12: Calculated listening areas for humpback (outer yellow regions) and pygmy blue whales (grey region) from Scott-South and Scott-North.

5.2.3 Bathymetry profiles to Scott East-4, West-4 and West-1 sites

The bathymetry profiles on headings radiating from Scott West-1 to West 3, Scott West 4 and Scott East-4 were required for modelling sound transmission at the sites on the Scott Reef platform. The bathymetry profiles about Scott East-1 to East-3 were considered to be flat at 45 m depth.

The Scott East-4 and West-4 noise loggers were on the lagoon platform 200 and 350 m (respectively) back from the deep channel which separates the northern and southern Scott Reef lagoons. The aim of these logger deployments was to determine if and when great whales traversed the channel separating the north and south Scott Reef lagoons. The Scott West-1 to West-3 deployment's were located 150 m back from the reef edge overlooking deep water to the west. The aim of these deployments was to listen into open water west of Scott Reef.

The location of each logger will have greatly influenced signal transmission from the deep water west or north of the receivers to the receivers set in 45-50 m depth on the reef platform. To determine sound transmission from deep water to the receiver a series of bathymetry paths were firstly derived. The location of each receiver and a 10 m resolution bathymetry grid was used to generate a series of bathymetry paths from deep water to shallow water for each receiver site. The bathymetry grid was derived from multiple sources supplied by Woodside in 2006 for analysis of proposed *Maxima* seismic survey signals. The bathymetry paths were generated along 5^o compass headings for headings into open water. The resulting ensemble of bathymetry paths for the three sites are shown on Figure 13. The headings 300^o, 0^o and 50^o have been used to calculate sound transmission loss for the Scott West-4 site, 300^o, 330^o and 65^o for the Scott East-4 site and 240^o, 316^o and 15^o for the Scott West-1 site.

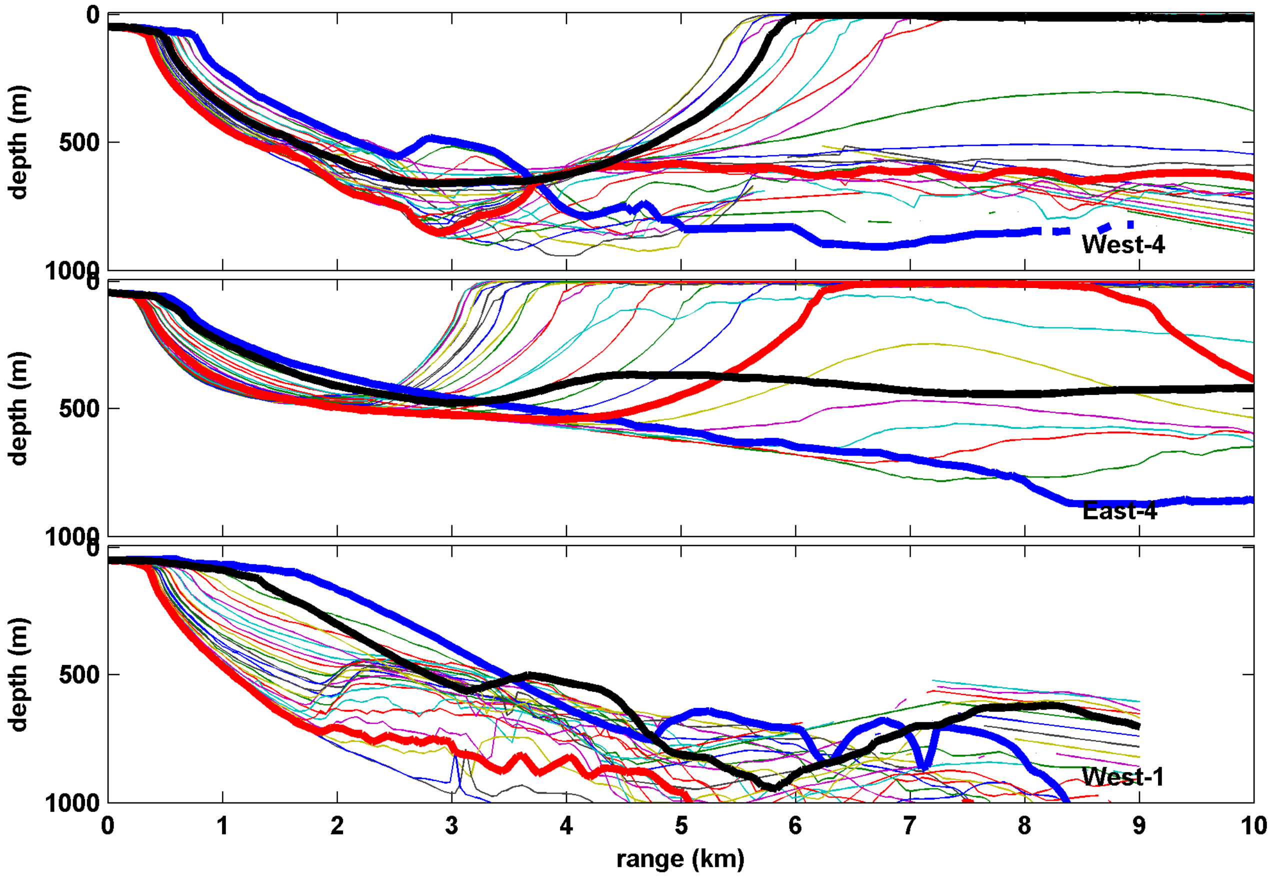

Figure 13: Bathymetry paths from the Scott West-1, West-4 and East-4 sites on different headings to deep water over: 300^o to 50^o at Scott West-4; 300^o to 65^o at Scott East-4; and 240^o to 15^o at Scott West-1. The heavy blue curves are on heading 300^o, 300^o and 240^o at Scott West-4, Scott East-4 and Scott West-1 (respectively), the heavy red curves on heading 0^o, 330^o and 316^o for Scott West-4, Scott East-4 and Scott West-1 (respectively) and the heavy black curve on heading 50^o, 65^o and 15^o at Scott East-4, Scott West-4, and Scott West-1 (respectively).

5.2.4 Pygmy blue whale listening area, Scott West and East

In order to determine how close pygmy blue whales detected on the Scott West-1, West-4 and Scott East-4 loggers were to the receivers, similar sound transmission modelling exercises were carried out as for McCauley and Salgado Kent (2008). For the Scott East-4, West-4 and West-1 sites running the sound transmission modelling from deep water up onto the reef rim comprised:

- Determining the bathymetry profile moving towards open water from the receiver location on three headings as described above and shown on Figure 13 (heavy lines). The location of these bathymetry paths overlain on the Scott Reef chart is shown on Figure 14;
- Truncating the length of the profiles at: 10, 9 and 5 km for the Scott West-4 site (300^o, 0^o and 50^o respectively); 10, 6 and 10 km for the Scott East-4 site; and 17 km for the Scott West-1 site, to cope with the tracks running into shallow water;

- Setting up the sound transmission model RAMS with a constant seabed type of limestone with geo-acoustic properties as given in Table 7, the bathymetry profiles shown along the paths on Figure 14, and a vertical sound speed profile as measured near to Scott Reef and used in McCauley and Salgado Kent (2008);
- Using reciprocity, where the modelled source was placed at the real-receiver depth and the full water column sound transmission loss field calculated, so that post analysis the real-source was placed at a modelled receiver depth to give an estimate of level at the real-receiver depth (ie. the modelled source and receiver locations where interposed post analysis to get transmission of the shallow whale source to the deep receiver);
- Running the model RAMS at frequencies of 18, 20, 22, 24, 26, 28, 30, 64, 66, 68, 70 and 72 Hz.

Table 7: Layering used in setting up the underwater sound transmission model. The parameters are: *Cp*= compressional wave speed ; *Cs* = shear waved speed ; ∝*p* = compressional wave attenuation*;* ∝*s* = shear wave attenuation

Layer	**Thickness (m)**	**Density kg / m^3**	***Cp* ms^{-1}**	***Cs* ms^{-1}**	**∝*p* (dB / λ)**	**∝*s* (dB / λ)**
limestone	800	2400	2,500	1315	0.1	0.2

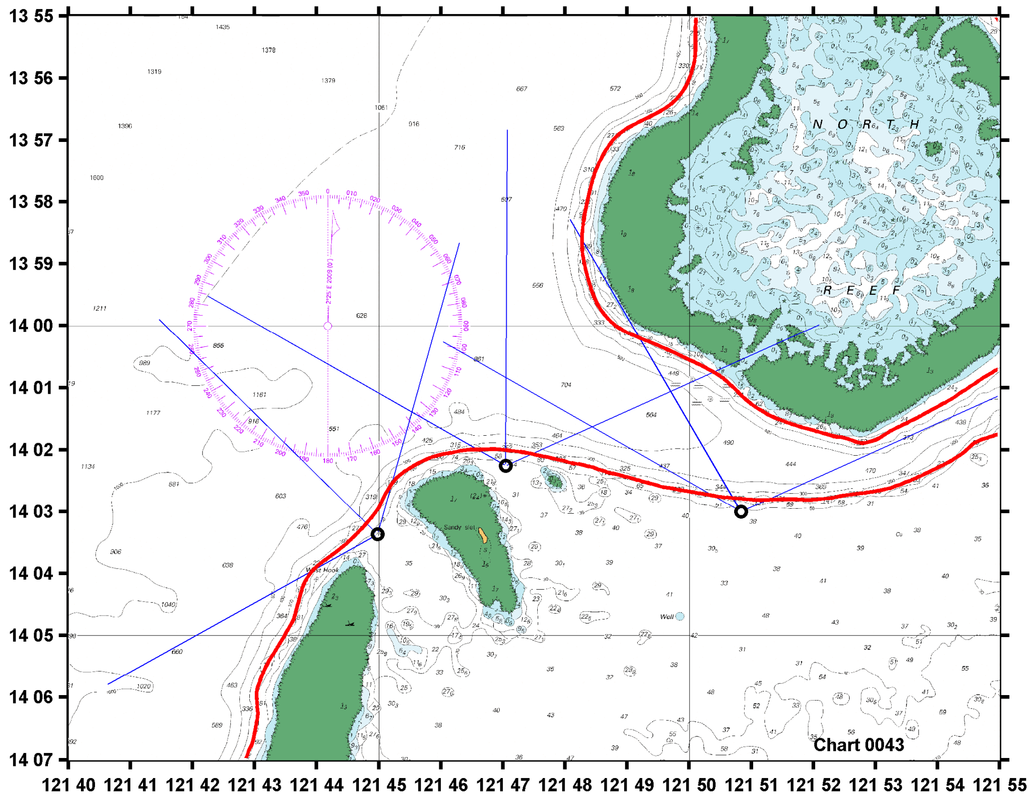

Figure 14: Headings along which bathymetry paths were calculated for sound transmission modelling. The heavy red line is the 100 m depth contour. Locations of the West-1, West-4 and East-4 loggers are shown by the circles.

The model gave sound transmission loss fields through the water column at the frequencies given above. For pygmy blue whales the dominant received energy of the common three component call is the frequency sweep over 15-26 Hz in the second call component (see 45-70 s on the call spectrogram shown on Figure 24 below or McCauley et al 2001 for description of calls), although more often the 66-72 Hz sweep of the second component transmits better due to sound transmission phenomena. Source levels of the pygmy blue whale call are estimated at 183-188 dB re 1µPa with the received level of the 66-72 Hz sweep 6 dB below this for nearby callers (McCauley et al 2001). An estimate of blue whale singer depth of between 20-30 m has been given for blue whales (D'Spain et al 1995).

To account for the frequency sweep a mean transmission loss field across the frequency bands 15-26 Hz and 66-72 Hz was determined for each spatial point in a 25 to 75 m (range) by 1 m (depth) resolution grid out to the range limit of the transmission modelling and down to 800 m depth. The range resolution was required to be altered to allow RAMS to run correctly. Further averaging of the transmission loss estimate was applied by then allowing the source depth to vary from 20-30 m, to give a mean transmission loss across a range of frequencies and source depths for the 15-26 and 62-75 Hz sweeps. The second step of averaging over source depth limited the results to the estimated transmission loss at the receiver depth only (ie range and transmission loss vectors only were returned). The appropriate source level then had this mean transmission loss subtracted to give the predicted received level at the receiver depth with range from source. An example of the predicted transmission of a call on a northerly heading from the Scott West-4 site is shown on Figure 15 (assuming a whale source at 20-30 m depth) using the high source level calls for the low and high frequency sweeps. The signal drops away considerably faster than spherical spreading and the high frequency sweep (62-75 Hz) transmits better than the lower frequency sweep (15-26 Hz) hence often tends to appear more commonly in the received pygmy blue whale signals even though it is transmitted at a lower power than the 15-26 Hz sweep. On Figure 16 the predicted transmission of pygmy blue whale low and high frequency sweeps is shown from the Scott East-4 site on three headings. Again, sometimes the lower source level, high frequency sweep transmits better than the low frequency sweep.

The predicted curves of transmission loss for the two source level extremes (183 and 188 dB re μPa) of the full signal, were then run down to a background noise level estimate at each site along the three tracks. Background noise levels were measured for all located pygmy blue whale signals (see section 3.5.1 below) in set 2818 (Scott West-4). The background noise levels were calculated in three ways over the frequency bands of the low and high frequency sweeps (15-26 Hz and 62-75 Hz). The sections with the second component of the pygmy blue whale calls were extracted, band pass filtered about the two frequency bands (not enough to impinge on the sweep energy), then a 0.24 Hz resolution calibrated spectrogram was calculated using a 50% overlap. The spectrogram values between the frequency limits were extracted and three statistics calculated using these values: 1) the mean of the lowest 50 values; 2) the median value; and 3) the mean of the highest 50 values. The distribution of these statistics calculated across all identified pygmy blue whale calls are shown on Figure 17. The low values were believed not indicative of normal sea noise, the high values were biased by the pygmy blue whale signals themselves or vessel noise which was persistent at the Scott West-4 and Scott East-4 sites. There appeared to be little difference in the noise levels when comparing the two frequency bands, which is not the case for receivers set in the deep ocean, where the noise level increases in the lower frequencies (while these receivers listened into deep water they were located in 45-50 m depth on a reef platform). Based on the distribution curves shown on Figure 17 a background noise level of 65 dB re 1μPa^2/Hz was selected as a limit to run the call estimated transmission down to.

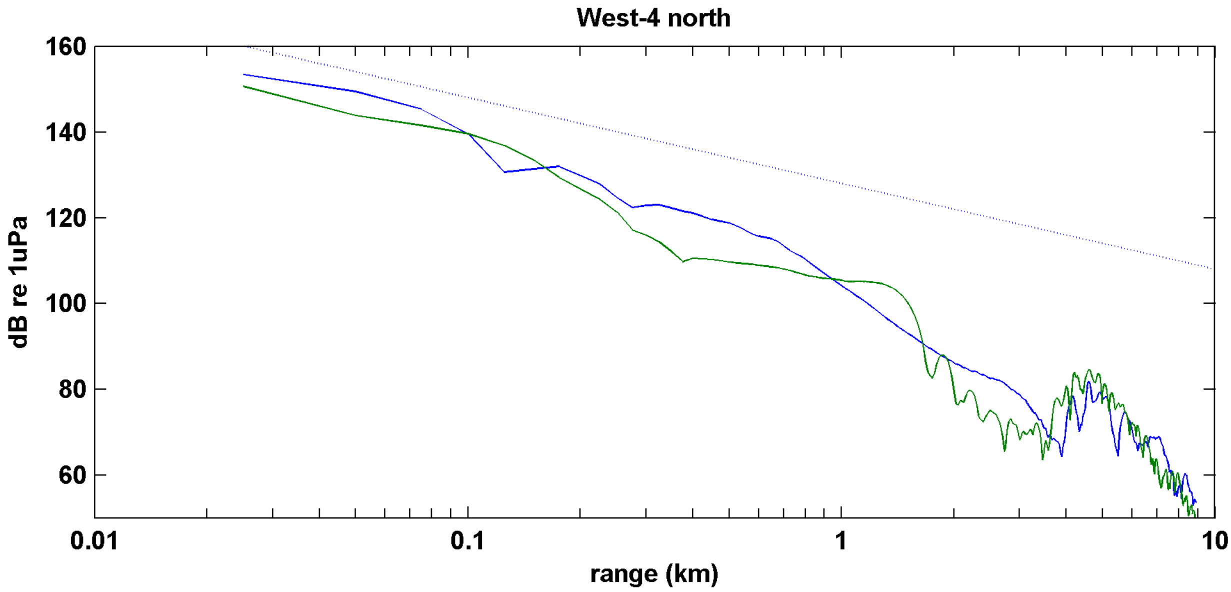

Figure 15: Predicted transmission of the pygmy blue whale call from the Scott West-4 site on a northerly heading, assuming a source at 20-30 m depth, for: a 188 dB re 1μPa source level signal of the frequency sweep over 15-26 Hz (blue curve); a 182 dB re 1μPa source level signal of the frequency sweep over 62-75 Hz (green curve); and spherical spreading assuming a 188 dB re 1μPa source level (straight line).

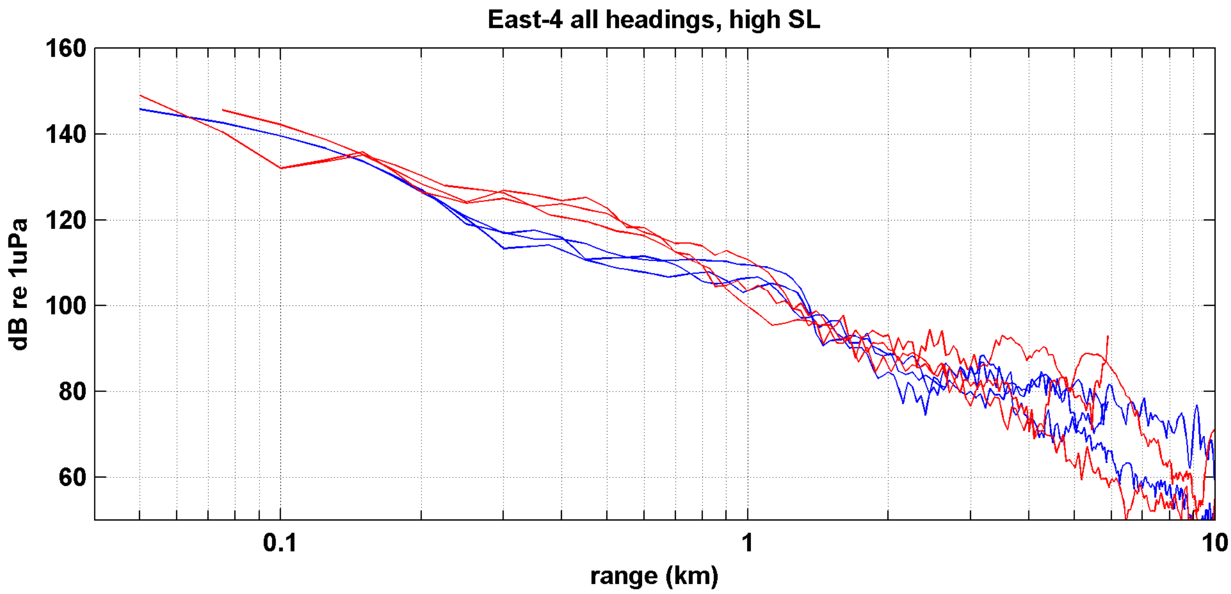

Figure 16: Predicted transmission of the pygmy blue whale call from the Scott East-4 site on 300, 330 and 65^{o} headings using the high source level call (188 dB re 1μPa) for the low frequency sweep (blue curves) and high frequency sweep (182 dB re 1μPa, red curves), assuming a source at 20-30 m depth.

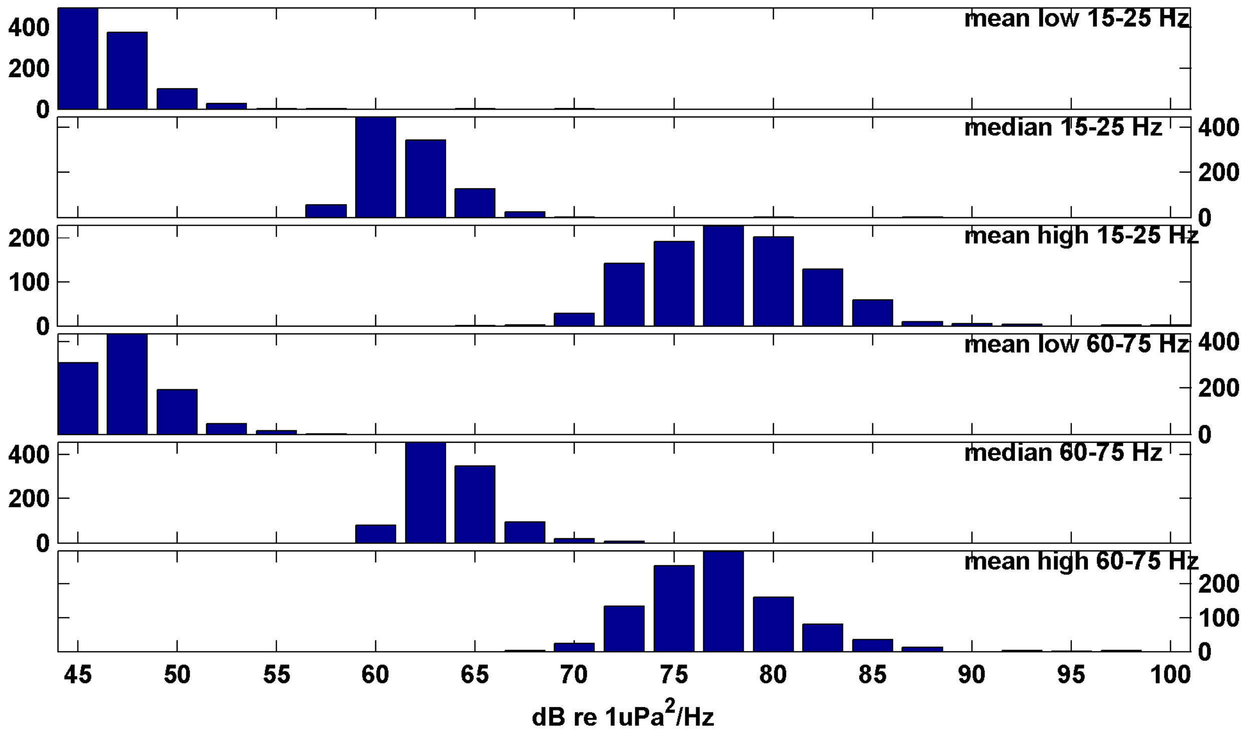

Figure 17: Distribution of ambient noise for all samples with pygmy blue whale signals in set 2818 (Scott West-4), measured in the range of the primary energy of pygmy blue whales, over the 15-26 Hz and 62-75 Hz bands. The measurements are given as: **mean-low** – the mean of the lowest 50 values in the frequency band within a sample; **median** – the median of all spectral level values in this frequency band within a sample; and **mean-high**, the mean of the highest 50 spectral level values within a sample.

