Underwater noise sources in Fremantle inner harbour: dolphins, pile driving and traffic

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ABSTRACT

Underwater noise measurements were made over a period of 5 months within the Fremantle Inner Harbour (from April 1st-July 2nd, and July 26th-August 20th, 2010). Noise was recoded from a range of sources, including vessel traffic which was intense at periods, noise from trains and vehicles passing over a nearby bridge, machinery noise from regular operation of the Fremantle Port, and pile driving (either vibratory pile driving, impact pile driving, or both) recorded during wharf construction over approximately 57 days, (mainly during the months of May, July, and August). All sources recorded are common to a busy and expanding port. Noise levels in the port during periods when pile driving was not occurring were typically between 110 and 140 dB re 1μPa^2 (mean squared pressure). Vibratory pile and impact pile driving increased noise levels within the Inner Harbour. Biological noises were also detected in the recordings. Dominant biological sources were snapping shrimp, followed by mulloway (*Argyrosomus japonicus*) chorusing in early to mid-April, and grunts from other fish species detected throughout the recordings. Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) whistles were also detected in the noise logger recordings.

INTRODUCTION

The Fremantle Inner Harbour is located south-west of the city of Perth on the west coast of Australia (Figure 1). Fremantle Inner Harbour serves as the main port for import and export of products and natural resources in Western Australia, and is heavily visited (in 2008/09 there were over 1,800 ship visits in that year). Ships range in size, with the largest of these being the G Class and post-Panamax vessels of about 65,000 gross tonnes. The North Quay berths within the Inner Harbour are used for unloading and loading cargo.

Underwater noise measurements within the Fremantle Inner Harbour were carried out during the Inner Harbour Deepening Project (Salgado et al. 2011), which included deepening of the Fremantle Inner Harbour Channel, the Entrance Channel, and the Deepwater Channel to accommodate larger ships at full cargo-carrying capacity (Fremantle Port Authority, 2009). As well as requiring increased channel and harbour depth, the bigger ships impose heavier loads on wharf infrastructure. Part of the Inner Harbour Deepening Project, therefore, included strengthening of the North Quay berths for container shipping and partial wharf reconstruction which required marine-based vibratory and impact pile driving (Fremantle Port Authority, 2009).

The Swan River estuary is known as a home to a variety of marine fauna. Those known to produce sound underwater include bottlenose dolphins, snapping shrimp and mulloway (*Argyrosomus japonicus)*. Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) occur regularly in the Port throughout the year (Moiler, 2008). Research from 2001-3 showed a total of 49 bottlenose dolphins using the Inner Harbour, including; 18 adult plus 6 calves which are resident to the Swan Canning Riverpark (based on re-sighting patterns showing consistent usage of the entire estuary), and an additional 25 which used only the lower reaches of the Swan River (from the port up to Freshwater Bay; Lo, 2009), and are considered part of the Cockburn Sound community (Finn, pers. comm.). Parsons et al. (2007, 2010) have regular reported underwater calls by mulloway in the Swan River (*Argyrosomus Japonicus*). This paper aims to characterise the noise spectra of the Fremantle Inner Harbour during the period of the recordings.

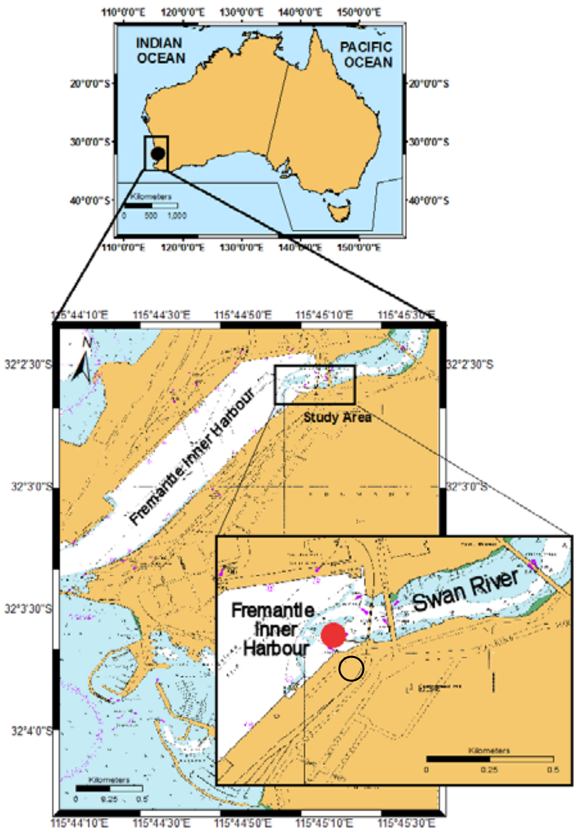

Figure 1. Fremantle Inner harbour. The location of the noise logger is given by the red circle.

METHODS

Underwater noise loggers

Underwater noise loggers were custom-built by Curtin University's Centre of Marine Science and Technology (CMST) to provide high-accuracy sea noise recordings in various, fully programmed regimes suitable for the purpose of each particular survey. The noise loggers used in this survey were equipped with an external hydrophone (HiTek HTI U90), entering the housing via a bulkhead connector to an impedance matching pre-amplifier (20-dB gain). The hydrophone signal was high-pass filtered at a roll-off frequency of 8 Hz to flatten the naturally high levels of low frequency ocean noise and increase the system's dynamic range. An additional amplifier of programmed gain applied extra gain of 20 dB to the noise signal, which was then low-pass filtered by an anti-aliasing filter and fed to a 16-bit analog-to-digital converter to sample the analog signal into a digital format. Digitized individual recordings were written on a flash card and then transferred to a hard disk when the flash card was nearly full.

Deployments

The noise loggers were set on the seabed within the Fremantle Inner Harbour at the end of the Fremantle Port Authority's small craft pen jetty (Figure 1) over a period of five months, between April and August 2010. Noise recorded was expected to be physical, anthropogenic, and biological in nature. Possible biological sources expected included Indo-pacific bottlenose dolphins (*Tursiops aduncus)* and fish of various species. Bottlenose dolphins are known to use and travel through the port on a daily or near-daily basis (Moiller 2008), and are most often seen foraging (fish and other prey). The noise logger settings and sampling schedule of the recordings were set to capture as wide a range of the signals as the noise loggers would allow, however the second deployment sample rate was lower to allow enough battery life to record on two channels with different gains to ensure that the most intense low frequency signals were recorded without saturation. These are given in Table 1. The recordings included a period prior to construction (2 weeks) associated with the Inner Harbour Deepening Project. Construction work included periods of marine-based vibratory and impact pile driving, which is known to produce high underwater sounds levels (Duncan et al., 2010).

Table 1. Logger settings and sampling schedule of the Fremantle Inner Harbour sea noise loggers (the second deployment sampled two channels with different gains).

Period	April 1st-2nd July, 2010	July 26th-20th August, 2010
Sample rate	12 kHz	6 kHz
Low frequency roll-off	8 Hz	8 Hz
Anti-aliasing filter	5 kHz	2.8 kHz
Total gain	40 dB	0 / 20 dB
Sampling schedule	200 s every 900 s	200 s every 900 s

Calibration

The electronic part of the logger receive channel was calibrated by applying white noise of known power spectrum density to the channel input with either the hydrophone or a capacitor of equivalent capacitance connected in series with the noise generator. This gave the total system gain versus frequency, which combined with the hydrophone sensitivity (-197.7 dB re 1 μPa/V for the Fremantle Port Apr 2010 logger) provided the overall gain or data conversion factor in Volts (ADC input) per 1 μPa. The system gain as a function of frequency measured for the Fremantle Port Apr 2010 logger is shown in Figure 2.

Analysis

The recordings were analysed in Matlab using the CMST developed Matlab toolbox 'CHORUS' (CHaracterisation Of Recorded Underwater Sound). Processing and analysis of sea noise data involved two stages:

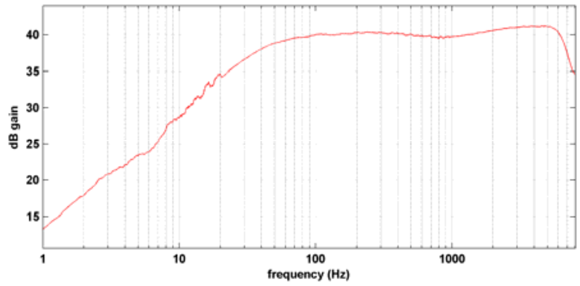

Figure 2: System gain curve of the first noise logger deployment.