The estimated received level of pygmy blue whale signals were then run down to the selected ambient noise level (using an approach outlined in McCauley et al 2001 which calculated the 95% probability of a call reaching a nominal level and removed much of the uncertainty given by range / level fluctuations due to multipath interference). The estimated detection ranges along the different headings are listed in Table 8. The higher frequency sweep of the second call component transmitted up onto the reef platform from longer ranges than the higher energy, lower frequency sweep for comparatively short distances from the reef rim to the receiver. As the distance from reef rim to receiver increased (on different headings) the lower frequency sweep then became the prominent received energy (probably via coupling through the limestone reef platform). The strongest example of this can be seen in Table 8 at the Scott West-1 site, where along the heading with the shortest distance to open water the 62-75 Hz sweep was predicted to be detected from 13.5 km, whereas on the extreme headings which included much longer paths across the reef rim, the detection range of the 62-75 Hz sweep was predicted to drop to < 7 km.

Table 8: Calculated detection ranges (km) of pygmy blue whale signals down to an ambient level of 65 dB re 1μPa^2/Hz. The * symbol indicates the calculations of outside detection range was physically blocked by the reef structure.

site	Heading	Detection range (km) in the 15-26 Hz band, source level 183-188 dB re 1μPa	Detection range (km) in the 62-75 Hz band, source level 177-182 dB re 1μPa
West-4	300^o	7.35 – 8.30	7.28 – 7.83
	0^o	6.73 – 7.68	7.63 – 8.20
	50^o	4.55 – 4.55*	4.65 – 4.65*
East-4	300^o	8.48 – 9.28	4.05 – 4.65
	330^o	5.30 – 5.30*	5.60 – 5.60*
	65^o	5.00 – 5.65	6.73 – 9.60
West-1	240^o	10.13 – 11.70	2.65 – 2.85
	315^o	10.48 – 12.08	13.48 – 13.5
	15^o	8.57 – 9.43	5.68 – 6.45
45 m constant depth	0-360^o	15.95 – 18.38	6.58 – 7.15

All of the sites Scott West-1 to West-4 and Scott East-4 had potential listening areas into the southern lagoon of Scott Reef. To calculate listening ranges for any animals which had entered the lagoon the sound transmission model Scooter was set up using reciprocity (source and receiver locations swapped), a 25 km path length, constant 45 m water depth with a limestone seabed and a sound speed profile of 1540 ms^{-1} at the surface to 1430 ms^{-1} at the seabed. The model was run at the same frequencies as the RAMS model and the same approach used to determine estimated call detection ranges down to a 65 dB re 1μPa^2/Hz background noise level with two extremes of source level. These detection ranges are listed in Table 8.

Once the pygmy blue whale detection ranges were calculated sets of heading boundaries were established about each receiver location which had aspects into clear water. Sections which had blocking bathymetry were established by perusing the bathymetry profiles in 2^o increments. The maximum pygmy blue whale estimated detection ranges on each heading given in Table 8 were derived from the mean of the two source levels for the frequency sweep which gave the greatest detection range. These maximum detection ranges along set headings were then interpolated into closely spaced bearings within the sections with clear sound transmission paths, and a series of arcs established along which the estimated outside call detections lay. A further filter was then applied such that along all headings in the arcs, the bathymetry paths in small steps were calculated along the heading and any range at which the water depth along this path was < 20 m was returned. These headings were then considered as blocked to pygmy blue whales at ranges beyond where 20 m depth was reached, either by the call not crossing the blocking bathymetry or the blue whale not entering shallow water. These series of range limited arcs were then used to derive the listening areas of each of the receiver locations. The estimated listening areas of the three receivers set near the rims of the reef inside Scott Reef are shown on Figure 18. The Scott West-4 and Scott East-4 sites had limited overlap in listening area in deep water while the Scott West-1 and Scott East-4 sites had no overlap in listening area for animals outside of the reef lagoon. All sites overlapped to some degree if animals were inside the reef lagoon. The listening areas for each site were calculated using the area on the spherical earth, for listening into open water plus inside the reef southern lagoon, and for listening into open water only. These listening area values are given in Table 9.

Note that to date no pygmy blue whale detections have been made on the Scott East-1 to East-3 noise loggers which were set inside the southern lagoon. This indicates that pygmy blue whales do not or rarely enter the southern lagoon. The listening areas given in Table 9 include the area with and without the listening area inside the southern lagoon, but it is probable that all pygmy blue whale detections were made from deep water.

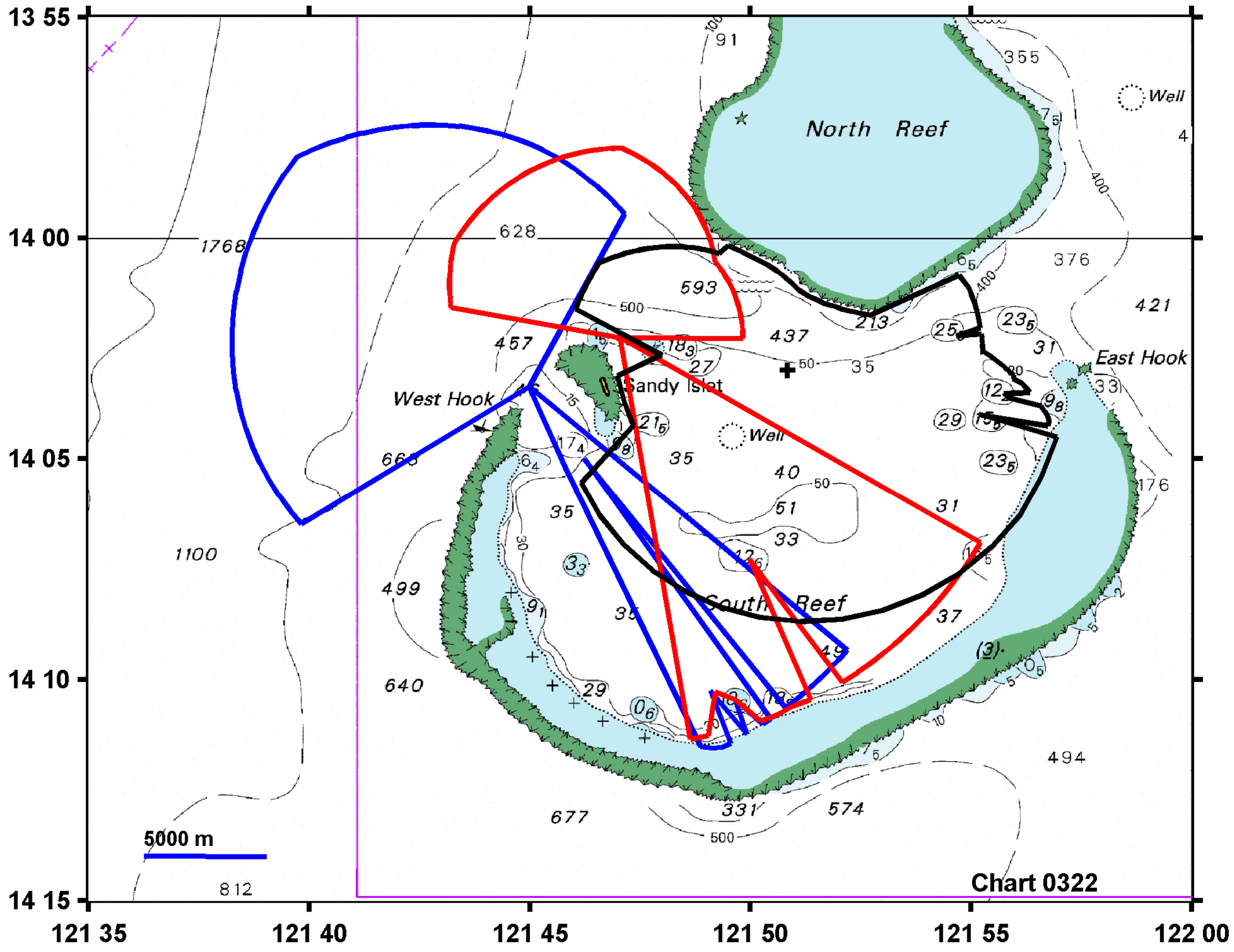

Figure 18: Estimated call listening areas for pygmy blue whales from receivers Scott West-1 to West-3 (westernmost site shown by the blue polygon), Scott West-4 (red polygon) and Scott East-1 (black polygon).

Table 9: Estimated call listening areas (km^2) for pygmy blue whales from the receivers set inside of Scott Reef and near the reef rim, given for listening into open water and inside the reef lagoon plus just listening into open water.

	West-1	**West-4**	**East-1**
Open water and lagoon	232	188	218
Open water only	176	69	50

5.3 Humpbacks

5.3.1 New data and analysis- humpbacks

The counts of individual calling humpback whales per sample for Scott East-4 and Scott West-4 have been added to the existing data sets. The presentation of the timing of humpback visitation at receivers has been streamlined and plots showing the timing amended with the new data.

5.3.2 Humpback whales in and around Scott Reef

Humpback whale singing has been heard from all of the Scott Reef locations. As discussed previously humpback song is composed of many individual song components, with 1-5 components each of up to a few s length, grouped into themes and the themes assembled into groups and repeated in some pattern. The themes may be repeated a set number of times within a group, although this is often variable. The groups of themes are assembled into a song with the theme grouping usually constant. Songs may run for 5-15 minutes depending on that year's version and to a lesser extent the individual as some animals include more or less repetitions of themes in a group, may add or skip themes, may insert new themes in and may skip groups. Song variation within and amongst individual whales is large and songs can be constant or different between years, with typically at any point in time the west coast humpback population using the same basic song structure.

When detected, only one humpback singer was detected at the Scott East-4 and West-4 sites. In one instance calls arrived at Scott East-4 and West-4 almost simultaneously from what was believed one singer which sang over a 17.5 hour period on the 13-14 Oct-2008. Examples of several themes recorded at short range from this singer are shown on Figure 19. The song was detected at high signal to noise ratio at the Scott East-4 site indicating it was close to the receiver.

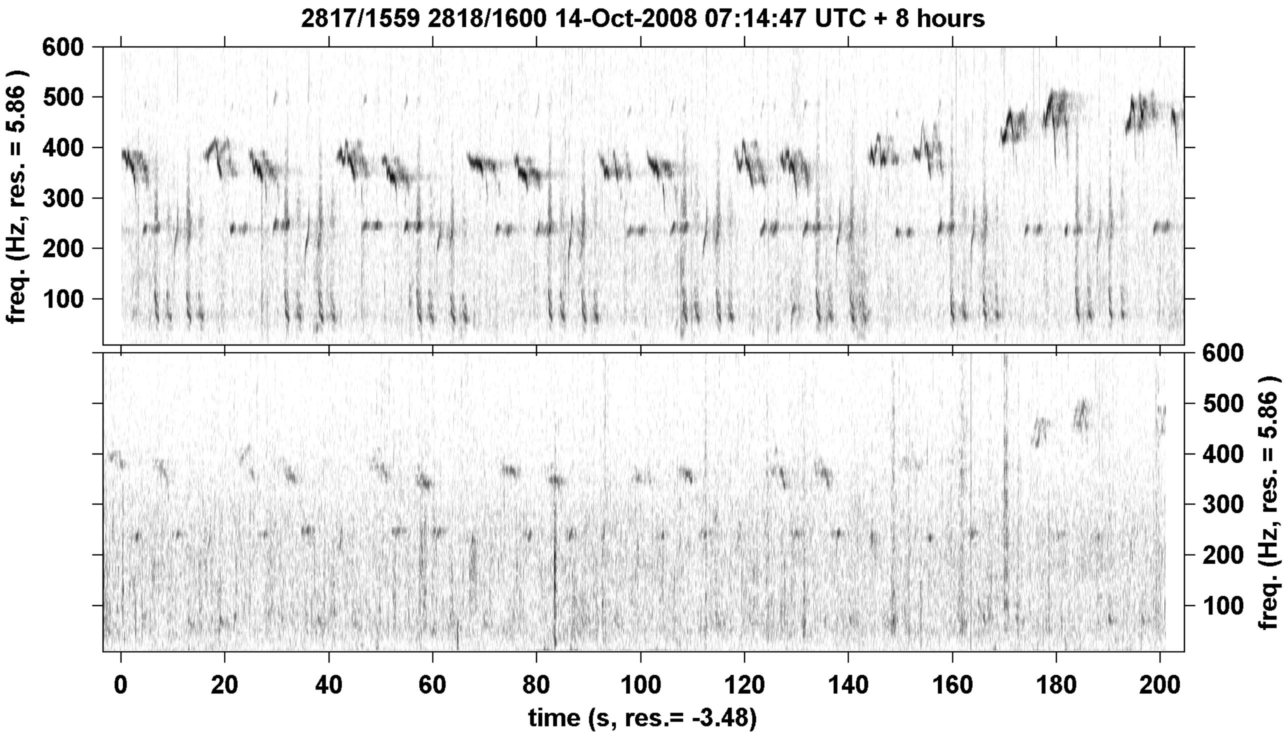

Figure 19: Example of close range humpback singing from the Scott East-4 site. The animal was located in the deep channel separating the north and south lagoons based on the echoes returned.

Strong echoes were present from this singer at the Scott East-4 site, separated by 2.218 s from the direct arrival. To have such strong echoes implied the animal was near an almost vertical wall, which would place it in the deep channel north of the Scott East-4 location (see Figure 13 for the bathymetry paths radiating north of Scott East-4 and Figure 18 for the general bathymetry and location of Scott East-4). The northern wall of the deep channel was 3080 m from the Scott East-4 site at its closest point (Figure 13). Assuming a sound speed of 1540 ms^{-1} enables the distance to the whale to be calculated from the time offset of the echo and the direct arrival. The whale was most likely around 1540 m north of the receiver, placing it close to the centre of the channel separating the north and south lagoons.

In previous data sets search algorithms were run over the data set to locate humpback signals then the hits manually checked to get the number of singing whales (see McCauley 2009b or Table 5). This search process was not carried out for humpbacks at Scott East-4 or West-4 as there were so few humpbacks present. Instead the periods of humpback detections were identified from five day stacked sea noise plots then these samples bracketed and checked individually. Only the one singing humpback was identified on the 13 to 14 Oct-2008. The same process was repeated from May-2009 to 09-Jun 2009 (the end of the deployment) to check on early humpback singer detections in 2009 but no humpbacks were detected.

The appropriate presence data from Scott East-4 has been included with all previously analysed humpback detection data from the Kimberley sea noise program in Table 10. The data from Scott East-4 can be considered as a continuation of the 2008 season from set Scott East-3, in that the Scott East-4 site spanned the end of the 2008 humpback season and was too early for the 2009 season. For humpbacks the Scott East-4 site can be considered to be similar to the West-4 site, both were on the northern rim of the southern lagoon. Data for the West-4 site was not presented in Table 10.

Table 10: Humpback whale detections at each site. Given are date/time of valid logger sampling, date/time of first and last humpback calling detected, date of initiation of persistent humpback calling (time bounds between which 90% of the calling occurs) and the maximum and median number of instantaneous singers. Times are WST.

Site	First to last valid samples	First humpback	Persistent calling	Max/ median # singers	Last humpback
West-1 2735	14-Jun-2007 16:00 to 12-Sep-2007 14:30	24-Aug-2007 18:15	none	1 / 1	24-Aug-2007 19:15
East-1 2740	14-Jun-2007 16:00 to 12-Sep-2007 11:00	24-Aug-2007 23:45	none	1 / 1	31-Aug-2007 00:45
East-3 2791	05-Feb-2008 08:54 to 28-Sep-2008 08:00	27-Jul-2008 00:45	18-Aug-2008 to 08-Sep-2008	2 / 1	27-Sep-2008 04:30
East-4 2817	28-Sep-2008 15:30 to 09-Jun-2009 19:00	13-Oct-2008 22:00	none	1 / 1	14-Oct-2008 15:30
South-1 2734	05-Sep-2006 16:00 to 30-Apr-2007 10:45	05-Sep-2006 16:00	05-Sep-2006 to 18-Sep-2006	2 / 1	23-Sep-2006 10:45
South-2 2761	14-Jun-2007 16:00 to 03-Feb-2008 06:30	30-Jun-2007 19:00	24-Jul-2007 to 10-Sep-2007	4 / 2	14-Sep-2007 17:15
South-3 2793	03-Feb-2008 13:00 to 27-Sep-2008 14:45	23-Jun-2008 07:15	28-Jun-2008 to 12-Sep-2008	3 / 1	16-Sep-2008 03:00
North-2 2762	14-Jun-2007 16:00 to 04-Feb-2008 06:00	25-Jul-2007 07:45	25-Jul-2007 to 09-Sep-2007	3 / 1	13-Sep-2007 07:00

Based on the values given in Table 10 the outside seasonal detections of humpbacks are to date:

- The outside humpback detection season from the Scott South location was 23-Jun to 23-Sep
- The outside humpback detection season from inside Scott Reef was 27-Jul to 14-Oct

The seasonal trend for humpbacks visiting the three locations sampled, Scott South, Scott East (inside the reef) and North, are shown over the full sampling period on Figure 20 using 24 hour means of the number of individual whales calling. The seasonality of visitation and the comparatively short stays each year can be clearly seen on Figure 20. There was a tendency for humpbacks to arrive inside Scott Reef up to 1-2 months later than as defined at Scott South, which is consistent with the animals fanning out slowly across shelf waters (the Scott South loggers were in 330-340 m of water and slightly west of the continental shelf with Scott Reef further to the west).

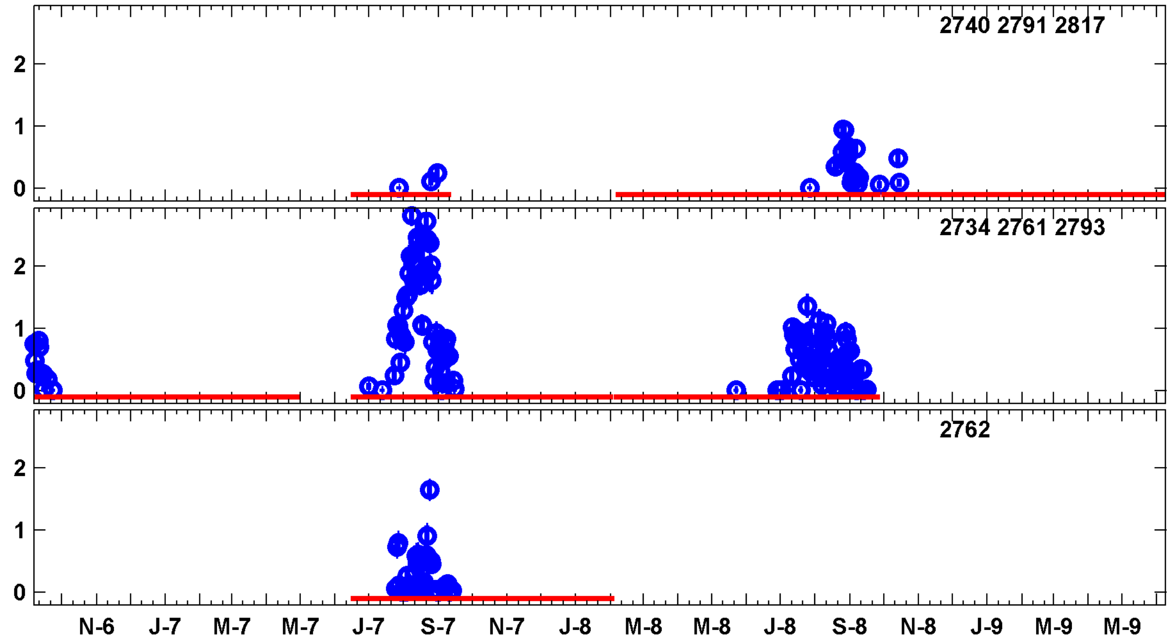

Figure 20: Mean number of calling humpback whales averaged over 24 hour periods (starting 12:00 one day to 12:00 the next) grouped by sites shown for the full recording period available, with: top, the Scott East site; middle, the Scott South site; and bottom, the Scott North site. The 95% confidence margins are shown, the red lines represent periods sampled and the minor tick increments are every ten days. Only the first character of each second month is given on the time axis.

The returned counts of the number of 'instantaneous' calling humpbacks were used as relative abundance estimates in McCauley (2009b). Since very few humpback detections were added in the Scott East-4 and West-4 data sets this analysis has not been elaborated here and readers are referred to the earlier report, McCauley (2009b) for an analysis of numbers of whales detected by the Scott Reef noise loggers. The 2009 humpback season is awaiting analysis and will be included in future reports of humpback comparative abundance.

5.4 Antarctic minke whales

5.4.1 New data and analysis – Antarctic minke whales

The data sets of Scott East-4 and West-4 were manually searched for Antarctic minke whale signals while: 1) checking spectrograms of other species; and 2) by looking at five day stacked sea noise spectra for the signatures of Antarctic minke whales (similar plots to Figure 7 but at a higher time definition of five days only). No Antarctic minke whale signals were found.

5.4.2 Antarctic minke whales in and around Scott Reef

A signal type believed to be produced by the Antarctic form of the minke whale was evident on a few days each year at the Scott South site but not from in the Scott Reef lagoon. It was heard over six days in early October (4-10th) from Scott South-1 in 2006 (noting this set only started in

September that year), in July (5, 6, 8 & 26th) and September (7th) in 2007 and in July (13th) and September (13th) in the Scott South-3, 2008 records. The signal type was not heard in the Scott East-4 or West-4 data sets, consistent with this whale rarely entering the Scott reef lagoons or immediate area.

5.5 Dwarf minke whales

5.5.1 New data and analysis – dwarf minke whales

The data sets from Scott East-4 and West-4 were systematically searched for dwarf minke whale signals and none found. Several previous data sets which had been searched using an algorithm only were manually cross checked to remove outliers which define seasonal visitation bounds (see Table 5). The addition of Scott East-4 and West-4 data and the checking of previous data sets has better defined seasonal patterns of dwarf minke whale visitation in and near to Scott Reef.