1. Firstly, the power spectral density (PSD) of sea noise (i.e. noise spectrum) was calculated for each individual recording (200 s). The PSD was corrected for the frequency response of the acoustic receiving system derived from the calibration data, so that the noise spectra and spectral levels were represented in absolute values (μPa^2/Hz and dB re 1 μPa^2/Hz respectively).

2. The CMST developed noise Matlab toolbox with a graphic user interface was developed to: 1) visualise spectral features of sea noise and their long-term variations by collating the pre-calculated spectra in spectrograms that represent the time period chosen to review; 2) select particular recording times based on the spectral features of interest visible in the spectrogram of low temporal resolution; and 3) analyse the waveform and spectrogram of sea noise within the individual recording made at the selected time. The CMST toolbox allows for the time-frequency characteristics of sea noise to be investigated in more detail using spectrograms of high resolution. In addition, high, low and band-pass filtering can be applied to selectively suppress unwanted noise, e.g. noise of non-acoustical origin. Moreover, a non-linear de-spiking filter can be applied to the noise signal to remove impulsive noise of high amplitude such as snapping shrimp or mooring noise. Snapping shrimp were the most prevalent biological noise sources and were audible throughout the recordings. Close impulsive signals from snapping shrimp were filtered out through the de-noising process to allow for better detection of other sources of interest, such as dolphin whistles and signals from fish. No other signials except for snapping shrimp were filtered out during this process. All recordings were searched for representative biological and anthropogenic signals.

RESULTS

Underwater signals recorded by the noise loggers over the period of 5 months within the Fremantle Inner Harbour (from April 1st-July 2nd, and July 26th-August 20th, 2010) are

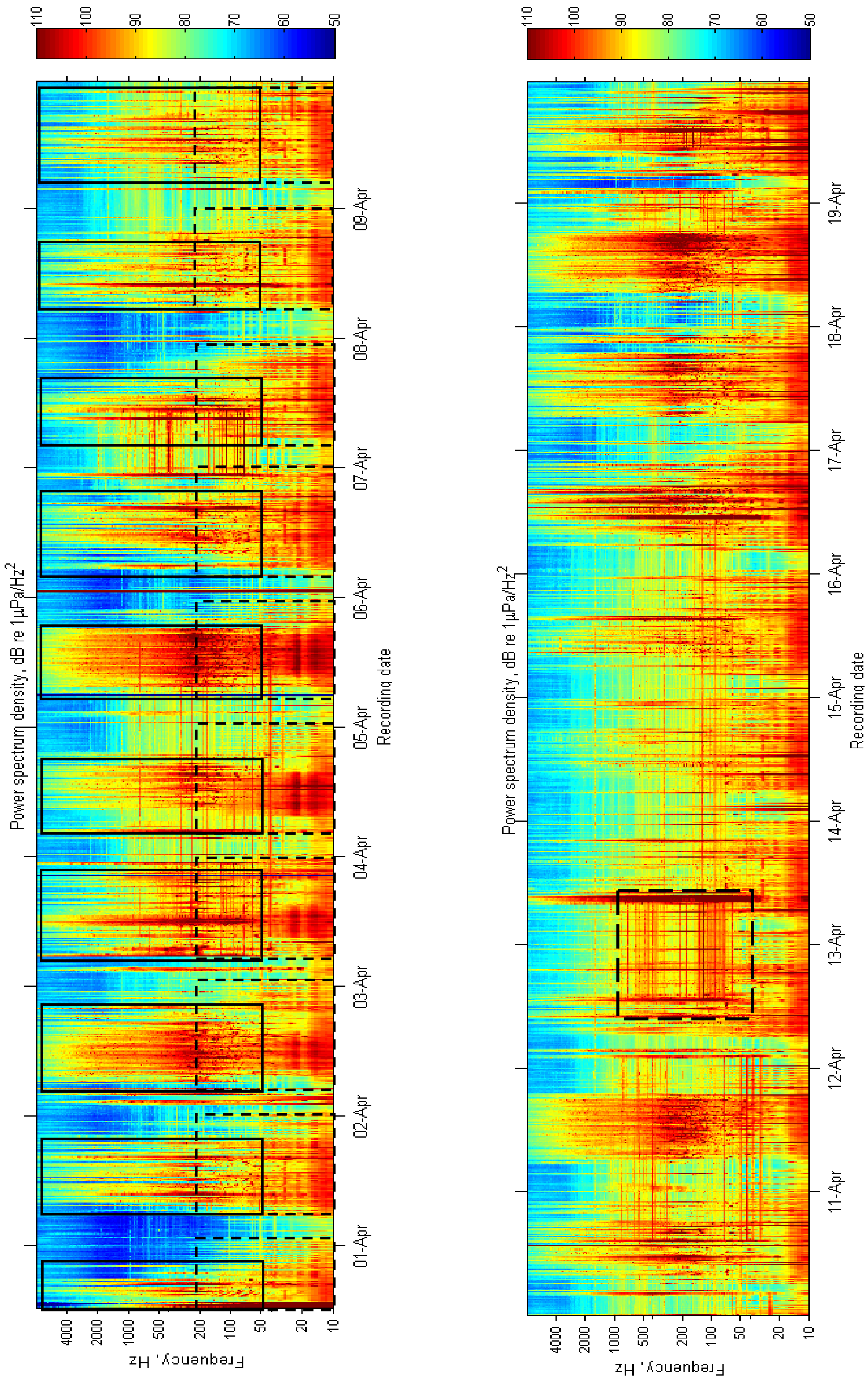

Figure 3. Spectrograms of noise sources during the period from the 31st of March to the 19th of April, 2010. In the top figure, examples of periods of frequent train noise (dashed lines) and periods of frequent vessel noise (solid lines) are demarcated. In the bottom figure, an example of continuous machinery noise is demarcated (dashed lines).