4.5.2 Dwarf minke whales in and around Scott Reef

Dwarf minke whale signals were present in the recording sets from Scott South, Scott East-1 to East-3 and North with an example call shown on Figure 21. These calls are similar to those reported by Gedamke et al (2001) from dwarf minke whales in the northern Great Barrier Reef, off Lizard Island (14^{o} 38’ S). Little is known of the calling habits of dwarf minke whales in Western Australia, aside what from what was presented in the previous analysis of Scott Reef dwarf minke calls (McCauley 2009b). At times dwarf minke calling was extensive in the Scott Reef data sets, for example it was present from late Sep to late Nov at Scott South-1 often with large numbers of calls detected within a sample, up to 62 separate calls counted in a 200 s sample. The dwarf minke calls were detected inside (Scott East-1 to East-3) and outside Scott Reef (South and North sites).

In a previous report (McCauley 2009b) an extensive analysis of dwarf minke whale calls was carried out. A search algorithm was developed and used to search the Scott South and Scott East-1 to East-3 data sets, although at this point only a minimum checking of the detection algorithm was carried out. The call repetition interval was determined (minimum of 6.1 s) using inter-call increments and call level differences and dwarf minke relative abundance outside and inside Scott Reef were determined.

The same search algorithm was run across the Scott West-4 and East-4 data sets and manually cross checked. No dwarf minke detections from the Scott East-4 and West-4 sets were found from the output of the detection algorithm, by perusing the five day stacked sea noise spectra (they show up on these plots as tones over many hours) nor when checking the data sets for other species. In addition to searching the Scott East-4 data set the Scott East-1 to East-3 and South-1 to South-3 data sets were partially manually cross checked to remove false detections (there has not yet been sufficient time to fully cross check all the dwarf minke detections)

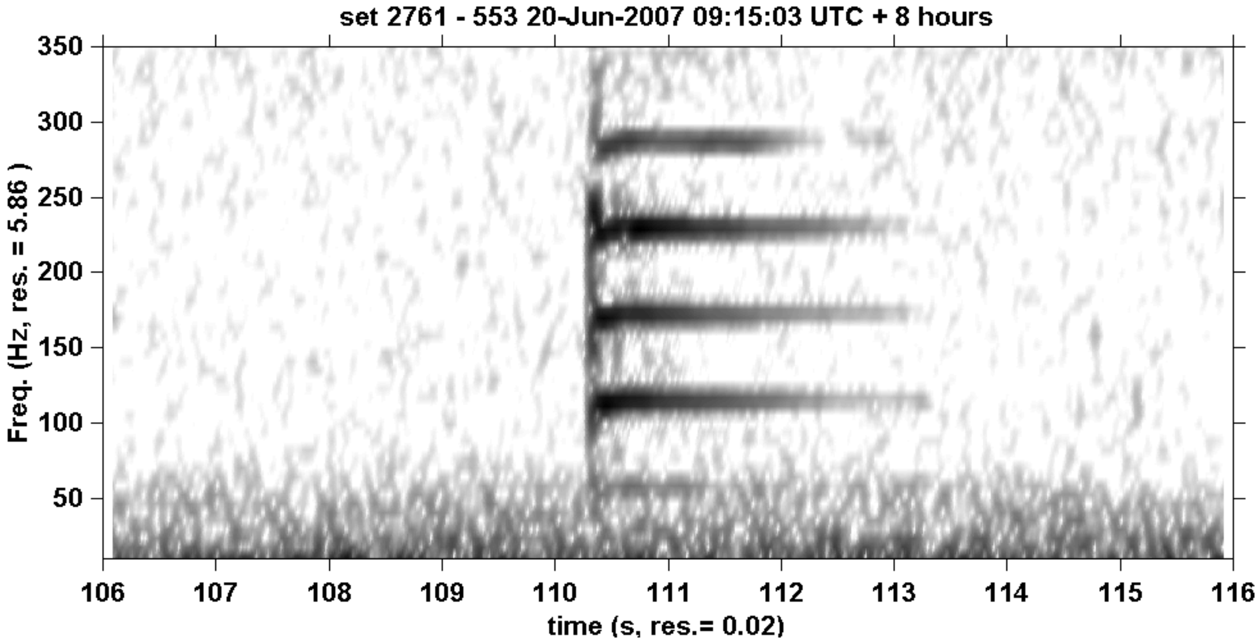

Figure 21: Spectrogram of dwarf minke whale signals from the Scott South 2 logger.

The revised call detections for the Scott-South and Scott East detections, shown on the same time frame across a year (Julian day), are shown on Figure 22. The Scott East-2 and East-4 data sets were outside of the expected time window in which dwarf minke whales were expected to visit Scott reef.

Using the revised dwarf minke counts the visitation patterns to Scott South and inside of Scott Reef are given on Table 11. To compare dwarf minke abundance inside and outside of Scott Reef the integrated number of calls per 200 s sample across the full whale respective dwarf minke season is given in Table 12 for the Scott East and South sites. Using the values given in Table 11 and Table 12 we can say that:

- The outside call detection bounds for the Scott South location are 13-May to 18-Sep
- Most (90% of) dwarf minke calling at Scott South occurred over 44-50 days within this time frame
- The outside call detection bounds for the Scott East location are 28-Jun to 25-Aug
- Most (90% of) dwarf minke calling at Scott East occurred over 30-43 days within this time frame
- The first arrival of animals at the respective sites varied considerably more than the date animals left
- There was consistency in the call numbers detected at the sites across the two years
- The Scott South site detected approximately 13-24 times more calls than the Scott East site
- The Scott South site detected approximately 5-6 times more calls than the Scott North site

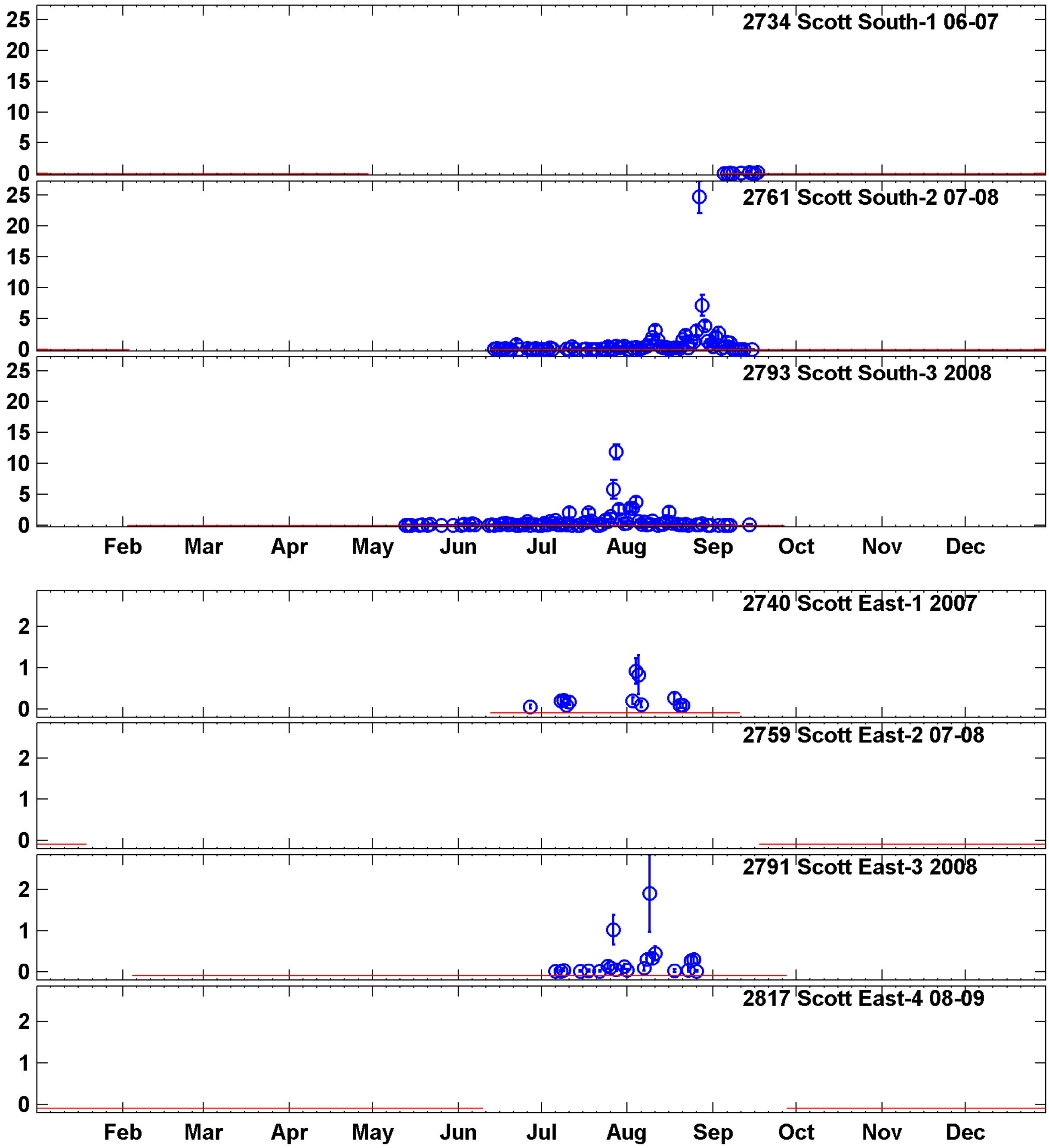

Figure 22: Presence of dwarf minke whales at Scott South and Scott East as given by the 24 hour mean of the number of calls detected per 200 s from every 15 minute sample (averaged over 12:00 to 12:00 the following day).

Table 11: Dwarf minke whale detections at Scott Reef sites. Given are date/time of valid logger sampling, date/time of first and last dwarf minke whale calling detected, date of initiation of persistent dwarf minke calling (time bounds between which 90% of the calling occurs) and the maximum and median number of calls per sample. Times are WST.

Site	First to last valid samples	First dwarf minke	Persistent calling	Max/ median # calls	Last dwarf minke (days with minke)
East-1 2740	14-Jun-2007 16:00 to 12-Sep-2007 11:00	28-Jun-2007 06:15	09-Jul-2007 to 21-Aug-2007 (42.9)	19 / 1	22-Aug-2007 04:30 (54.9)
East-2 2759	19-Sep-2007 12:45 to 18-Jan-2008 12:45	No dwarf minke detected, outside of expected detection period			
East-3 2791	05-Feb-2008 08:54 to 28-Sep-2008 08:00	05-Jul-2008 22:15	25-Jul-2008 to 24-Aug-2008 (30)	20 / 1	25-Aug-2008 12:15 (50.5)
East-4 2817	28-Sep-2008 15:30 to 09-Jun-2009 19:00	No dwarf minke detected, outside of expected detection period			
South-1 2734	05-Sep-2006 16:00 to 30-Apr-2007 10:45	06-Sep-2006 08:30	07-Sep-2006 to 18-Sep-2006 (10.6)	2 / 1	18-Sep-2006 04:15 (12.1)
South-2 2761	14-Jun-2007 16:00 to 03-Feb-2008 06:30	15-Jun-2007 01:45	22-Jul-2007 to 03-Sep-2007 (43.9)	48 / 1	15-Sep-2007 20:00 (92.8)
South-3 2793	03-Feb-2008 13:00 to 27-Sep-2008 14:45	13-May-2008 00:45	25-Jun-2008 to 16-Aug-2008 (52.2)	31 / 1	14-Sep-2008 08:30 (124.3)
North-2 2762	14-Jun-2007 16:00 to 04-Feb-2008 06:00	18-Jun-2007 20:15	18-Jul-2007 to 29-Aug-2007 (42.7)	20 / 1	09-Sep-2007 21:3 (83)

Table 12: Integrated values of individual calling dwarf minke whales across matching periods for Scott East and South.

Site	Whale.days	Days integrated	Date bounds	Year
2740 East 1	3.25	58	28-Jun-2007 to 25-Aug-2007	2007
2791 East 3	5.25	58	28-Jun -2007 to 25-Aug -2007	2008
2761 South 2	78.87	92.3	13-May-2007 to 15-Sep-2007	2007
2793 South 3	69.15	125.0	13-May -2008 to 15-Sep-2008	2008
2762 North-2	13.12	92.3	13-May-2007 to 15-Sep-2007	2007

5.5.3 Regional scale patterns in dwarf minke detections

The dwarf minke search algorithm was run across nine data sets from northern Western Australia, with statistics of detections including the maximum and median number of calls and individual callers shown on Table 13. The maximum number of calls counted could be high, up to 91 calls per 200 s, although the median number of calls detected was low, at one to two calls per 200 s sample. The maximum number of individual dwarf minke whales calling at any point in time was derived as seven with the median number of individuals calling at any point in time one. Thus calling was mostly dominated by single animals but could on occasions comprise up to seven individuals.

The outside dwarf minke whale detection bounds given on Table 13 have been plotted with latitude on Figure 23. There appears to be a similar pattern as for humpback whales, with a shorter visitation period as one moves further north, suggesting that like humpbacks, dwarf minke whales migrate north and south each season. The migratory end points and routes of dwarf minke whales are currently unknown.

Table 13: Details of all NW Western Australian data sets searched for dwarf minke whale calls. The number in brackets following the set number, is the location shown on Figure 6.

set	where	Outside detection bounds (days)	Max / median calls / 200 s	Max / median whales calling
2720 (5)	North Monte Bello Islands	21-Mar-2006 to 27-Nov-2006 (251)	91 / 2	7 / 1
2623 (7)	NW of Broome	20-Mar-2003 to 11-Aug-2003 (144)	41 / 2	5 / 1
2740 (8)	Scott East-1	28-Jun-2007 to 22-Aug-2007 (55)	19 / 1	3 / 1
2761 (9)	Scott South-2	15-Jun-2007 to 15-Sep-2007 (92)	48 / 1	6 / 1
2762 (10)	Scott North-2	18-Jun-2007 to 09-Sep-2007 (83)	20 / 1	4 / 1
2791 (8)	Scott East-3	05-Jul-2008 to 25-Aug-2008 (51)	20 / 1	5 / 1
2793 (9)	Scott South-3	13-May-2008 to 14-Sep-2008 (124)	31 / 1	4 / 1

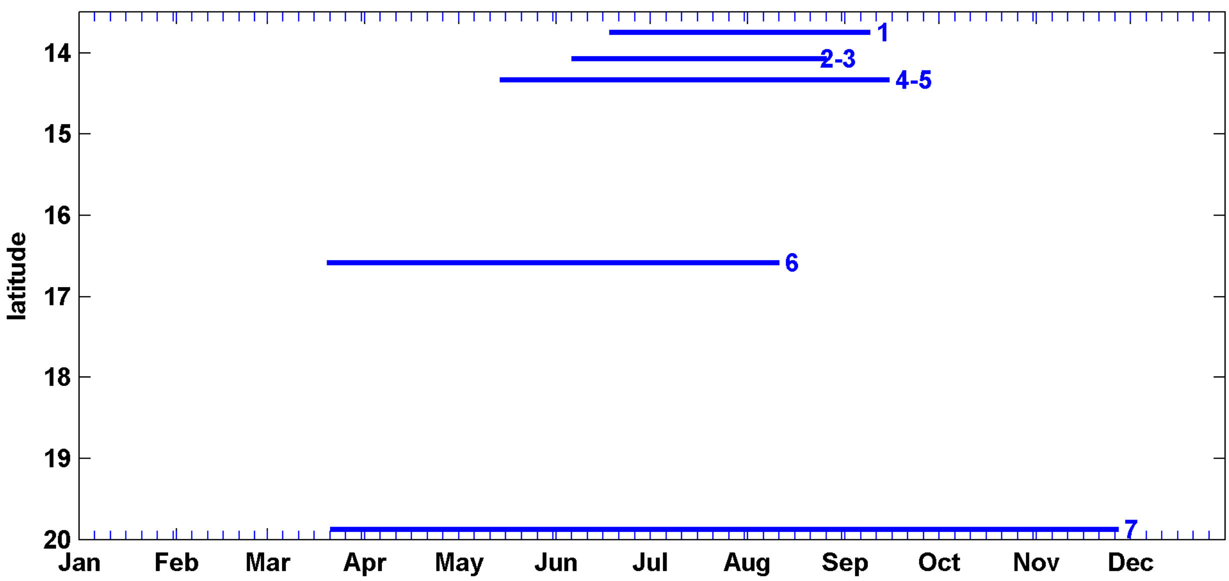

Figure 23: Outside dwarf minke call detection bounds aligned by Julian day and spaced according to latitude (S). The numbers refer to sites: 1) Scott North; 2-3) Scott East; 4-5 Scott South; 6) a site NW of Broome; and 7) north of the Monte Bello Islands on the shelf edge.

5.6 Pygmy Blue whales

5.6.1 New data and analysis – pygmy blue whales

In this report effort has gone into understanding the visitation patterns of pygmy blue whales near to Scott Reef. The listening ranges of pygmy blue whales from noise loggers set on the reef platform were calculated above. The Scott East-4 and West-4 data sets were thoroughly searched for pygmy blue whales and this data added to the full data set for defining the migratory patterns and numbers of whales passing. The Scott East-4 and West-4 noise loggers ran concurrently thus could be analysed for pygmy blue whale calls which arrived at the two receivers within a short space of time, thus enabling patterns of whale movement near to the reef to be studied, since the two locations had only a small to no overlap in their respective listening ranges.

5.6.2 Pygmy blue whale visitation in the Scott Reef area

Pygmy blue whale signals have been detected from the Scott South, North, East-4 and West locations. An example of a pygmy blue whale signal recorded near to the Scott West-4 receiver is shown on Figure 24. As discussed above, the noise loggers set just inside the reef rim at Scott West detected pygmy blue whales with a preferential bias towards sometimes the lower and sometimes the higher frequency components of the call due to sound transmission effects and the whale location. The signal shown on Figure 24 has greater energy in the higher frequency components indicating a short path to deep water, putting the animal towards north of the receiver (Table 8).

The gross signal structure of this call type is identical to signals recorded from the Perth Canyon by the author and attributed to pygmy blue whales. The 'song' is comprised of three complex long tonal signals (components) which have most energy over 15-26 Hz but harmonics and a secondary source with energy up to 75 Hz (ie. 10-120 s on Figure 24).

The noise logger data from Scott South, North and West have been systematically searched for pygmy blue whale signals by running an algorithm across each sample which looked for the characteristic up-sweep of the second call component (ie. up-sweep centred near 70 Hz over 45-75 s on Figure 24). No evidence of pygmy blue whale calling appearing in the Scott East-1 to East-3 noise loggers set well back inside the reef have been found by examining the five day sea noise spectrograms or during searching for other species.

For the Scott South, North and West data sets the spectrograms of each of the search algorithm detections were manually checked to confirm blue whale presence and counts of individuals calling as per the methods. Counts of individual whales calling were determined from the number of detections of the second call component in each 200 s sample. Normally the three component 'song' has a repeat interval of 170-200 s (time from initiation of one component in one song to initiation of same component in the next song). Thus each detection of the second component in an ~ 170-200 s sample represents a different individual whale. By manually checking each sample, instances of the detection algorithm repeating a count of the same whale (ie. the second component repeated twice in the 205 s samples) were removed.

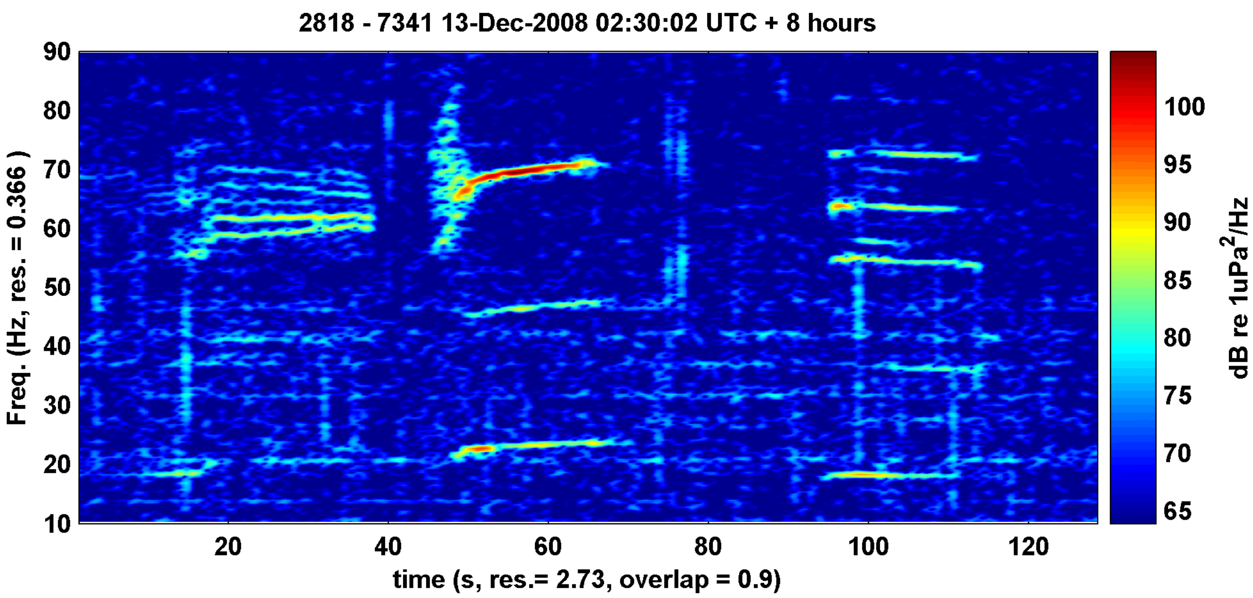

Figure 24: Example of pygmy blue whale calling recorded from Scott West-4. A full pygmy blue 'song' is of three components typically separated by > 50 s before the song repeats. Some vessel tones (horizontal lines) are present as are fish calls (vertical bars).

The Scott East-4 site was searched in a different fashion. Rather than running the search algorithm across the data set, which would have returned many false detections from the common vessel noise tones present, the time periods with identified pygmy blue whale calling from the Scott West-4 set were bracketed in the Scott East-4 data set and manually searched. Calling detected was mostly weak and often lacked the 62-75 Hz sweep, but on at least 14 separate occasions pygmy blue whale calls comparatively close to the receiver were detected at the Scott East-4 site. Given the listening area of the Scott East-4 logger (Figure 18) then these higher level signals must have been produced by animals traversing the channel separating the north and south Scott Reef lagoons. This issue is explored further in the following section (Section 5.6.3). An example spectrogram of a pygmy blue whale call detected close to the Scott East-4 receiver is shown on Figure 25. This call had much better transmission in the higher frequencies (since the 15-26 Hz sweep is of higher source level but at a much reduced received level).

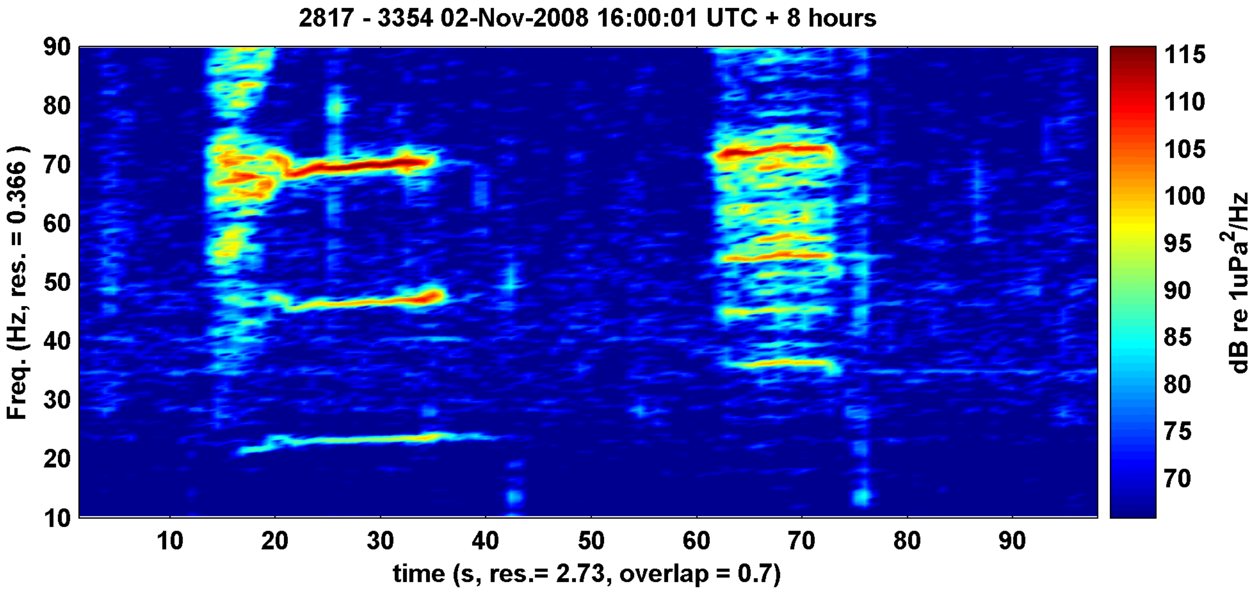

Figure 25: Spectrogram of pygmy blue whale detected on the Scott East-4 logger, calling from within the channel separating the north and south Scott reef lagoons.

All counts of the number of individual pygmy blue whales calling were converted to the number of calling individual whales per 200 s as a standardised relative abundance measure. For the Scott West-4 and East-4 sites this was done by counting all time-stamped detections within a 200 s window. Pygmy blue whales are known to have daily and lunar cycles in their calling behaviour. For example McCauley et al. (2004) showed an average 2.2 times greater call rate during darkness than daylight, with crepuscular peaks in call rates. Thus to remove time of day bias from the relative abundance estimates presented across a season, the values are averaged over a 24 hour period running from 12:00 one day to 12:00 the next, to give the mean number of instantaneous individual calling whales, averaged over a one day period.

The measured counts of calling blue whales from all Scott Reef loggers are shown on Figure 26 where the time frames across years overlap. These figures show the 24 hour averages when pygmy blue whales were present only and display the 95% confidence limits as error bars, although these may not be easily seen. The pygmy blue whale visitation from the Scott Reef locations across the full sampling time frame is shown on Figure 27 with statistics of visitation given in Table 14.

The migratory directions of pygmy blue whales moving along the WA coast have been defined in previous reports (McCauley and Salagdo Kent, 2008, McCauley 2009b) and are based on sea noise logger records and visual observations from various sources. The north and south bound pygmy blue whale pulse down and up the Western Australian coast has been repeatedly observed over several seasons from noise loggers set along the WA coast. It seems the pygmy blue whales move along the shelf break, often in deep water, to and from Indonesia. Off Scott Reef the south bound pulse of pygmy blue whales was observed clearly in 2006, with overlapping noise loggers set at the Pluto gas field north of the Monte Bello Islands also detecting the same pulse that year but with more calling pygmy blue whale detections. Some pygmy blue whale calling during the 2006 south bound migratory pulse was also recorded from the inshore Browse Island sea noise logger (see location 11 on Figure 6 or McCauley 2009a).

The proportion of samples with increasing number of calling individual pygmy blue whales is shown on Figure 28 using all Scott Reef data. Most samples had one caller (78%), 18% had two callers, 4% had three, 0.3% had four and 0.2% had five.

Table 14: Details of pygmy blue whale detections from Scott Reef. Given are the sampling periods and details of the southbound and northbound pygmy blue whale passage from each data set. The sampling overlap is days sampled between the time bounds listed for the south or north bound migratory pulse. The date of the first and last call and the days encompassed are then given. Persistent calling is defined as the time bounds through which 90% of calling animals pass with the days encompassed. The maximum and median number of singers are then given. It should be noted that not all sample sets span a full migratory season.

Set	**Sampling**	**South bound (01-Oct to 01-Feb following year, 123 days)**					**North bound (01-Apr to 01-Sep, 153 days)**				
	First samp. last samp.	**Samp. overlap (days)**	**First call last call days**	**Persistent calling days**	**Peak season**	**Max / med. singers**	**Samp. overlap (days)**	**First call last call days**	**Persistent calling days**	**Peak season**	**Max / med. singers**
2734 South-1	05-Sep-2006 30-Apr-2007	123 (full)	26-Oct-2006 21-Dec-2006 55.8	26-Oct-2006 15-Dec-2006 50	28-Oct	4 / 1	29.4 (part)	No calls detected - Insufficient overlap			
2761 South-2	14-Jun-2007 03-Feb-2008	123 (full)	12-Oct-2007 12-Oct-2007 0	none	12-Oct	1 / 1	78.3 (part)	14-Jun-2007 01-Aug-2007 47.6	15-Jun-2007 24-Jul-2007 38.8	22-Jun	3 / 1
2793 South-3	03-Feb-2008 27-Sep-2008	No overlap					153 (full)	08-Apr-2008 14-Aug-2008 128.1	09-May-2008 26-Jul-2008 77.9	13-May	5 / 1
2735 West-1	14-Jun-2007 12-Sep-2007	No overlap					78.3 (part)	16-Jun-2007 23-Jul-2007 37.0	23-Jun-2007 19-Jul-2007 26.7	22-Jun	3 / 1
2757 West-2	19-Sep-2007 08-Nov-2007	38 (part)	No calls detected				No overlap				
2792 West-3	05-Feb-2008 06-Jul-2008	No overlap					96.5 (part)	16-Apr-2008 29-Jun-2008 74.0	27-Apr-2008 09-Jun-2008 43	03-May	3 / 1
2818 West-4	28-Sep-2008 09-Jun-2009	123 (full)	06-Oct-2008 04-Jan-2009 90.8	06-Oct-2008 13-Dec-2008 68.2	07-Nov	3 / 1	128.7 (part)	01-Apr-2009 06-Jun-2009 66.6	01-Apr-2009 03-Jun-2009 62.6	19-May	4 / 1
2817 East-4	01-Oct-2008 01-Feb-2009	123 (full)	06-Oct-2008 13-Dec-2008 68.1	06-Oct-2008 13-Dec-2008 67.9	12-Dec	3 / 1	128.8 (part)	01-Apr-2009 05-Jun-2009 65.4	29-Apr-2009 30-May-2009 31.4	29-May	3 / 1
2762 North-2	14-Jun-2007 04-Feb-2008	123 (full)	07-Nov-2007 17-Jan-2008 70.9	16-Jan-2008 17-Jan-2008 0.7	16-Jan	3 / 2	78.3 (part)	14-Jun-2007 13-Aug-2007 59.5	15-Jun-2007 23-Jul-2007 38.7	22-Jun	4 / 1

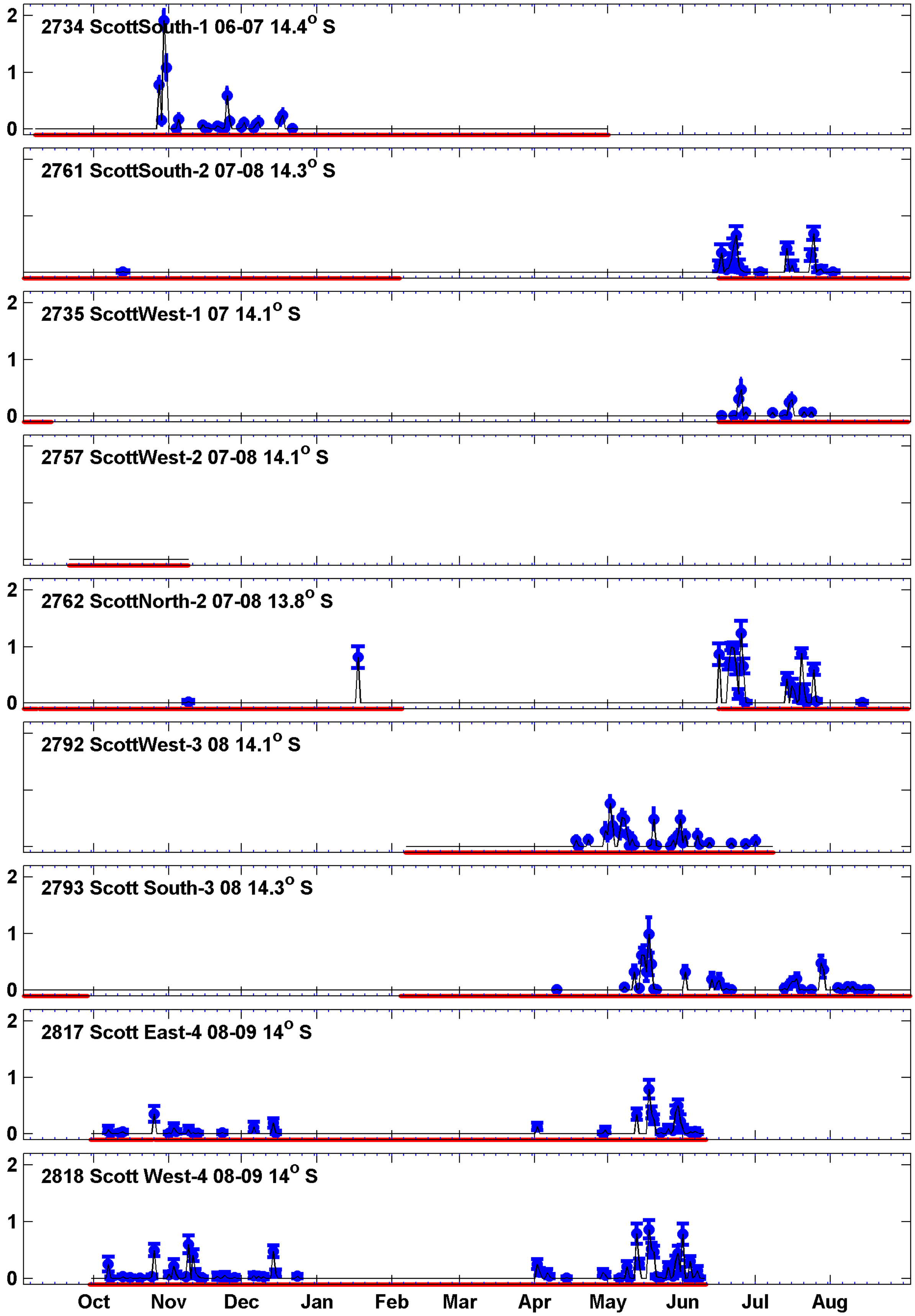

Figure 26: Numbers of individual pygmy blue whales calling per 200 s averaged in 24 hour periods over 12:00 - 12:00 hours, for all Scott Reef logger data available laid out on the calendar year. The full sampling period for each data set is shown by the bottom line (red). Minor tick marks are five day intervals.

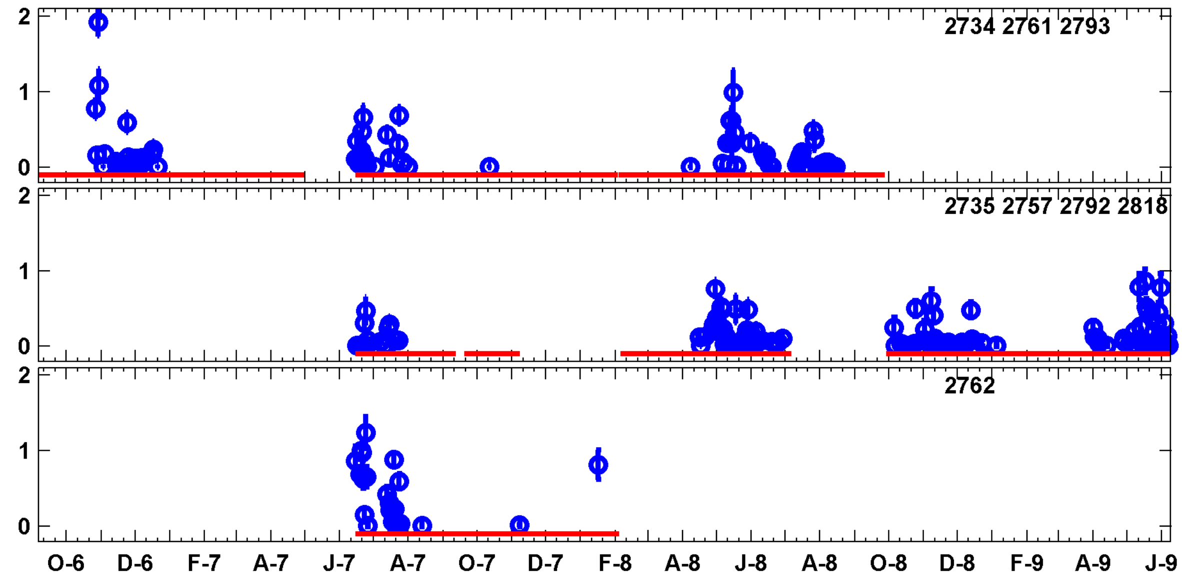

Figure 27: Numbers of individual pygmy blue whales calling per 200 s averaged in 24 hour periods over 12:00 - 12:00 hours, for all Scott Reef logger data available laid out for the full sampling period available for the three sites samples (**top panel is Scott South**, **middle is Scott West** and **lower is Scott North**). The full sampling period for each data set is shown by the bottom line (red). Minor ticks are 10 day increments, only every second month and the year as a single digit (2006-2009) are shown on the x label.

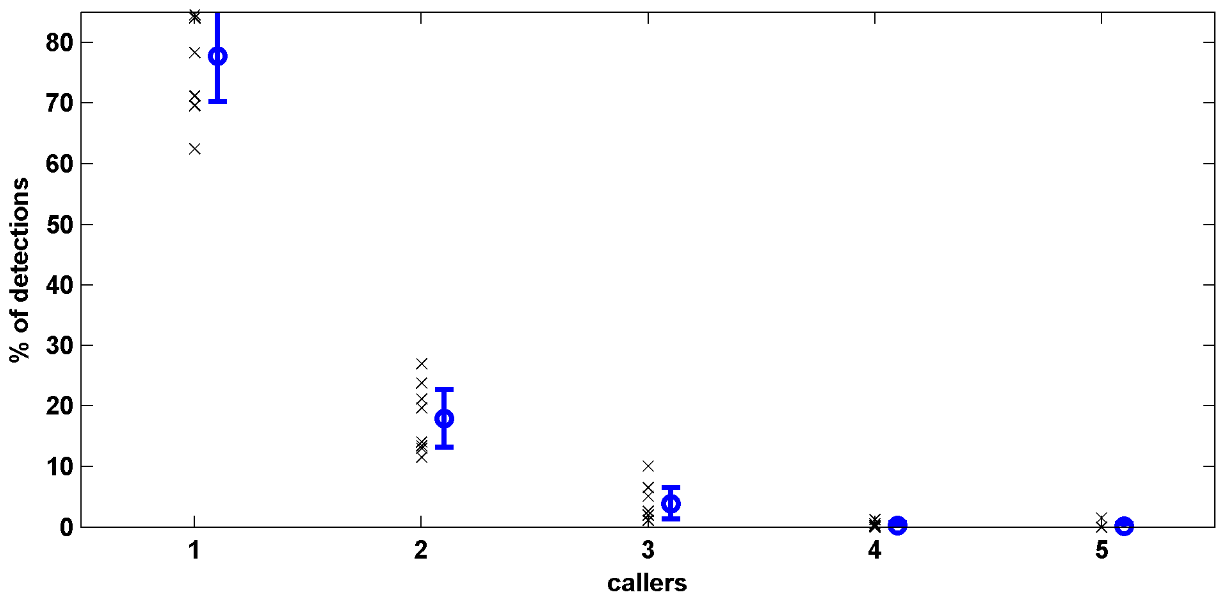

Figure 28: Proportion of samples with one to five individual pygmy blue whales singing at any point in time. The black crosses represent different data sets from eight Scott Reef sites with pygmy blue whales. The mean (± 95% confidence limits) is shown slightly offset.

A number of features are evident from this data set:

- An extended north bound (mid Apr to early Aug) passage of blue whales past Scott Reef showed up clearly during 2007, 2008 and 2009;
- A south bound pulse of pygmy blue whales appeared in 2006 and 2008 but this pulse was barely detected in 2007 (isolated detections only);
- No pygmy blue whales were detected inside the Scott Reef southern lagoon from the Scott East-1 to East-3 location;
- Pygmy blue whales were detected traversing the channel separating the north and south lagoons on at least nine occasions by the Scott East-4 logger set over Sep-2008 to Jun-2009;
- The Scott West and East-4 logger detected pygmy blue whale signals were often modified by transmission up onto the reef platform from deep water, with commonly the 15-26 Hz sweep removed and on occasion the 62-75 Hz sweep removed;
- The outside time bounds (first and last detections using data from all seasons) for south bound pygmy blue whales passing Scott Reef are 06-Oct to 17-Jan the following year
- The outside time bounds (first and last detections using data from all seasons) for north bound pygmy blue whales passing Scott Reef are 01-Apr to 14-Aug
- Typically single calling pygmy blue whales were heard calling (78% of the time) although it was common for larger groups of calling animals to be detected (ie 18% of the time two animals calling).

5.6.3 Fine scale passage of pygmy blue whales near Scott Reef

The analysis of pygmy blue whale call detections at Scott West-4 and East-4 was carried out in a way which enabled the level and arrival time of each call to be derived. Given the reasonably small detection ranges of pygmy blue whales from the Scott East and West sea noise logger locations (see Figure 18 for listening ranges) it was anticipated that if an animal was swimming steadily along the deep water section of the receivers listening range then its received signal level would fluctuate up and down accordingly as the animal swam past, and give an estimation of the time taken to swim past. The level of received pygmy blue whale calls was calculated for the unfiltered (ie full energy of the call second component), 62-75 Hz and 15-26 Hz sweep levels. The low signal levels and presence of many extraneous noise sources (fish, vessels etc) made interpreting analysis of received pygmy blue whale levels problematical especially for the Scott East-4 data set which had mostly low level pygmy blue signals detected. The received unfiltered pygmy blue whale call levels across the full Scott West-4 data set are shown on Figure 29. There do appear to be changes in received signal levels of around 10 dB associated with bouts of calling, and bouts of calling separated in time, perhaps indicative of animals moving past the receiver.

To further investigate the possibility of following an animal in time, sections with the time between consecutive pygmy blue whale calls ≥ 6 hours were considered as different calling bouts and extracted at the Scott West-4 site. The call times for each section of consecutive calls were zeroed to the first call detection, the trend of call level with time smoothed using a running linear fit (four points either side of receive point used in averaging) and over-plotted, using the level of the full call, as shown on Figure 30. There were calling periods where levels increased and decreased reasonably uniformly, but there was no clear trend in this, with fluctuations at small time scales (hours) suggestive of multipath sound transmission phenomena and fluctuations at longer time scales (> 6 hours) suggestive of animals swimming past or backwards and forwards in the area (ie. no consistent travel direction) or of a procession of calling animals passing through. Given that the number of calling individual whales was dominated by single animals (ie. 78% of samples with pygmy blue whale calls had one caller, Figure 28) then it is probable that the longer term trends (>

6 hours of calling) where several peaks in call level occurred as seen on Figure 30, were produced by single animals swimming backwards and forwards past the receivers.

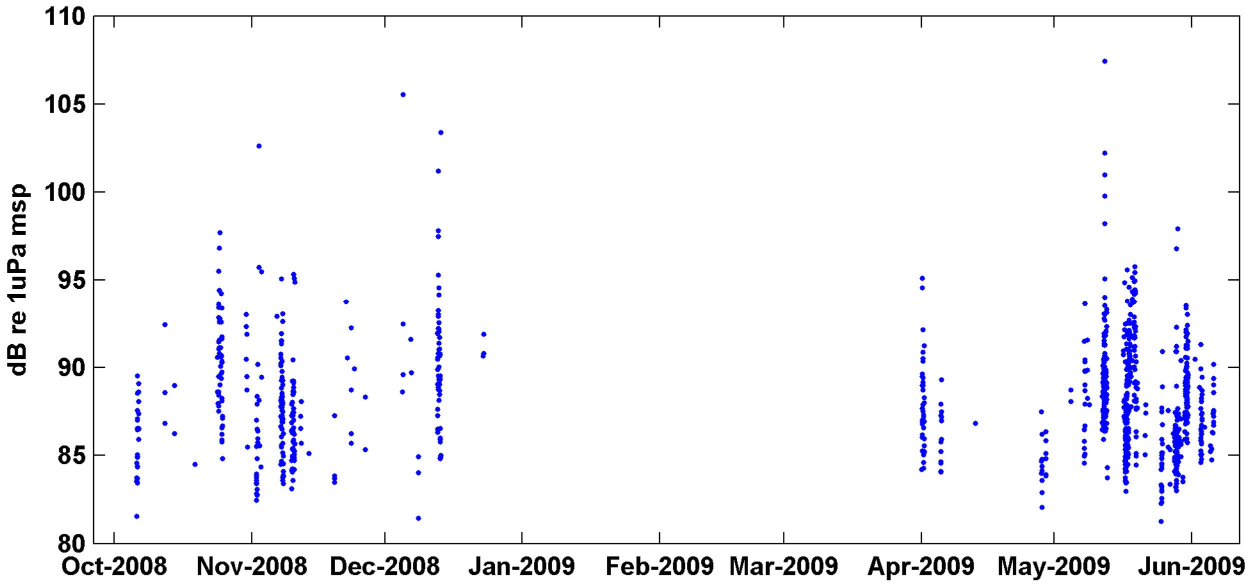

Figure 29: Received levels (mean squared pressure) of pygmy blue whale calls from the Scott West-4 recording.