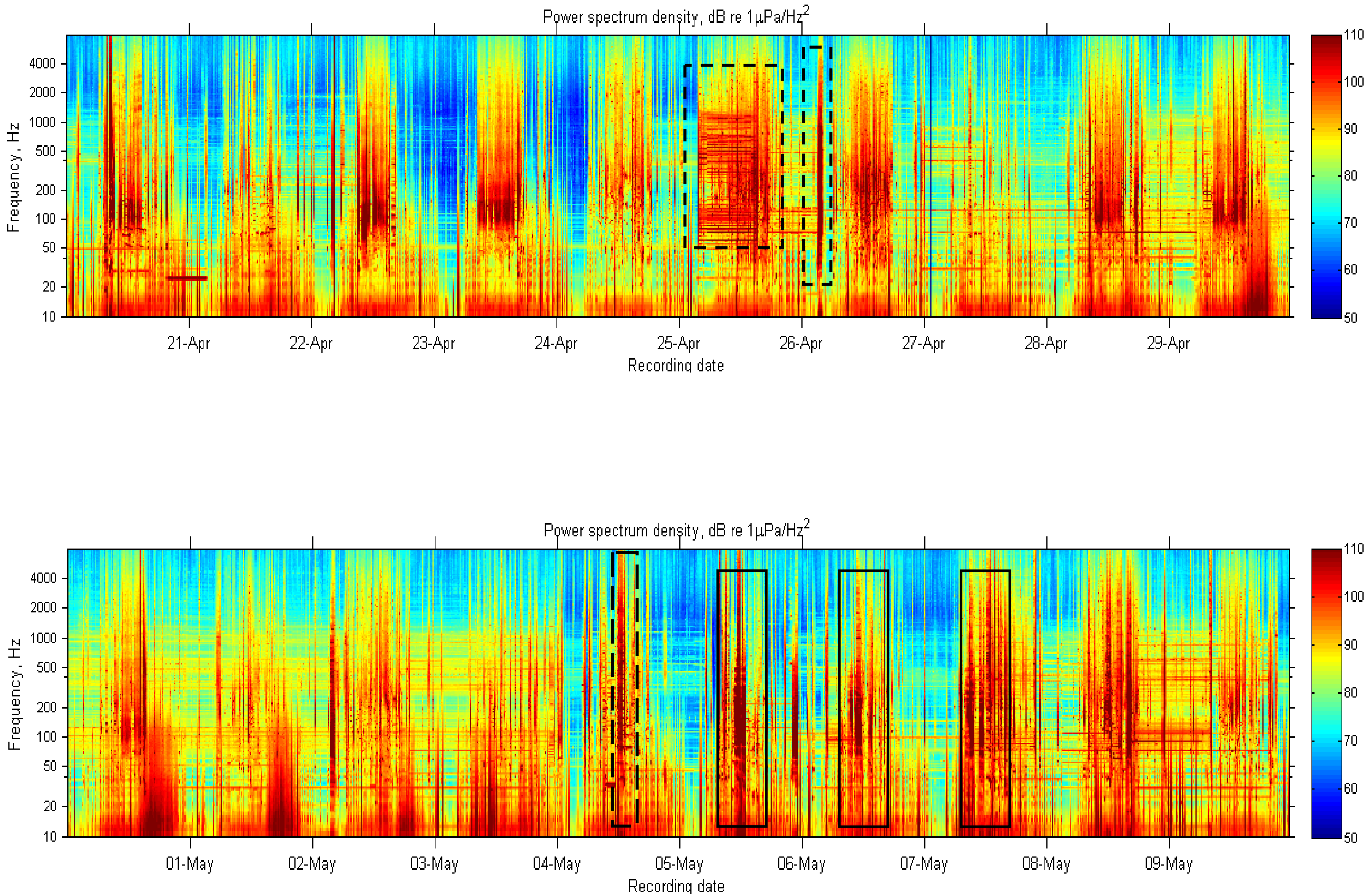

Figure 4. Spectrograms of noise sources during the period from April 20th to May 9th 2010. In the top figure, examples of machinery noise are demarcated with dashed lines. In the bottom figure, examples of periods of vibratory pile driving are demarcated with dashed lines, and periods of impact pile driving noise with solid lines.

represented as the low temporal resolution spectrograms in Figure 3 and Figure 4, respectively. Noise detected in the deployments can be divided into two broad categories: anthropogenic noise and biological noise.

Anthropogenic noise

Noise recorded was produced primarily by: mechanical sources associated with the operation and dredging of the port, vessel noise from passing vessels and docking ships, noise from passing trains and road traffic over the nearby bridges and by pile driving. Two types of pile driving noise were recorded: impact pile driving and vibratory pile driving. Noise produced by trains crossing the nearby bridge was present in the recordings between 6 am in the morning and approximately 12:30 am the following morning (Figure 3). The dominant frequencies associated with this source ranged from 10 Hz to approximately 2 kHz (Figure 5). Vessel noise increased from 6 am, peaked around midday, and dropped off around 6 pm in the evening. Vessel noise during these periods was often greater during weekends (Figure 3), which was likely associated with greater numbers of leisure craft passing through the Inner Harbour. Occasionally, vessels were detected during hours between 6 pm and 6 am. Most of these were likely to have been support vessels associated with shipping movements in and out of the Fremantle Port. The frequency range of vessel noise was typically between 200 Hz and 6 to 8 kHz (Figure 6).

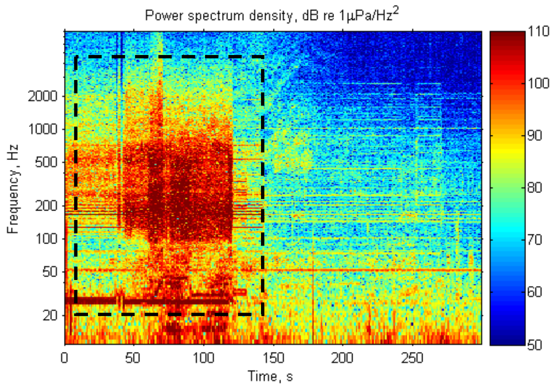

Figure 5. Spectrogram of underwater noise from a train passing over a nearby bridge (demarcated by the dashed lines).