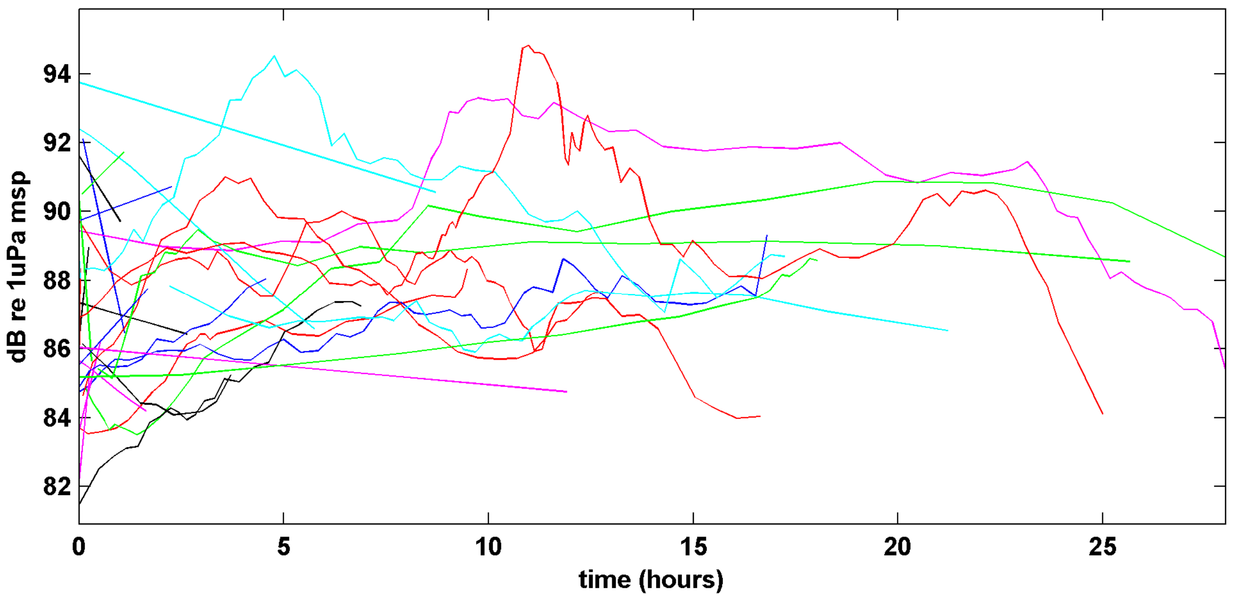

Figure 30: Received level (mean squared pressure, full call) of consecutive periods of pygmy blue whale calling, as given by periods with ≥ 6 hours between calls from the Scott West-4 site. The curves have been smoothed using a running linear fit (four averages each side of a time point), which tends to bring the higher levels down. The different colours represent periods where pygmy blue whale calling occurred continuously, with no breaks < 6 hours.

The normalised distribution of the length of these bouts (time between first and last call) with all singing bouts and singing bouts with a median of one calling animal are shown on Figure 31 (Scott West-4 data only). There was a predominance of shorter singing bouts, from several minutes only (probable long range detections) up to the maximum length displayed of 28 hours (one bout of 77 and one of 80 hours were also present). The mean and median singing bout length for all bouts and bouts with predominantly one singer (ie bouts where median number of singers was one) were 9.2 and 11.0 hours (mean) and 5.0 and 6.8 hours (median), respectively (all data and predominantly one singer). The same data was split across the south (2008-2009) and north (2009) migratory pulses and did not give significantly different results. In calculations below of abundance estimates from the Scott West-4 pygmy blue whale data sets, a residency time is required. The value of the mean time taken for predominantly one singer to complete a singing bout, of 11 hours length, has been used as the residency time.

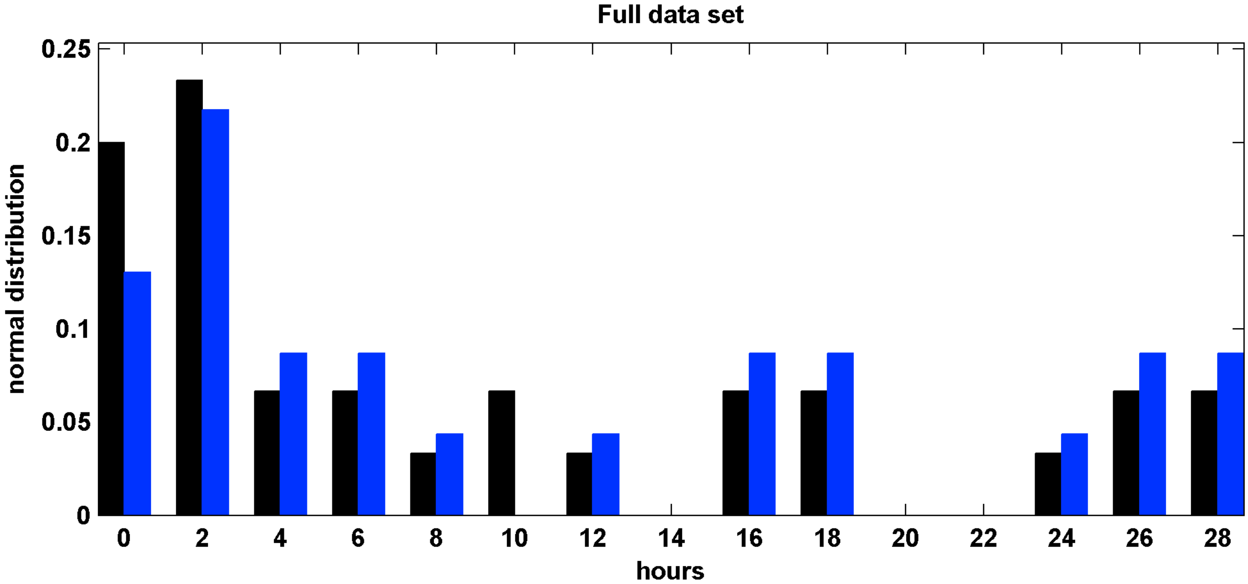

Figure 31: Distribution of length of pygmy blue whale singing bouts at Scott West-4. The black bars include all bouts, the blue bars include only bouts where the median number of individual callers was one animal.

The absence of calling pygmy blue whales from the Scott East-1 to East-3 data sets implies that pygmy blue whales rarely used the water inside the Scott reef southern lagoon. Assuming this is the case then the Scott East-4 and West-4 noise loggers only had a small overlap in estimated pygmy blue whale listening areas (see Figure 18), plus the Scott East-4 logger only listened into deep water in the channel separating the north and south Scott reef lagoons.

Since the Scott East-4 and West-4 noise loggers ran over the same time frame we can compare the pygmy blue whale detections and determine:

- if whales were west of Scott Reef in deep water (only detected on the Scott West-4 logger in a given time period)
- if whales were close to the western side of the channel separating the north and south lagoons (detected on Scott West-4 and East-4 in a given time period)
- if whales were in the channel separating the north and south lagoons (either high received level at Scott East-4 or on the Scott East-4 logger but not the Scott West-4 logger in a given time period)

The Scott East-4 pygmy blue whale detections were mostly low level and often obscured by other noise sources (the signals were visually detectable on spectrograms but had overlying, higher level: fish; air-gun; or vessel signals). Thus in the analysis of pygmy blue whale signal level below from Scott East-4, the level of any frequency sweeps in the 15-26 Hz or 62-75 Hz bands which were within 3 dB or below the ambient noise were set to the ambient noise level to ensure other noise sources (fish, boats etc) were not included in analysis.

The Scott West-4 data was divided into sections of calling bouts, as defined by the end of one call being separated by more than 12 hours from the beginning of another. The Scott West-4 calls within a bout were then cross checked with the Scott East-4 calls to check if any East-4 calls fell within 19 minutes of a Scott West-4 call (19 minutes was one noise logger sample plus the sampling length and maximum clock time differential). These calculations used the received call time as given by the GPS corrected logger clocks. Details for the West-4 site of the numbers of calls which overlapped with the East-4 site during a singing are listed in Table 15. This table lists values where in a calling bout there was an overlap between a call being received at the East-4 and West-4 sites (call at either site preceded or followed by a call at the other site within 19 minutes). In total 19 of 39 singing bouts detected at the West-4 site had overlapping calls from the East-4 site. The higher level calls as recorded at East-4 and listed in Table 15 were closer to the East-4 receiver and vice-versa.

Table 15: Details of pygmy blue calling bouts discerned at West-4 (a bout defined as a section of calling with no breaks > 12 hours) where an overlap with calling at East-4 was detected. Given are: ***# T*** – the number of calls within that bout (West-4); ***# 19 min*** – the number of calls within that bout which had a corresponding call received at East-4 within ± 19 minutes; ***Level*** - the level (dB re 1uPa2.s) of the highest call received at East-4 which overlapped that West-4 bout; ***# 12 s*** – the number of calls within that bout which had a corresponding call received at East-4 within ± 12 s; ***% 12 s*** -the proportion of West-4 calls within that bout which had a corresponding call received at East-4 within ± 12 s; ***First*** – date and time of first call within this bout; ***Last*** – date and time of last call within this bout.

# T	# 19 m	Level	# 12s	% 12 s	first	last
27	6	100.7	3	11.1	06-Oct-2008 02:30:16	06-Oct-2008 12:02:34
3	3	87.8	2	66.7	12-Oct-2008 10:15:10	12-Oct-2008 11:15:57
52	18	138.8	10	19.2	24-Oct-2008 05:02:05	25-Oct-2008 09:01:40
29	18	129.7	10	34.5	02-Nov-2008 01:31:11	03-Nov-2008 04:31:05
64	11	144.2	7	10.9	07-Nov-2008 11:30:38	08-Nov-2008 03:59:31
52	4	88.8	2	3.8	09-Nov-2008 23:00:12	10-Nov-2008 15:45:10
5	1	95.9	1	20.0	12-Nov-2008 00:44:54	12-Nov-2008 14:30:40
5	4	88.1	3	60.0	05-Dec-2008 00:16:35	05-Dec-2008 03:00:09
55	23	95.4	13	23.6	12-Dec-2008 21:14:06	13-Dec-2008 14:30:24
39	13	140.6	5	12.8	01-Apr-2009 02:43:19	01-Apr-2009 15:29:46
10	3	83.9	0	0.0	28-Apr-2009 01:14:26	28-Apr-2009 04:59:41
6	6	87.1	2	33.3	29-Apr-2009 00:45:10	29-Apr-2009 02:29:01
108	44	140.5	21	19.4	11-May-2009 19:30:12	12-May-2009 20:29:01
198	129	148.2	66	33.3	16-May-2009 12:59:23	19-May-2009 17:59:31
4	1	85.5	0	0.0	21-May-2009 11:13:22	21-May-2009 12:59:03
23	15	88.3	1	4.3	25-May-2009 01:12:23	25-May-2009 07:59:44
183	93	122.3	27	14.8	27-May-2009 18:15:14	31-May-2009 02:29:28
32	1	83.7	0	0.0	02-Jun-2009 17:27:52	03-Jun-2009 19:14:23
19	4	86.0	1	5.3	05-Jun-2009 03:27:30	05-Jun-2009 21:29:15

The following comparisons between the Scott West-4 pygmy blue whale call times and the Scott East-4 call times, plus the received level trend of the East-4 calls showed that:

- 39 pygmy blue whale calling bouts were identified on the Scott West-4 logger and 25 at the Scott East-4 logger using a 12 hour period of no calling to separate bouts;
- Of the 39 bouts from Scott West-4, 20 had no Scott East-4 pygmy blue whale signals within 19 minutes of any Scott West-4 call (ie 20 calling bouts were believed from animals which stayed west of Scott reef and were not detected at the Scott East-4 site) – all of these bouts involved few call detections;
- 19 bouts at the Scott West-4 site included animals which were also detected on Scott East-4 within 19 minutes of any call heard at the Scott West-4 site;
- Within the 19 bouts where pygmy blue whale calls were detected at Scott East-4 and West-4, on average 23% of the calls overlapped between the loggers implying that 23% of these

periods had caller locations in the western entrance of the channel separating the northern and southern lagoons, implying animals were moving through the channel. This was determined by a < 12 s difference between the arrival of calls at the different receivers. Given the generally poor signal to noise ratio of overlapping calls at the two receivers, it was not possible to do position calculations from the arrival time differences but the short time separation of signals strongly suggests they were produced by a single source located at the extreme range of the respective receivers.

- Of the 25 pygmy blue whale calling bouts identified at the Scott East-4 location, 14 were estimated to involve animals swimming within 2 km of the receiver (based on maximum levels reached in the calling bout and a 90 dB re 1μPa threshold for an animal at 2 km as derived from estimated call transmission, as shown on Figure 16), and all bouts involved animals swimming in the channel between the north and south lagoons (since they could only be in the channel or reef lagoon to be heard at Scott East-4 and no pygmy blue whale calls have yet been detected at the Scott East-1 to East-3 sets inside the lagoon).
- Of the 25 pygmy blue whale calling bouts identified at the Scott East-4 location, six must have involved animals which swam east through the channel or stopped vocalising as they moved west, as they did not turn up on the Scott West-4 logger (19 overlapping with the Scott West-4 calling bouts, six not overlapping using a 12 hour bout separation).

5.6.4 Match of visual and acoustic pygmy blue whale observations

The Centre for Whale Research ran vessel surveys for great whales in the Scott Reef area over early to late 2008 in four, 20 day survey blocks (Jenner et al, 2010). Four pygmy blue whale pods were sighted in this time, two pods in the vicinity of Scott reef, one close to the NW and one distant to the SE. The sighting times and locations of these pods were supplied for comparison with the acoustic records.

The two pods sighted closest to Scott Reef were detected by the noise loggers. Details of locations and acoustic comparisons are given in Table 16 and the locations of pygmy blue whales at first sighting (they were subsequently followed by the vessel) and the noise loggers are shown on Figure 32.

Table 16: Visual sighting details of pygmy blue whales at first sighting, the time difference between nearest acoustic detection minus the first visual sighting time and received signal level for the Scott East and West loggers (negative times are acoustically detected before sighting, positive times are acoustically detected after sighting). The first sighting observation (Jun-2008) was before the Scott East-4 and West-4 loggers were deployed.

Date	**First sighting location**	**# whales**	**Nearest acoustic detection (hours for East / West loggers)**	**Level of nearest acoustic detection (dB re 1μPa for East / West)**
14-Jun-2008 16:46:00	14° 14.567' S, 123° 49.775' E	1		
30-Oct-2008 11:55:00	14° 2.440' S, 121° 57.924' E	3	10.3 / 6.8	94 / 92
02-Nov-2008 17:17:00	14° 2.981' S, 121° 45.588' E	3	-1 / -0.3	105 / 86
12-Nov-2008 16:00:00	13° 53.206' S, 121° 18.684' E	1	-14.5 / 1.5	96 / 83

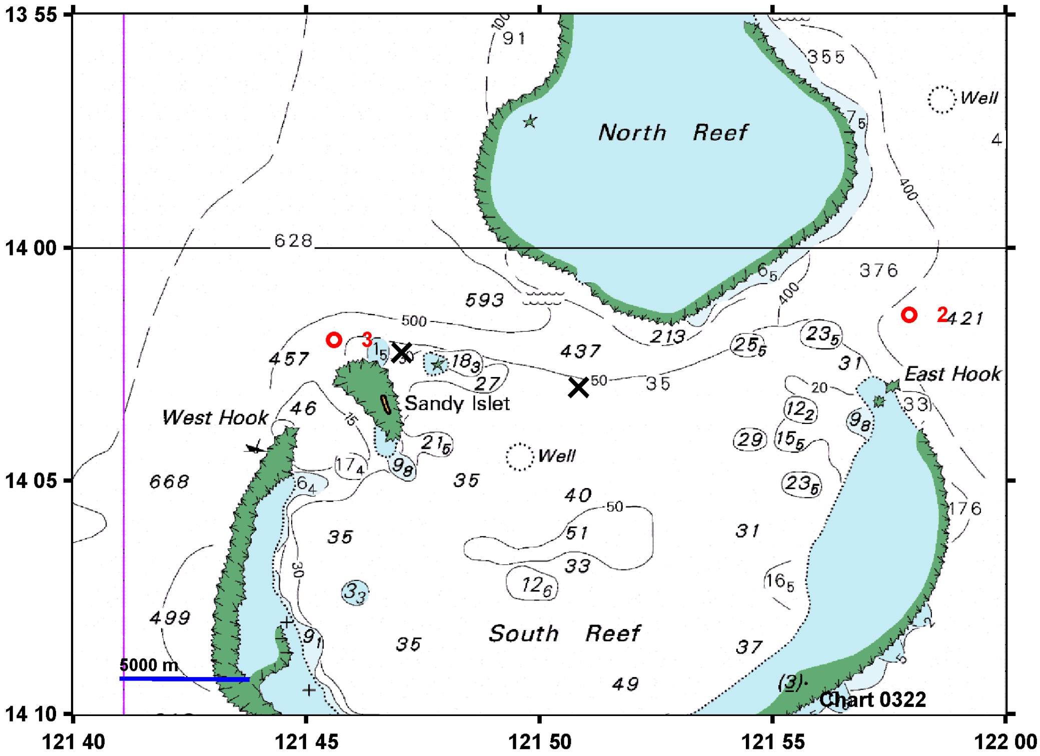

Figure 32: Location of Scott East and West-4 noise loggers (black crosses) and the first sighting location of pygmy blue whales (red circles) with the adjacent numbers the row number for Table 16.

The third pygmy blue detected in the visual observations was picked up by the noise logger at Scott West-4 so one of these three animals must have been vocalising (20 minutes before the sighting the last of a series of vocalisations was detected). There were detections within a short time frame for the fourth whale sighted and it is possible that this whale had moved north from near Scott Reef to the sighting location. The second visual sighting on the eastern side of Scott Reef may have been from the same animals previously heard on the noise loggers (the closest acoustic detection was 6.8 hours prior the visual sighting from Scott East-4) or from another animal not sighted by the visual surveys. In all cases the visual sighting of pygmy blue whales near to Scott Reef correlated with acoustic detections within a 15 hour period, suggesting that the animals moved through in groups.

5.7 Bryde's whale signals

5.7.1 New data and analysis – Bryde's whales

The data sets Scott East-4 and West-4 where systematically checked for Bryde's whale calls and the results synthesised with previous data.

5.7.2 Bryde's whales near Scott Reef and northern WA

In the previous report of McCauley (2009b) a common low frequency signal which was believed to be attributable to Bryde's whales was observed at the Scott Reef sites. The similarity of the calls detected throughout northern Australia and near Scott Reef to signals described by Heimlich et al (2005) for Bryde's whales in the eastern tropical Pacific is strong enough to imply the signal type detected around northern Australia are produced by Bryde's whales.

Apart from the report of McCauley (2009b) based on acoustic detections there is no information available on Bryde's whale habits, including calling behaviour, in northern Australia. In order to begin an investigation of their presence and habits in the noise logger data sets a search algorithm was built to locate the signal type. The detection algorithm matched the envelope of a high signal to noise ratio call against sequential sections from each sample, then looked at the energy content above and below the energy of the call to remove any broad band signals, such as air guns. Manual checking of spectrograms was carried out for 5823 records with the mean difference at 0.1 ± 0.02 calls per sample (auto detect consistently slightly higher), which was considered small when looking for general preliminary trends only. The Scott East-4 and West-4 Bryde's whale search algorithm detections were manually checked and the real detections bracketed by five samples and this process iterated until no more new detections were found. The majority of the other data sets described her for Bryde's whale trends have not been manually checked (see Table 5 for status of Scott Reef whale searching).

Using the output given by the detection algorithm with cross checking, the seasonal visitation of Bryde's whales inside and close to Scott reef as given by Scott East-4 and West-4 is shown on Figure 33. As has been found at other sites where the Bryde's detections have been analysed, there does not appear to be any clear seasonality in the presence of Bryde's whales.

The Brydes whale detection patterns across a year are shown for more widely dispersed sites, including Scott East, Scott South and a site NW of Broome (site 7, Figure 6), as is shown on Figure 34. As we do not yet know the call repetition rate the measures of relative abundance is based on the mean number of detections / 200 s samples averaged over 24 hour periods (12:00 to 12:00, 24 hours later). The algorithm was run over the location in 200 m water depth, 209 km NW of Broome (set 2623) shown on Figure 6 (location 7). As the long time series plots suggest, there appears to be no clear regular seasonal patterns in the data on Bryde's visitation. The passage of a small number of vocalising whales in the vicinity of the loggers for extended periods can be clearly seen at Scott South (ie in Apr-2008), but at this stage no distinct patterns indicative of migrations along the coast are evident.

As for the dwarf minke whales, the total detections of Bryde's whales is considerably lower inside or near Scott Reef than in open water nearby. The transmission of Bryde's whale signals will not be that different to the low frequency sweep of the second call component of pygmy blue whales, as the call frequencies are similar. The total call detection ranges for Scott East-4 and West 4 for pygmy blue whales where 218 and 188 km^2 (including waters in the lagoon, Table 9) as compared with 2501 km^2 for the Scott South location. Assuming the Bryde's call transmission is similar to the pygmy blue whale then the Scott South location had a listening area for Bryde's whales 11-13 times greater than at Scott East-4 or West-4. This difference in listening area would account for the difference in detections and so the lower call detection rates observed near or in Scott Reef do not imply lower densities of Bryde's whales.

The analysis presented here and in McCauley (2009b) is the first that has been carried out on these signals. As of yet we do not know the shortest call repetition interval, thus the number of call detections normalised to 200 s has been used as a relative abundance estimate. No other aspects of the call have to date been studied.

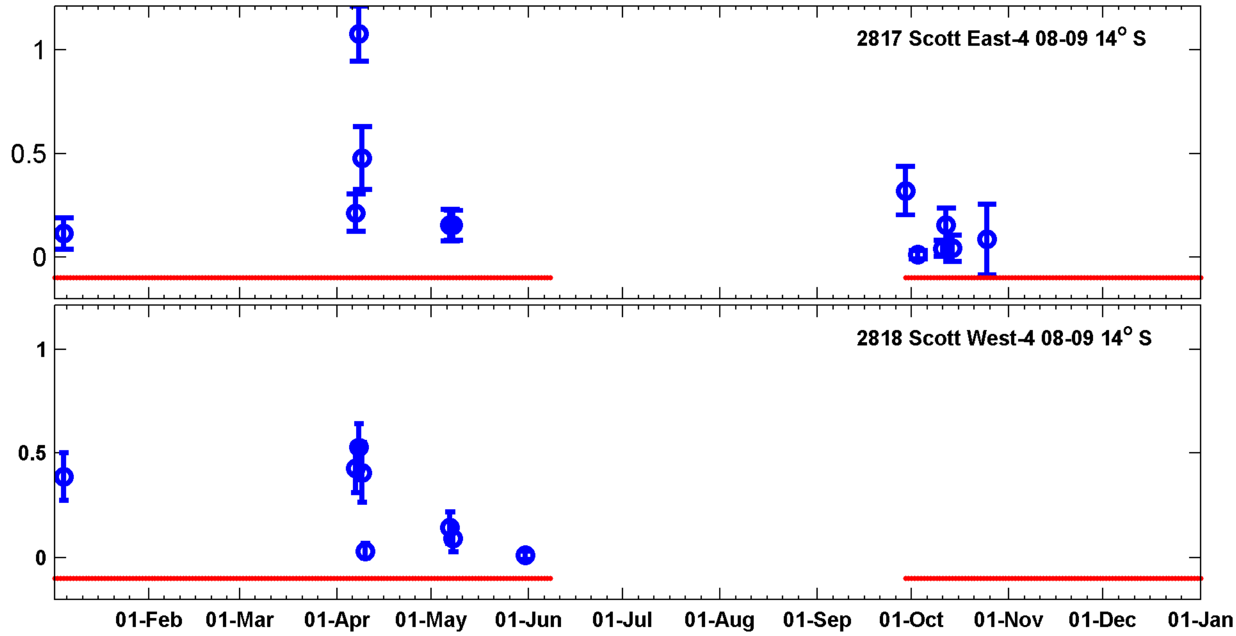

Figure 33: Mean 24 hour average of Bryde's whale calls/200s sample made every 15 minutes (averaged over 12:00 to 12:00) from the Scott East-4 and West-4 sites. The red bars below the zero axis are sampling periods.

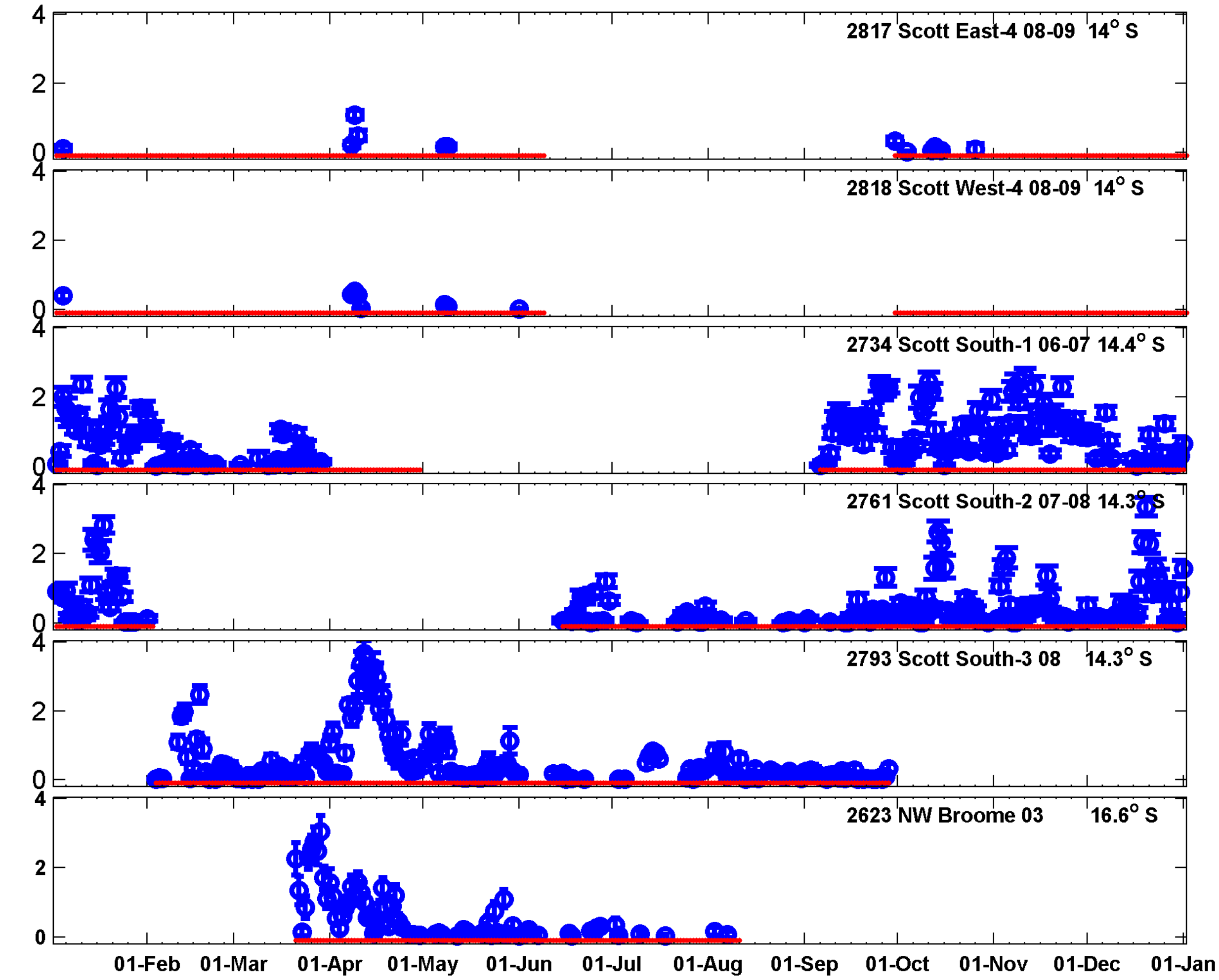

Figure 34: Mean 24 hour average of Bryde's whale calls per 200 s, (averaged over 12:00-12:00) from a site 209 km NW of Broome (set 2623, bottom panel), the three Scott South data sets, Scott East-4 and West-4. The data has been aligned by Julian Day. The red bars indicate sampling periods at each site. Given are the 24 hour means with 95% confidence limits. Minor ticks are five day increments. The red bars are sampling periods.

5.8 Fish choruses

5.8.1 New data and analysis – fish choruses

The Scott East-4 and West-4 fish chorus data was calculated using the intensity in various 1/3 octaves which are indicative of a chorus, to define patterns. This data has been synthesised with previous data to show long term trends.

5.8.2 Fish choruses in and around Scott Reef

Numerous fish choruses were observed across the Scott Reef sites (Scott South, in the southern lagoon of Scott Reef, Scott West and Scott North). Several of these choruses can be seen on the 50 day stacked sea noise spectra of Figure 7 to Figure 11. Many fish commonly form schools and call *en masse* over certain daily time periods of usually a few hours, either for reproductive purposes or to compare information on the location of patchily distributed prey (McCauley 2001). Such fish choruses are commonly observed in sea noise records, for example sea noise loggers set along the Kimberley coast are dominated by fish chorusing.

The fish choruses at Scott South and inside Scott Reef from the Scott East-1 to East-3 site were briefly presented and discussed in McCauley (2009b). Only a small elaboration of the time series for one evening chorus type, that centred near 800 Hz and produced by nocturnally active planktivorous fishes, has been presented here.

5.8.3 Within Scott Reef fish choruses

Within the Scott Reef lagoon at least four chorus types were present. The initial four chorus types identified (there are more) had different daily cycles and different spectral content. The choruses were:

- A chorus each evening just after dusk centred at near 800 Hz but with energy into several kHz (Scott East and Scott West)
- A chorus centred at near 400 Hz late each evening (Scott East and Scott West)
- A chorus centred at near 150 Hz occurring just after dusk (Scott West)
- A tonal chorus centred at 700 Hz evident over midnight to early morning (Scott West and only in Jun-Aug).

The higher frequency chorus (centred near 800 Hz) had the character of choruses reported by the author and emanating from near to reef systems (McCauley 2001). This chorus type has been widely heard across northern Australia and is believed produced by nocturnally active reef fishes such as Holocentridae, Priacanthidae or Apogonidae, foraging in the water column. Given the ubiquity of this chorus type, that it has been studied previously and it occurred consistently across the deployments in Scott Reef, the time-trends in its occurrence were analysed previously (McCauley 2009b) to correlate with the *Maxima* seismic survey activity. Apart from a small aberration in an increase in chorus activity over the seismic survey period, the seismic survey did not appear to have altered chorus behaviour inside Scott Reef lagoon. This analysis has been extended with the addition of the 2008-2009 data set from Scott East-4.

Trends in the evening chorus level have been followed through time by averaging the energy across the 1/3 octave frequency band which best matches the dominant energy content of the chorus. For the chorus centred in the 800 Hz 1/3 octave, energy was averaged over 707-890 Hz (the 1/3 octave bounds). To normalise time to something meaningful to the fish, the time each day was zeroed to the time of local sunset. This was achieved by returning the time of local sunset for that location and day from the Geoscience Australia website and zeroing each days time base to time of sunset (suns upper limb hitting horizon).

The pattern of the 800 Hz chorus across the Scott East recording period (14-Jun-2007 to May 2010) is shown on Figure 35. The top panel displays energy in the 800 Hz 1/3 octave across each evening with time zeroed to the time of local sunset and the appropriate moon phase (full moon only) shown. The energy in the chorus has been integrated each evening to give a single value for that day, and this plotted with time on the middle panel of Figure 35. The time of the chorus peak in level has been measured from each evenings curve and is plotted on the lower panel of Figure 35. The measure of the time of chorus maximum was often shifted from the fish chorus trend by extraneous noise sources in the 800 Hz 1/3 octave, as happened when a rig tender was holding station near the receiver in mid to late 2008.

There are clear patterns in the 800 Hz chorus with distinct daily, lunar and seasonal periodicity. For each lunar period and beginning at the day of full moon, the chorus was at a comparatively low level and starting comparatively early in the evening (with respect to local sunset). As the moon waned the chorus level increased steadily each day and started later each evening, up until the chorus level reached a peak at the time of the new moon, when the chorus activity was greatest some 3-6 hours post local sunset. After the new moon the chorus either stopped or continued each evening at a low level until the next full moon cycle began. There was a longer period seasonal trend in the daily timing of the chorus with respect to local sunset and level. Maximum chorus levels appeared in late summer to early autumn and minimum levels over winter. This pattern is identical to that observed for the same chorus type sampled over a two year period off the Kimberley coast near the Maret Islands (McCauley 2009a).

The previous report on the Scott Reef sea noise (McCauley et al 2008b and McCauley 2009b) dealt with potential changes to the 800 Hz fish chorus in Scott Southern lagoon from the *Maxima* seismic survey. This analysis is not elaborated further other than to display the chorus nature into May-2010, or two years after the *Maxima* seismic survey program commenced. There did not appear to be any change in the chorus nature nor any differences between the chorus behaviour observed inside Scott Southern lagoon out to 22 months after the *Maxima* seismic survey was completed. The long time frame nature of the Scott Reef 800 Hz chorus was identical with a similar chorus recorded near to the Kimberley coast over a matching time period. This suggests that the *Maxima* seismic survey had no detectable long term impact on the fish complement which produced this chorus (primarily nocturnal foraging fishes of the families Priacanthidea, Holocentridae and Apogonidae).

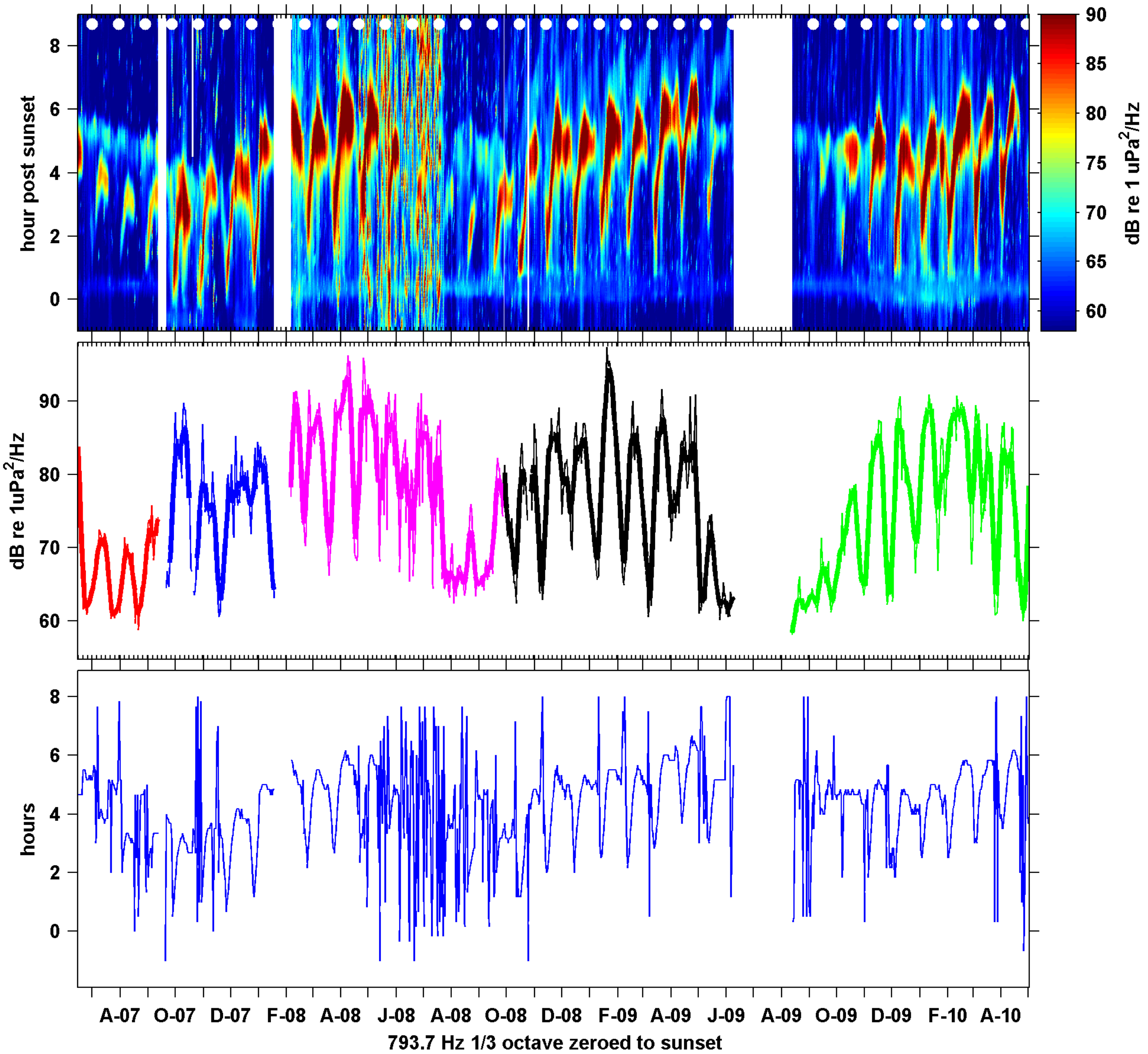

Figure 35: Pattern of the 800 Hz 1/3 octave level each evening across Jun-2007 to May-2010 at the Scott East site shown by: 1) **(top panel)** each evenings energy in the 800 Hz 1/3 octave shown with time zeroed to time of local sunset; 2) **(middle panel)** the seasonal trend in chorus level shown as the integrated energy across the 800 Hz 1/3 octave chorus between 1 and 7 hours post dusk each evening; and 3) **(lower panel)** the time of maximum chorus level each evening relative to local sunset (this curve shows high variability due to extraneous noise sources and / or low chorus levels). In the top panel the 800 Hz chorus dominates in the long time frame oscillatory trend with evidence of a second type of chorus seen beginning around 5.5 hours post dusk and linearly dropping to 3.3 hours post dusk in early Nov when it stopped each year. The moon phase is shown by the circles (full moon only) on the top panel. Zero time on the y-axis is the time of local sunset at the site. The different colours on the middle panel are different data sets. Only the first character of every second month is shown on the time axis. See the text above for an elaboration of how the data presented was calculated.

5.9 Dynamite fishing 2008-2009 Scott Reef

During searching for humpback song inside Scott Reef using the 2007 data sets a number of signals characteristic of underwater explosions were detected from the Scott East-1 logger (set 2740, Table 3). These signals and their presence (occurred on most days, often one charge late morning and one mid afternoon) are described in McCauley (2009b). The well defined explosive signals were relatively short range and had distinct characteristics, notably a large waterborne signal with a steep fronted impulse (rapid rise time) often preceded by ground borne low frequency energy and the waterborne arrival followed by various echoes, multipath bounces and a large amount of reverberation. The only possible source of repetitive explosive signals inside Scott Reef at that time in 2007 for the Scott East-1 data set was from illegal dynamite fishing by ‘traditional’ Indonesian fisherman, although this was not verified and is speculative.

The 2008 data sets (Scott East-4 and Scott West-4) were searched for explosive like signals based on the algorithm output. No explosive events were found in the set Scott East-4 but at least seven were detected at the Scott West-4 site. Six of these events occurred between the 15-Oct-2008 and 27-Oct-2008, one occurred on 01-Dec-2008 and one on 01-Jan-2009. Thus it appears that explosions consistent with dynamite fishing, albeit at a lower level than as recorded in 2007, still occurred at Scott Reef in 2008.

6. Discussion

A discussion of humpback, dwarf minke and Bryde’s whale distributions was presented in McCauley (2009b). These discussions are not elaborated greatly here. A discussion of pygmy blue whale abundance around Scott reef has been calculated but is not presented as the technique requires validation by scientific review. Where appropriate estimates of whale population size by relative abundance have been given through the results and are summarised in the synthesis. Using data collected near to Scott Reef over Sep-2008 to Jun-2009, this section builds on the similar analysis carried out for humpbacks and pygmy blue whales using data up to Sep 2008 as reported in McCauley and Salagado Kent (2008) and McCauley (2009b).

6.1 Humpback calling along the WA coast

The timing of humpback passage along the northern WA coast was compared by displaying relative abundance estimates of singing whales made at various locations along the northern WA coast in McCauley (2009b). In this report only humpback singing detections inside or near Scott Reef were analysed and added to the existing data sets. The table of timing of humpback detections along the WA coast has been expanded to include the Scott East-4 data set and is presented in Table 17. The Scott East-3 and East-4 data sets have been combined in this analysis.

The outside season bounds for humpbacks were 23-Jun to 23-Sep outside Scott Reef and 27-Jun to 14-Oct inside the reef. The time over which 90% of whale calling occurred (maximum visitation) was late July / early June to mid September outside Scott Reef and mid August to mid September inside Scott Reef.

There appears to be comparatively low numbers of humpbacks which utilise waters inside and close to Scott Reef and a gradation of humpback density moving north and west from the coast (discussed in more detail in McCauley 2009b). Humpbacks use all parts of Scott Reef southern lagoon (sightings have been made inside the lagoon), including the channel separating the north and south lagoons (ie. the animal 1.5 km north of the Scott East-4 location with strong echoes reported here).

Table 17: Summary of times humpback singing detected along northern WA. Only valid dates are listed (often full seasons were not sampled)

Location	Year	First song	Persistent song starts	Season peak	Persistent song ends	Last song
Exmouth	2000				07-Nov	13-Nov
Exmouth	2004				16-Nov	16-Nov
North end Monte Bello Isl.	2005	15-Jun	14-Jul	02-Aug		
western end NW shelf	2006	23-Jun	08-Jul	12-Aug		
Scott South	2006				15-Sep	23-Sep
Scott South	2007	30-Jun	27-Jul	22-Aug	06-Sep	14-Sep
Scott South	2008	28-Jun	12-Jul	13-Jul	31-Aug	16-Sep
Scott East	2007	27-Jul	24-Aug	31-Aug	31-Aug	31-Aug
Scott East-3 & East-4	2008	27-Jul	27-Aug	28-Aug	14-Oct	14-Oct
Scott North	2007	25-Jul	26-Jul	22-Aug	25-Aug	13-Sep
Maret Isl.	2006				27-Sep	01-0ct
Maret Isl.	2007	11-Jul	12-Jul			

Humpback numbers are increasing at 10-12% (best estimates, Salgado Kent pers. com. based on aerial surveys off NW Cape). This strong increase rate and their current high numbers (estimated at around 30,000 whales for the WA population) implies that humpbacks will expand their geographic range, as has occurred along coastal areas of the northern WA. For example McCauley et al (2003) found no humpbacks inside of the 20 m depth contour north of Exmouth in aerial surveys carried out in October 1996 whereas Jenner (pers. comm.) has reported large numbers inside the 20 m depth contours in 2008-2009 again based on October aerial surveys. It is probable that as more data is collected over time the humpback season visitation bounds will expand slightly and the numbers seen in and around Scott Reef will increase concurrent with the population increase.

6.2 Antarctic minke whale calling

The signal type believed to be produced by the Antarctic minke whale form has been detected in low numbers from the Scott South receivers but not inside Scott Reef. It is probable that the waters around Scott Reef are at the northernmost extremity of the range of the Antarctic minke. Little is known of the movements of these animals and the Antarctic minke presence has not been explored here.

6.3 Dwarf minke whale calling along the WA coast

Along the WA north coast it appears that dwarf minke whales have a restricted season length of 51-55 days inside Scott Reef as compared with 92-124 days outside of the reef (values from Table 13). In general dwarf minke whales are known to migrate north during winter and south during summer, although some animals may not migrate at all. This trend appears in the sea noise data for the most southerly latitude sampled, as displayed by the outside season bounds with latitude on Figure 23.