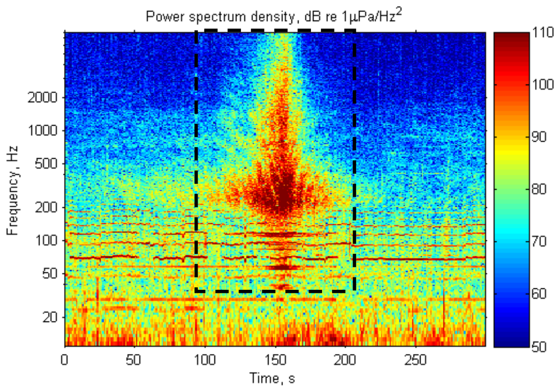

Figure 6. Spectrogram of noise from a vessel passing (demarcated by the dashed lines).

Noises of mechanical origin were likely to be from sources such as generators or pumps. This kind of noise was often of long duration, sometimes extending over periods of days (Figure 3 and Figure 4). The noise was broadband, normally ranging from frequencies in the tens of Hz to ~2 kHz.

Pile driving (either vibratory pile driving, impact pile driving, or both) occurred during approximately 57 days of the recordings, mainly during May, July, and August. Impact pile driving (Figure 7) was normally recorded over several hours a day during approximately 33 of these days, while vibratory pile driving (Figure 8) was recorded over several hours during approximately 50 days. Usually the different pile driving types (impact and vibratory) were used at different times (even if they were used on the same days, of which occurred during 26 of the days), but in some cases their use occurred simultaneously.

Received noise levels in the port during periods when pile driving was not occurring were typically between 110 and 140 dB re 1μPa^2 (mean squared pressure), the higher levels of which included noise from vessel traffic, dredging, and trains passing over the nearby bridges.

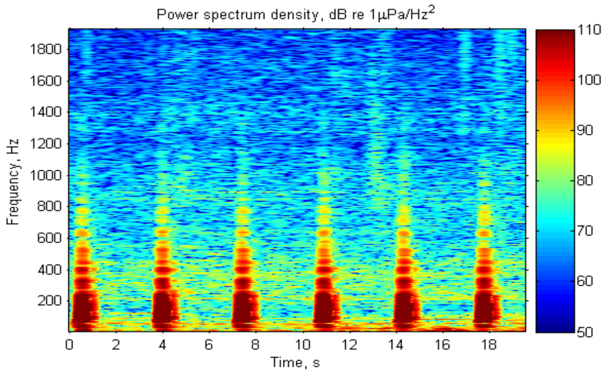

Figure 7. Spectrogram of noise from impact pile driving.

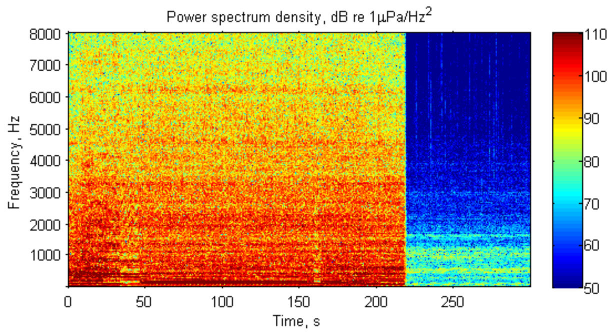

Figure 8. Spectrogram of noise from vibratory pile driving.

Biological sources

Mulloway choruses were detected from the 31st of March to the 12th of April, between 6 and 9 in the evening (Figure 9). The frequency range of the fundamental and its harmonics of a typical mulloway call was between 100 and 1 kHz (Parsons et al. 2007, 2010). Mulloway choruses were much more detectable during quieter periods (i.e. on the 31st of March) due to a diminished effect of masking from vessel traffic and other man-made noise sources (Figure 3 and Figure 4). Grunts of other fish species were also audible throughout the recordings, and typically ranged in frequency from 200 to 500 Hz.