The presence of dwarf minke whales, as given by 24 hour averages of the number of whales calling from sites off the North end of the Monte Bello Islands to Scott Reef is shown on Figure 36. There is a wide season of dwarf minke whale presence outside of Scott Reef, running from mid May until late September each year and peaking in August or September. Off the northern end of the Monte Bello Islands dwarf minke whales have been detected from the beginning of sampling in late March up until late September, with isolated detections into October. The trend shown on Figure 36 is similar to humpbacks, in that around the latitude of the top end of the Monte Bello Islands there is a protracted season for dwarf minke presence while further to the north the season length is shorter and encompassed by that to the south. This evidence supports a northerly migration of dwarf minke whales along the WA coast, ending in the Kimberley in late September with only a fraction of animals heading as far north as Scott Reef.

Currently no estimates of abundance have been made from the dwarf minke whale data, nor have comparisons of relative abundance between sites although the data around Scott Reef suggest few animals venture inside the reef.

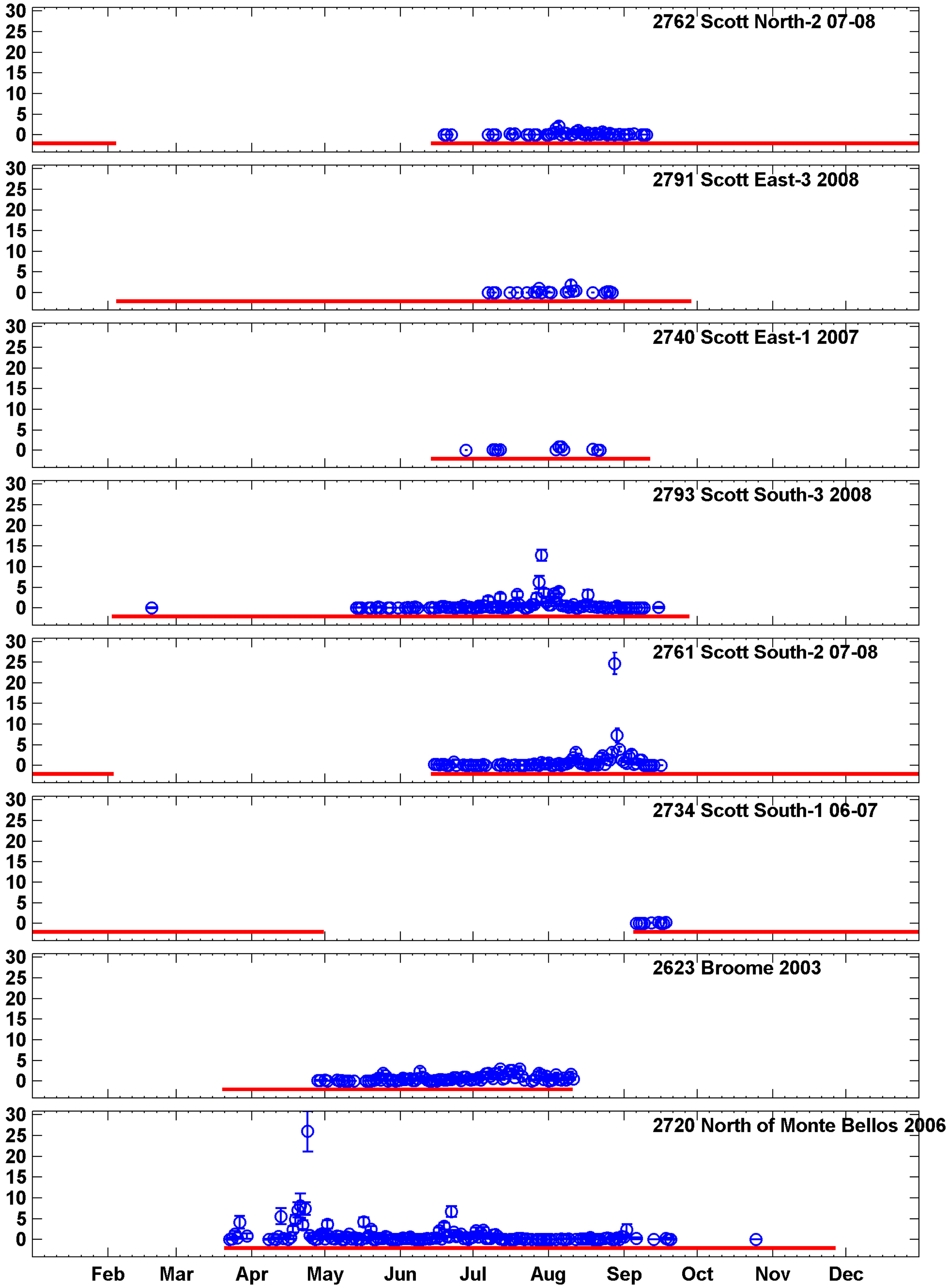

Figure 36: Averaged counts of dwarf minke whales (24 hour average) from sites from the north end of the Monte Bello Islands to Scott Reef with 95% confidence limits shown. The red bars are sampling periods for the respective sets.

6.4 Pygmy blue whales along the WA coast

Pygmy blue whale signals had been recorded in Western Australia from north of the Monte Bello islands including Scott Reef and near Browse Island, south along the whole Australian coast, then east across to Bass Strait and as far south as the Antarctic convergence zone (45^{o} to 55^{o} S). Figure 37 shows pygmy blue whale calling rates for locations along the Western Australian coast and across to a receiver on the shelf break off Robe in South Australia, the sites available which have been systematically searched for pygmy blue whales. From the Scott Reef noise logger data sets combined with the data shown on Figure 37 and sites further south, it is apparent that each year a flux of pygmy blue whales pass south down the Western Australian coast. Pygmy blue whales pass south by Scott Reef over late October to late December. Off Exmouth and the north end of the Monte Bello Islands the southbound pygmy blue whale passage seems well defined, spanning October to the end of January and peaking in late November to early December. The number of singers detected is considerably higher during the southbound (and northbound) migratory pygmy blue whale phase off Exmouth than off Scott Reef. These southbound pygmy blue whales then fan out across southern Australian waters to feed on krill patches over summer to early Autumn. The animals aggregate in certain areas along Australia's southern regions such as the Perth Canyon (during their return northbound leg) and along the Bonney coast of western Victoria and south eastern South Australia, where a suitable high abundance of krill can be sourced. They can head a long way south, as far as the Antarctic convergence zone, and have been detected acoustically nearby to loggers set at 55^{o} S off southern Tasmania (Australian Antarctic Division data).

In April to May some proportion of the pygmy blue whale population around southern Australia head north along the Western Australian coast with the main season in the Perth Canyon believed due to animals on their northern migratory leg. In the Perth Canyon individual pygmy blue whales seem to come and go, possibly using the area between Cape Naturaliste and Lancelin. The protracted northbound season seen in the Perth Canyon on Figure 37 is due to animals staying pending food availability, or moving in and out of the area. A north bound flux of animals is detected off Exmouth and Scott Reef over June - August. At the same time an unknown proportion head north along the eastern Australian coast, as indicated by a noise logger set in Bass Strait (authors data) and stranding data along the east coast. We have evidence that some portion of northbound animals which travel up the Western Australian coast head into northern Indonesian waters (the Banda Sea) to over-winter, based on visual sighting data (Benjamin Kahn, pers. com.).

Three noise logger sets made in 45 m of water at the north end of the Monte Bello Islands, on the NW shelf and in 200 m of water NW of Broome (well inside the straight line passage between the north end of the Monte Bello Islands and Scott Reef) during the expected June-July northern pygmy blue whale migration did not detect pygmy blue whale signals, indicating that in northern Australia pygmy blue whales primarily travel along the shelf break or in open water and rarely on the continental shelf. The signals did not transmit up onto the continental shelf for receivers set near the northern end of the Monte Bello Islands.

The northbound pygmy blue whale migratory pulse is long and drawn out with comparatively low densities of calling animals when compared with the character of the acoustically derived southbound pulse of pygmy blue whales for receivers set off Exmouth and in deep water off the northern end of the Monte Bello Islands. This suggest southbound animals move quickly and determinedly, whereas northbound animals tend to take more time, potentially searching for food as they head north along the WA coast.

There is currently too little resolution in the Scott Reef data to determine any time lag between the south bound peaks off Exmouth. Seven seasons of passive acoustic studies in the Perth Canyon suggest that the north bound pygmy blue whales which arrive there in mid summer cue their migratory times to the moon with the appropriate moon set by the summer solstice. Thus given the relatively small seasonal coverage at present off Scott Reef and the complication of at least parts of the pygmy blue whale migration apparently not tied to our Gregorian calendar, an analysis of migratory speeds along the coast has not been carried out.

Based on the passive acoustic data, visual sightings and strandings (east coast), a hypothesised, and partially complete geographic span of pygmy blue whales in the Australian / Indonesian context is shown on Figure 38. Not illustrated on Figure 38 is a migratory route up the east Australian coast and the migratory span into the southern ocean where pygmy blue whales are known to feed along the Antarctic convergence zones. There are many unknowns in this migratory pattern, including:

1) The numbers of whales which migrate along the east Australian coast;
2) The full link between animals seen along the Bonney coast (south-eastern Australia) and which pass up the West Australian coast;
3) How whales utilise western Indonesian waters and upwelling systems known to occur along the southern Indonesian Islands directly bordering the Indian Ocean;
4) How many whales head west between 30-40^{o} S into the southern Indian Ocean (whaling data suggest a considerable fraction of the population resides in the lower Indian Ocean);
5) Is there a northern link around the top of Paua New Guinea / Indonesia linking animals which pass up the east and west coasts of Australia?

In the Scott Reef context it appears that pygmy blue whales regularly transit waters around the reef system and regularly pass close to the reef, with approximately half the animals which visit the immediate surrounds of Scott Reef as recorded on the Scott West loggers, traversing the channel separating the north and south lagoons. A receiver set along the reef rim of the southern lagoon adjacent the channel (East-4) detected pygmy blue whales in the channel on 25 occasions over Sep-2008 to Jun-2009 (an occasion being a calling bout with no calls separated by more than 12 hours). Nineteen of these calling bouts detected in the channel were also heard from a logger placed on the reef rim but listening to the west of Scott reef (Scott West-4) implying the animals had swam through the channel. Six detections of whales in the channel were not detected to the west implying the animals entered the channel from the east and headed out to the east again, or stopped calling if they went west. The receiver set on the western reef rim detected 39 bouts of pygmy blue whale calling over Sep-2008 to Jun-2009, many of these involving animals passing close to the reef rim. Several visual detections of pygmy blue whales around Scott Reef in October 2008 were matched by acoustic detections.

For pygmy blue whales in and around Scott reef, converting the acoustic detections of pygmy blue whales to estimates of numbers of whales passing over a season suggests:
1) The whale densities inside and near to Scott reef are similar to those detected in open water;
2) That the Scott West loggers have detected a constant increase in call detections over 2007, 2008 and 2009;

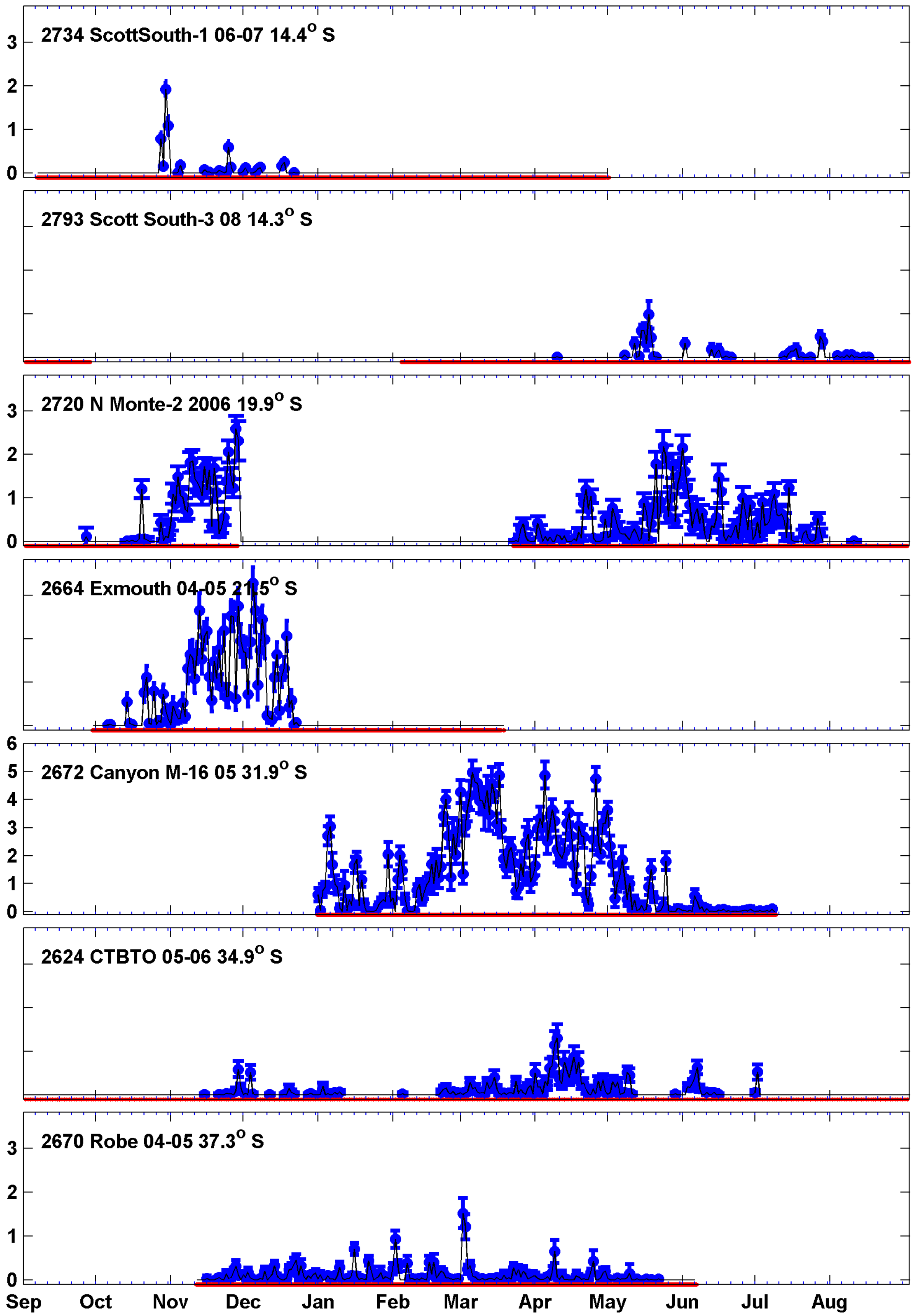

Figure 37: Numbers of individual pygmy blue whales calling per 200 s averaged in 24 hour periods over 12:00 - 12:00 hours for various sites along the Western Australian coast and off Robe in South Australia. The plots are aligned from north (top) to south (bottom). Zero detections are not shown. The full sampling period for each data set is shown by the bottom line. Minor ticks are five day increments. The CTBTO data set was from 34° 53' S, 114° 8.4' E, the Robe set was near the shelf break SW of Robe in South Australia.

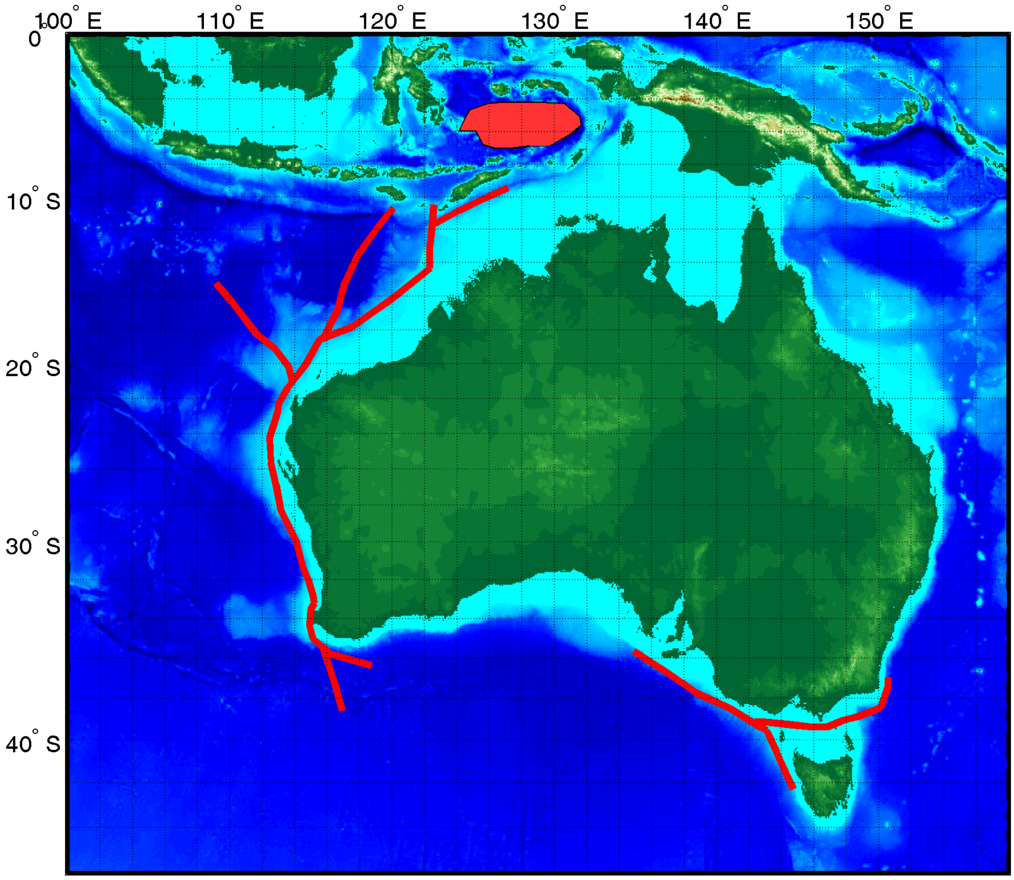

Figure 38: Hypothesised routes of pygmy blue whales in the Australian / Indonesian context. The red patch in the north is the believed migratory end point. See text for notes on unknowns.

The Scott South-2 and Scott North-2 loggers either failed to detect, or detected very few, calling pygmy blue whales during the expected 2007 south bound migration, suggesting the southbound migration route had changed in late 2007. That the whale migration route had deviated and that some proportion of the population had not headed south was supported by the finding that off Scott Reef the expected returning animals in the northbound 2008 migratory pulse (ie. the late 2007 southbound animals passing Scott Reef would be expected to pass north in Jun-Aug 2008) did arrive but in numbers 2-4 times lower than for the 2007 northbound migratory pulse (when comparing overlapping time periods). In the Perth Canyon the numbers of animals passing north in 2008 was approximately half of the number passing north in 2007, further strengthening the case that for some reason pygmy blue whales did not pass south by Scott Reef coast as expected in late 2007.

There appears to be large differences in pygmy blue whale call detection rates between Scott Reef and off Exmouth during the south bound migration pulse. The comparison of call detection rates passing the different sites is believed due to many pygmy blue whales traversing deep water once they swim north of the north end of the Monte Bello islands and so being out of the listening range of the noise loggers, as reflected on Figure 38.

6.5 Bryde's whale calling in northern WA

Very little is known about Bryde's whales in Australian waters. There have been a few sightings and strandings in Australian waters (ie. see the Australian Governments whale sighting web page, http://data.aad.gov.au/aadc/whales/species_sightings.cfm?taxon_id=35), but little other information. In New Zealand recent observations have revealed Bryde's whales to be relatively common in Hauraki Gulf, occurring mostly as single animals often observed feeding (O'Callaghan and Baker, 2002). Feeding Bryde's whales where observed east of Scott Reef in 2008 on the shelf break in an area observed to be comparatively rich in zooplankton biomass from sonar records (Jenner pers. comm.), so are known to frequent the general area. From the limited analysis of the acoustic records so far carried out it appears Bryde's whales are present in the Scott Reef area year round in low densities, with mostly a single singer heard, animals often slowly moving and calling in long bouts. They have been detected widely across north western WA, from near coastal regions to the shelf edge. They were particularly prominent in a recording set NW of Broome made in 2003 (site 7 in Figure 6).

As yet, Bryde's whales do not appear to have any pronounced seasonality in their presence anywhere along the WA coastline (ie. Figure 34). At Scott reef their calls have been detected inside or near to the reef system over most of the year with no clear peaks in presence. There may be a tendency for more Bryde's whales to be detected around Scott Reef over April to May each year (Figure 33 and Figure 34) but the trend is weak and not distinct with the current data. The call detection rates outside of Scott Reef are comparable with other open-water recording sets made in northern Australia. The call detection rates inside of Scott Reef are considerably lower than outside but this is most likely a function of the reduced listening area inside Scott Reef than a change in whale densities. It was calculated that there was an 11.5-13.6 increase in detection range for open water locations outside the reef than for sites around the southern lagoon rim, for pygmy blue whales which span a similar frequency range to Bryde's whales.

6.6 Underwater explosive signals in Scott Reef

Dynamite fishing is unfortunately a common and widespread practice in Asian waters with well known destructive results. The explosive blast will kill or stun fish within some radius, possibly many tens of metres depending on the blast size and detonation depth, with the fish then collected either when they float to the surface (most do not) or by divers. The physical impact of the blast destroys a small section of reef with the cumulative effect eventually destroying entire ecosystems or reef complexes. Dynamite fishing is a common practice in Indonesian and Philippine waters which for many fisherman offers them a short term income (ie. Pet-Soede et al, 1999), until the environment is destroyed and all fish killed. Scott Reef is an area gazetted under a *Memorandum of Understanding* between Australia and Indonesia, which allows Indonesian fisherman to operate in the area using 'traditional' fishing techniques. Dynamite fishing is not a traditional fishing technique.

In McCauley and Salgado (2007) on average one recorded event of dynamite fishing per day was present in the 2007 Scott East data set (when counts were adjusted for the noise logger duty cycle). This analysis was carried out conservatively in classifying events as being produced by explosives, with many probable events with low signal to noise ratio discounted. Thus there has probably been considerable illegal dynamite fishing occurring at Scott Reef over the years. While there was a far reduced rate of dynamite fishing in the 2008-2009 Scott East-4 and West-4 recordings, it still occurred, particularly in Oct-2008.