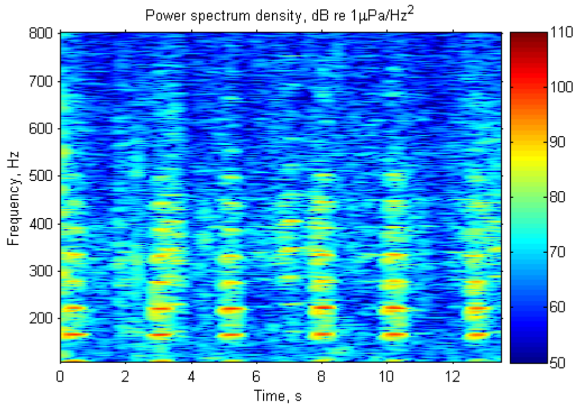

Figure 9. Spectrogram of mulloway calling.

Indo-Pacific bottlenose dolphins were detected at various times during the recordings, with the frequency of the whistles typically ranging from 1 and 8 kHz (Figure 10). Finally, there were some unidentified sounds. Figure 11 shows four pairs of 'hooting noises' in the frequency range 1 to 1.2 kHz.

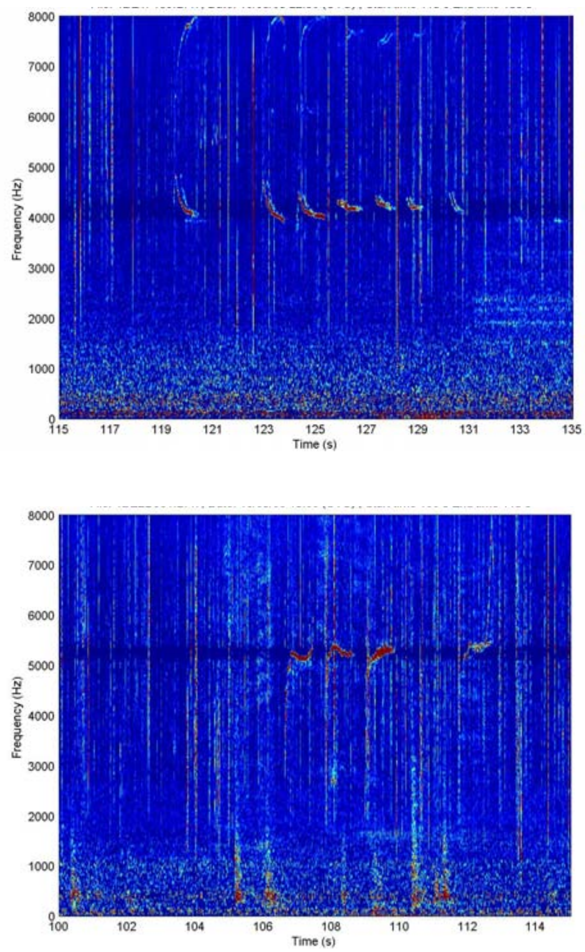

Figure 10. Spectrograms of dolphin whistles (linear scale). Mean background frequency trend removed to aid identification of signals.

Schultz et al. (1995) recorded similar signals in Moreton Bay (Queensland) and attributed them to bottlenose dolphins.

Although it is not evident these sounds are also from dolphins, they sound like a biological source and are unlikely to be from fish.

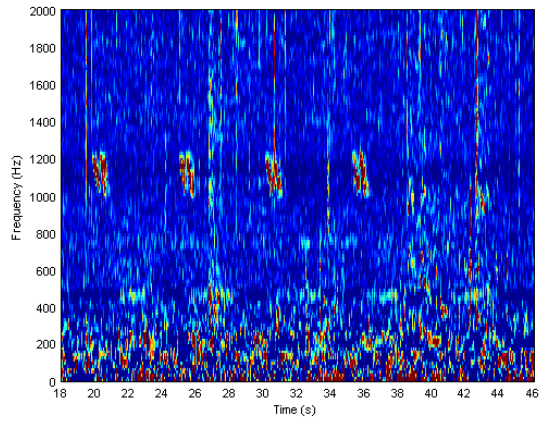

Figure 11. Spectrogram of 'hooting' noises. Mean background frequency trend removed to aid identification of signals.

DISCUSSION

Underwater noise recorded in the Fremantle Inner Harbour was dominated by broadband, man-made sources over the entire 5 months period of the study. Sources not directly associated with wharf construction included vessel traffic which was intense at periods, noise from trains and vehicles passing over a nearby bridge, and machinery noise from regular operation of the Fremantle Port; all of which are common sound sources in busy ports. Biological noises were also recorded including dolphin whistles, mulloway calls and snapping shrimp clicks.

Figure 12 shows the mean broadband noise level (10 – 4500 Hz) in Fremantle harbour over all recordings versus time of day. Broadband noise levels in the port were typically between 110 and 140 dB MSP, but had a diurnal cycle.

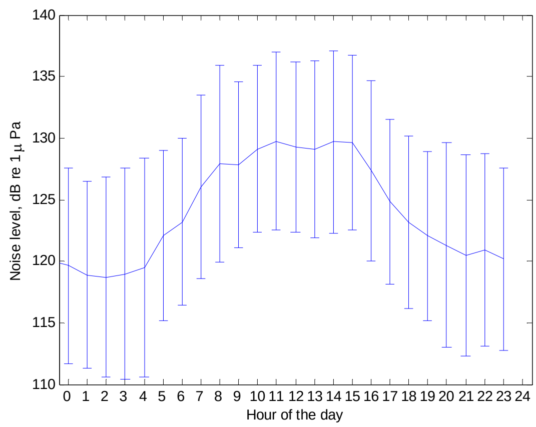

Figure 12. Mean broadband (10-4500 Hz) noise level versus hour of the day, error bars show one standard deviation.

On average, noise levels were at their highest between 10 am and 3 pm and at their lowest between 9 pm and 4 am the follow day. Over the whole deployment there was typically a 10 dB difference in noise levels between day and night. This difference was likely due to anthropengic activity such as vessel traffic and train activity. Determining the relative contributions of the different noise sources to the ambient noise of Fremantle Port will be part of a future study.

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REFERENCES

Duncan, AJ, McCauley, RD, Parnum, I & Salgado-Kent, CP 2010, ‘Measurement and modelling of underwater noise from pile driving’, *Proceedings of 20th International Congress on Acoustics*, International Comission for Acoustics, Sydney, Australia, pp. 23-7.

Fremantle Port Authority 2009, *Inner Harbour Deepening Project*, July 2009 Newsletter Posting, Fremantle.

Lo, HN 2009, ‘Bottlenose Dolphins (*Tursiops* sp.) in the Swan River, Western Australia: community size and composition, residency patterns, and social structure’, Unpublished Honours thesis, Curtin University of Technology, Perth.

Moiler, K 2008, ‘Bottlenose Dolphins (*Tursiops* sp.) – a study of patterns in spatial and temporal use of the Swan River, Western Australia’, Unpublished Honours thesis, Curtin University of Technology, Perth.

Parsons, M, McCauley, R & Mackie, M 2007, ‘The use of passive techniques to evaluate a spawning aggregation of mulloway (*Argyrosomus japonicus*)’. *Underwater Acoustic Measurements: Technologies & Results, 2nd International Conference and Exhibition*, Heraklion, Crete, 25-29 June.

Parsons, MJG, McCauley, RD, Mackie, MC & Duncan, AJ 2010, ‘A comparison of techniques for ranging close-proximity mulloway *(Argyrosomus Japonicus)* calls with a single hydrophone’, *Australian Acoustics*, vol. 38, no. 3, pp. 145 – 51.

Salgado-Kent, C, McCauley, RD, Paiva, E, Gavrilov, AN & Woods, A 2011, *Bottlenose dolphin behaviour in association with pile driving within Fremantle Inner Harbour*, Report R2011-36, Curtin University of Technology, Perth.

Schultz, KW, Cato, DH, Corkeron PJ & Bryden, MM 1995, ‘Low frequency narrow-band sounds produced by bottlenose dolphins’, *Marine Mammal Science*, vol. 11, no. 4, pp. 503 - 9.