6.7 Data synthesis

For the Scott South site, the presence of all pygmy blue, humpback, Antarctic and dwarf minke, Bryde's whales and two fish choruses are shown on Figure 39 for the 753 day span of recording (as per McCauley 2009b). A similar plot is shown for inside Scott Reef on Figure 40 where data from the Scott East and West loggers at deployments 1-4 has been pooled. There is a clear seasonality in the presence of all whales with May to October having humpbacks, the two minke sub-species and pygmy blue whales present. During this time the humpbacks are believed to linger in the area, the pygmy blue whales are migrating north and the behaviour and potential feeding of the minke sub-species is unknown. On some, but not all years, pygmy blue whales may return south through October to January. Currently we have observed pygmy blue whales passing south in 2006 and 2008 but hardly at all in 2007. Bryde's whales appear to be present all year round in low numbers around Scott Reef with as of yet no clear trends in migratory behaviour or links to local productivity.

There is seasonality in the fish choruses with winter lulls in calling behaviour of all choruses. The chorus believed due to nocturnal planktivorous fishes inside Scott Reef reached highest levels over late summer into Autumn. It is possible that this chorus reflects feeding activity thus indicating greatest productivity in the Scott Reef area over late summer. The next data sets retrieved will allow us to begin to compare the fish chorus activity across seasons to show any inter-annual variability which may have external environmental drivers.

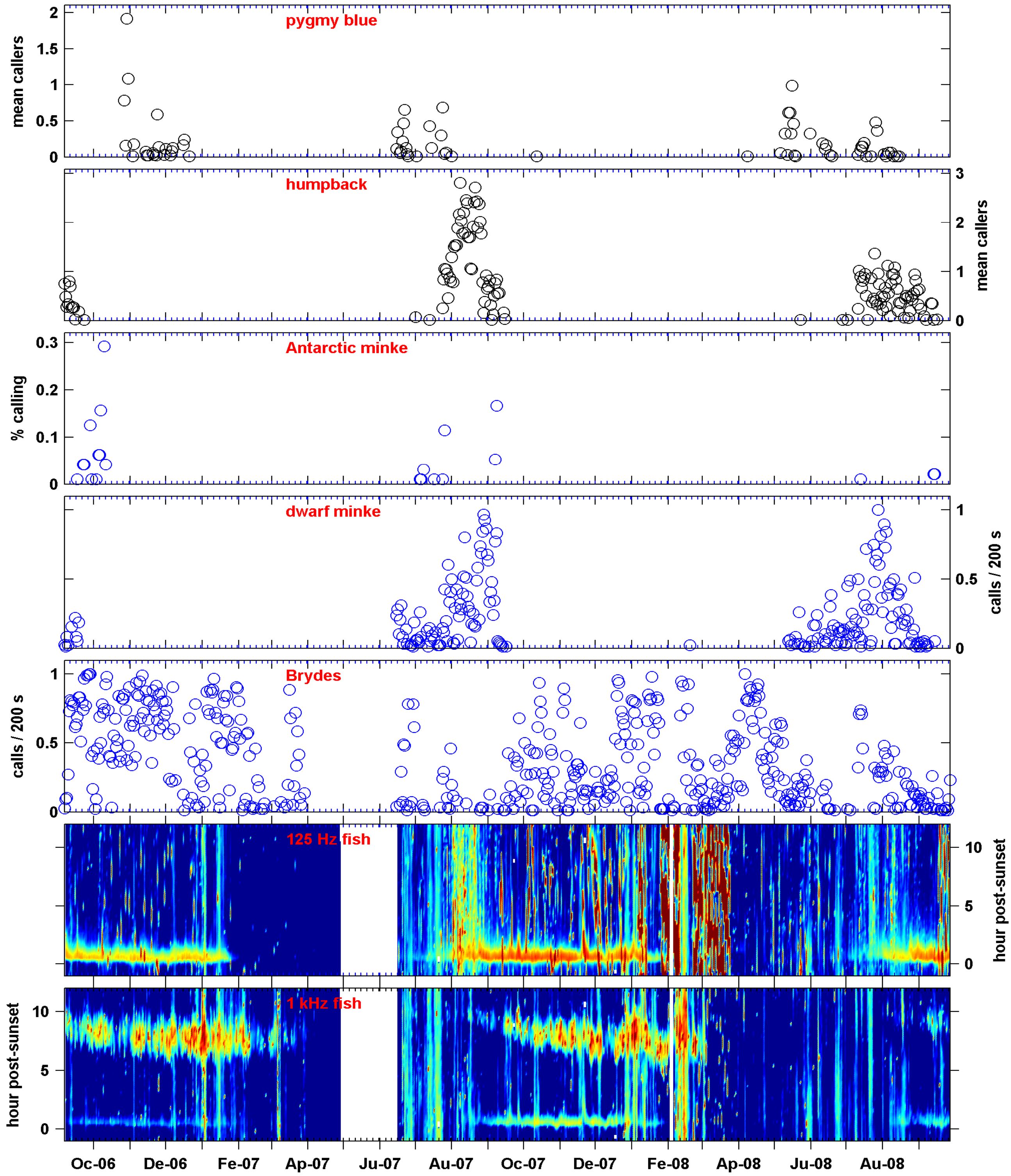

Figure 39: Presence of major biological sources at Scott South site over the 753 days of recording. The pygmy blue and humpback measures are 24 hour means of the number of instantaneous callers, while the minke signals are the proportion of samples with detections per 24 hours. The presence of two fish choruses is indicated by the spectral level plots showing each evenings energy in the appropriate 1/3 octave, with the evening time zeroed to time of local sunset. The bands at 0-2 hours post sunset indicate the 125 Hz fish chorus and the 6-10 hour band the 1 kHz chorus. Minor ticks are at 5 day increments. The month labels are given for every second month only.

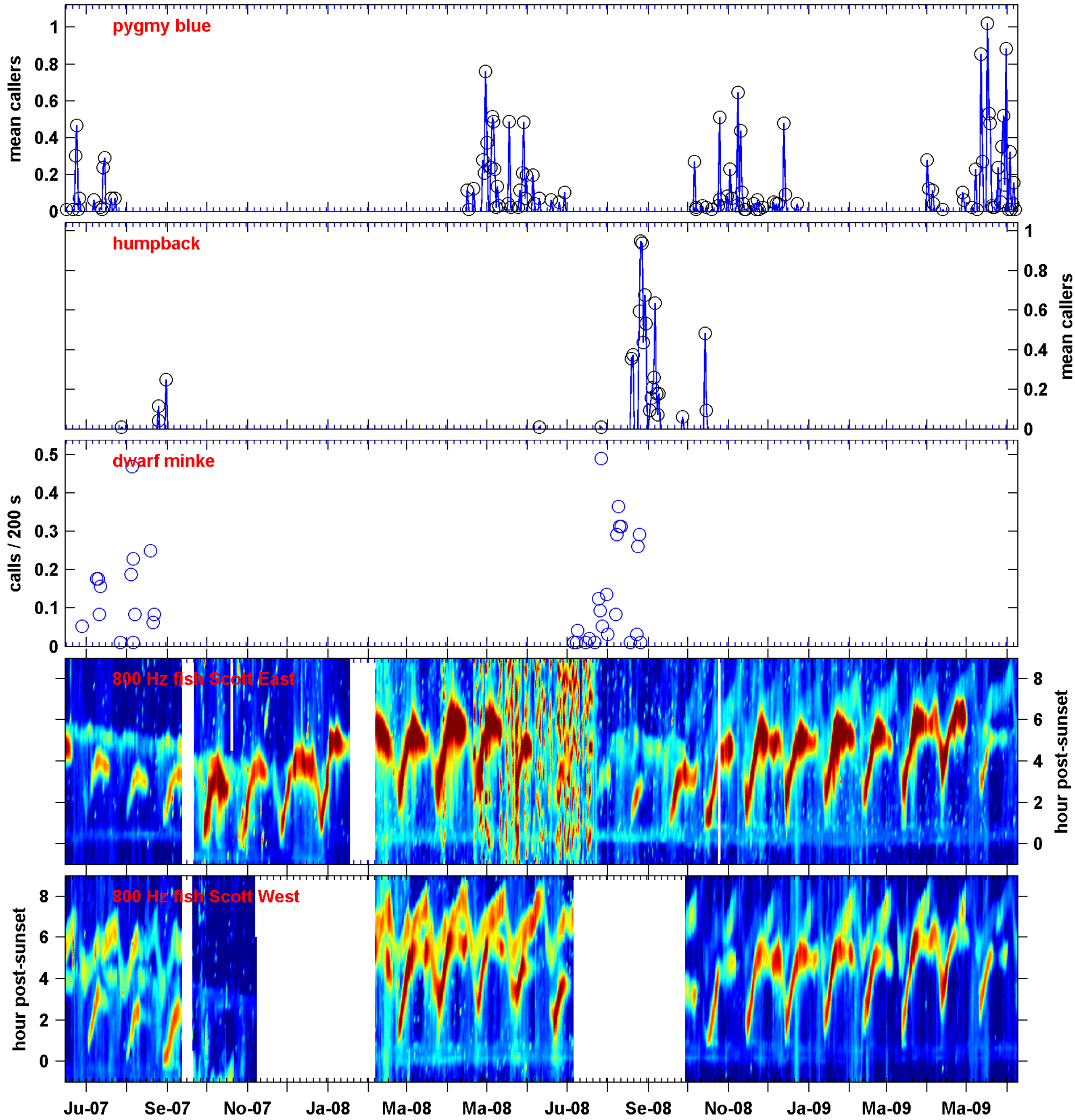

Figure 40: Presence of major biological sources in and around Scott Reef over the 726 days of recording (Jun-2007 to Jun-2009). The pygmy blue and humpback measures are 24 hour means of the number of instantaneous callers, while the minke signals are the proportion of samples with detections per 24 hours. The presence of the 800 Hz nocturnal planktivorous fish choruses is indicated by the spectral level plots showing each evenings energy in the appropriate 1/3 octave, with the evening time zeroed to time of local sunset. Minor ticks are at 5 day increments. The month labels are given every second month only.

6.8 Kimberley sea noise logger program summary to date

Sea noise loggers have been set inside and around Scott Reef since late 2006 up to the present. This report summarises data specifically from Sep-2008 to Jun-2009 but incorporates this with the previous data. Analysis from this and previous reports (McCauley and Salgado Kent 2008, McCauley 2009b) has shown:

1) Great whale signals from humpback, pygmy blue, Antarctic minke, dwarf minke and Bryde's whales have so for been found. All great whale sources were present over July to October each year, on two of three years sampled a sizeable pulse of south bound pygmy blue whales were detected over October to January and Bryde's whales appear to be present in low numbers year round.
2) A variety of fish choruses have been recorded, with more chorus types inside than outside Scott Reef and more from a location to the SE of Scott Reef than from a logger to the NE.
3) Vessel and seismic survey activity feature prominently in all recordings, dominating the sea noise spectra below a few hundred Hz for long periods, particularly in late 2007 and early 2008.
4) The listening range of noise loggers has been calculated for different species at different sites. While the outside detection ranges vary according to background noise levels and individual whale source levels, typical detection ranges for receivers in deep water outside of Scott Reef (Scott South and Scott North) are of the order of 50 km for humpbacks and 25-35 km for pygmy blue whales. For receivers sitting on the Scott Reef lagoon rim and listening into open water (Scott West and Scott East-4) the detection range for pygmy blue is of the order of 6-14 km, and for listening into the reef lagoon (Scott East 1 to 3) is around 16-18 km. The listening range for Bryde's whales is unknown as the source levels for these signals have not been defined, but as they span a similar frequency range to pygmy blue whales then may be akin to the ranges calculated for pygmy blue whales.
5) Comparison of humpback whale singing periods along the northern WA coast suggested that many humpbacks do not reach the Kimberley area but rather spend their time further south. The humpback season in the Exmouth area stretches approximately 136 days whereas in the Scott Reef region, some 1200 km further north, it was only 80 days outside the reef and 34-62 days inside the reef.
6) For humpback whales the season around Scott Reef with 90% of singing humpbacks detected was late July / early June to mid September outside Scott Reef and mid August to mid September inside Scott Reef. The dates of first and last humpbacks detected per year, across seasons are: 23-Jun to 23-Sep to the SE of Scott Reef; and 27-Jul to 14-Oct inside the reef southern lagoon.
7) Humpbacks were detected on noise loggers inside Scott Reef in late July and stayed in low numbers, with usually one animal singing and this sporadically, until mid September usually, but early October in one instance. The number of acoustic detections inside Scott southern lagoon was considerably lower than to the SE of Scott Reef. Calling rates were comparatively low inside and around Scott Reef, with a maximum of four singing animals detected at any one time SE of Scott Reef but usually only one singer present. More humpbacks were heard SE of Scott Reef than NE by a factor of six. This and the lower numbers heard inside Scott Reef than to the SE suggest most humpbacks detected by the Scott South loggers were localised inshore towards the 200 m contour, out of the listening range of the Scott North logger and that Scott Reef was on the periphery of the area in the Kimberly utilised by humpback whales. Approximately twice as many whales were detected at Scott South in 2007 as in 2008, suggesting there is considerable inter-annual variability in use of the area of Scott Reef by humpbacks. Humpbacks did use the channel separating the northern and southern Scott reef lagoons.

8) Dwarf minke whales calls were commonly heard in sea noise records, often with high numbers of calls per sample (up to 48 calls) although with a median of one or two calls per sample. The season for dwarf minke whales in and around Scott Reef was long with outside detection bounds across seasons of 13-May to 18-Sep each year (128 days) for the Scott South location. Most calling (90% of) at Scott South occurred over a 44-50 day period ranging from late June to early September.
9) Inside or near to Scott Reef the first and last detection bounds for dwarf minke whales ranged from 28-Jun to 25-Aug spanning 58 days. Most calling (90% of) occurred over a 30-43 day period within this time.
10) There was more variability with when dwarf minke whales arrived at Scott Reef than with when they left, with animals consistently leaving over 9-18 Sep.
11) Individual dwarf minke whales where found to have call to call increments of either 6.1 s or 25-36 s. Using the 6.1 s increment counts were converted to the relative abundance estimate of the number of individual callers. Individual callers ranged from normally one animal up to six around Scott Reef.
12) Without correcting for listening area there were 4-8% of dwarf minke detections inside Scott Reef compared with to the SE. On a regional scale it appears that dwarf minke whales migrate north and south in northern WA, having a long protracted season over late March to late September off the north end of the Monte Bello Islands, and a shorter season over May to mid September in the Scott Reef area. Like humpbacks, it is probable that not all dwarf minke whales migrate to the Kimberley region.
13) Antarctic minke whale calls were detected in low numbers at the Scott South location but as of yet little systematic analysis has been carried out. These calls appear seasonal in nature, emulating the pattern seen for dwarf minke whales.
14) Pygmy blue whales passed through the Scott Reef region usually twice per year, south bound in October to December (and potentially into January) with a peak passage in November and north bound over mid April to early August.
15) There was evidence for preferred routes around Scott Reef being used by pygmy blue whales, primarily to the west of the reef, as abundance estimates in the same season differed between the North and South loggers. Comparison of swim time for detections between Scott North and South loggers for what where believed to be the same cohorts of whales gave the mean migratory speed as 4.2 kn (7.8 $kmhr^{-1}$) in the region.
16) No pygmy blue whales have so far been detected inside the Scott Reef southern lagoon based on the Scott East-1 to Scott East-3 data sets, but pygmy blue whales commonly visited the reef rim area and swam between the channel separating the north and south lagoons. In overlapping loggers set over 2008-2009, approximately half of the pygmy blue whale singing bouts detected by the noise logger listening primarily into open water west of Scott reef (Scott West-4) were detected a short time before or after by a logger listening only into the channel separating the lagoons (Scott East-4). In total 39 pygmy blue whale bouts of singing were recorded over Sep-2008 to Jun 2009 by the logger listening into open water and 25 by the logger listening into the channel. Of the 25 singing bouts detected in the channel, 14 were estimated to involve animals swimming with 2 km of the receiver, or in the middle of the channel.
17) The relative abundance of pygmy blue whales passing close to Scott Reef based on the acoustic detections from near the reef, showed a consistently increasing number of animals over the 2007-2009 northbound migratory seasons.
18) In late 2007 the expected south bound pulse of pygmy blue whales did not turn up. The reasons are at this stage not clear but may have involved a westward migratory shift induced by either a large amount of seismic survey activity concurrent in the region (at least two surveys in the area) or natural events.
19) Calculation of pygmy blue whale densities off Exmouth and the Scott Reef South location, found that: 1) 65% more whales were heard passing Scott North than Scott South in the

2007 north bound pulse; and 2) only between 6-40% of animals passing by Exmouth pass by Scott Reef (based on widest margins from whale number estimates of south bound pulse 2007). The lower numbers detected off Scott South than North suggest a preferred migratory route to the west of the reef. The lower numbers recorded off Scott Reef than off Exmouth suggest that only a fraction of animals which pass up and down the WA coast utilise the shelf break further north and that the other animals use deeper areas of the Indian Ocean, further to the west.

20) Signals believed produced by Bryde's whales were detected at Scott South and inside or near to, Scott Reef (Scott West-4 and East-4). The animals appear to be present year round in low numbers around Scott Reef, possibly with a peak in calling density in April to May (weak trend) calling profusely generally as single animals but occasionally with multiple singers. Calling patterns indicate the animals move slowly and may call for long periods, up to almost a day at least. The signals attributed to Bryde's whales have been heard from north of Darwin to off Exmouth with similar patterns and no clear seasonality in presence at any site. Bryde's signals were very common at a site in 200 m of water NW of Broome.

21) Multiple fish choruses were detected, each displaying regular diurnal patterns, calling typically occurring at night with different sources calling at different times, and all having daily, lunar and seasonal patterns with winter lulls. A chorus of nocturnal fishes from inside Scott Reef displayed diurnal calling habits closely coupled to moon phase and remarkably consistent. This fish chorus continued its expected pattern after the *Maxima* seismic survey into Sep-2009, indicating the seismic survey inside the southern lagoon of Scott Reef did not seem to impact this fish complement.

22) Explosive signals believed produced by illegal dynamite fishing from Indonesian fisherman were common over Jun-2007 to Sep-2007 and also detected in lower numbers over Oct-2008 inside the southern lagoon of Scott Reef. In early 2007 explosive events averaged at one event per day when using probable explosive like signals. The daily distribution of signals classified as of explosive origin suggested most events occurred around 11:00 and 16:00 hours. It was probable that multiple vessels were engaged in dynamite fishing.

23) Multiple seismic surveys ran in the area of the noise loggers over the recording time frame. Two loggers transpired to be set directly within seismic survey regions, the *Maxima* survey inside Scott Reef and the *Endurance* survey to the SE of Scott Reef. The *Endurance* signals overloaded the Scott South noise logger commonly and featured prominently on a noise logger set 147 km to the NE of the centre of the *Endurance* operations, near Browse Island. The *Endurance* seismic signals did not appear on a noise logger set along the Kimberley coast, approximately 200 to 300 km from the survey region. Noise loggers set inside of Scott Reef and completely shielded by the reef structure from any waterborne paths of the *Endurance* seismic source, still received energy from the signals via coupling of waterborne energy into the limestone reef platform. The Scott East-4 site received limestone coupled and waterborne air gun array signal energy, possibly from the *Canis* seismic survey, in late 2008 into 2009.

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8. Glossary

Acoustic units spectral level (dB re 1μPa^2/Hz) The value has been normalised so that the intensity is presented in the equivalent of a one Hz bandwidth, even if the actual bandwidth the measurement was calculated in was not one Hz. These units are used widely in underwater acoustics and are useful for comparing the energy content of different sources, as the units can be directly overlain, even if for example the power spectral frequency resolution differs.

Acoustic units – intensity (dB re 1μPa) – this is the intensity across the measurement bandwidth, with the bandwidth potentially differing. The bandwidth may be across the power spectra frequency resolution or it may be across the source effective frequency, as discussed below

Acoustic units broadband intensity (dB re 1μPa) – this is the integrated energy across the full frequency bandwidth of the source. Usually exact frequency bandwidths are not stated so it is assumed that the measurement encompasses the frequency range of dominant energy in the source (ie the signal energy outside of this frequency range does not contribute to the overall source energy received).

Acoustic units 1/3 octave (dB re 1μPa) 1/3 octaves are recognised logarithmically increasing frequency bands used in airborne acoustic studies. Each band has a defined lower frequency, centre frequency and upper frequency. The dB re 1μPa within a 1/3 octave band is the intensity summed across the band. The 1/3 octave bands are normally referenced by their centre frequency.

Acoustic units source level (dB re 1μPa @ 1 m) – or source level – this is the intensity of a measured source at some range, which has been assumed to be a point source and which has had the transmission loss correction for that range and frequency applied. The source level is then the intensity at one m range the source would radiate if it were an infinitesimal point. Most real sources are not infinitesimal points so for large sources such as vessels and air gun arrays, where the radiated noise is actually the sum of many spatially separated sub-sources, source levels are never reached. Source levels are useful for estimating the transmission of sources and comparing source total noise output.

Acoustic units Sound Exposure Level and Mean Squared Pressure (dB re 1μPa^2.s SEL & dB re 1μPa *msp)* – The first measure, SEL is widely termed as *sound exposure level*. It is a measurement which is approximately proportional to the signal’s energy. This measurement is used to describe impulsive signals, such as air guns, which are short and sharp. For measuring long term noise the *mean squared pressure* (**msp**) units are commonly used. As the name suggests, *mean squared pressure* levels are simply the mean value of the squared pressure converted to appropriate dB values. To take a mean value implies an averaging time, which if the noise in question is stationary (ie changes little over the time frame of averaging) is not of major consequence. Impulse signals are short, usually less than one second, thus the *mean squared pressure* level of an impulse measure may be critically dependant (or vary) according to the way the averaging time is defined. Since SEL measures are calculated in a way that accounts for time, they are independent of averaging time. Given that SEL is also a closer match to the energy delivered by an impulse signal (noting that it is not a correct energy measure itself) then the SEL value is now widely accepted as the best unit to define the approximate the energy of an impulse signal.

Logger listening area – The area around a receiver at which a signal type is detectable in the background noise present. For computer search techniques the signal type is generally slightly above the noise level, for manual searching the signals can be discerned very close to the ambient noise level. The listening ranges around a receiver are generally different on different headings and some aspects may have blocking bathymetry.

Noise logger – The noise loggers are stainless steel tubes which lie on the seabed with a hydrophone, or underwater microphone, laid on the seabed nearby and cabled into the housing. A noise logger captures samples of sea noise at prescribed increments, generally here they have sampled 200 s every 15 minutes at a 6 kHz sample rate. This sample rate is suitable to detect all of the great whale calls, fish calls, most of the energy in vessel and air gun seismic sources and most physical sea noise sources.