The Ambient Sound Field in Three Freshwater Environments

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ABSTRACT

A number of ambient sound recordings took place in three clear-water wetlands in Perth, Western Australia for one month in summer, 2003. The wetlands differed in terms of their degree of enrichment, habitat structure, substrate material and water depth. Temporal and spatial variations were evident in the macroinvertebrate distributions and the biologic calling activity, with seven distinct calls recognised in this study. Noise levels were greatest at dusk and to a lesser extent at midnight with chorusing only evident at the most enriched wetland. Biologics used frequencies ranging from 3 kHz up to around 14 kHz with the exception of the 'bird-like song' which extended from 500 Hz up to around 10 kHz. There was negligible sound contribution to ambient noise at low wind speeds of Beaufort Wind Scale 0, 1 & 2.

INTRODUCTION

There is an extensive body of literature describing ambient noise in the marine environment environment (e.g. Lomask and Frassetto, 1960; Wenz, 1962; Fish, 1964; Clapp, 1964; Piggott, 1964; Cato, 1976, 1978), but by contrast there is a paucity of data on ambient noise in freshwater environments. The aim of this study was to describe the ambient sound field in three clear-water wetlands: Lake Leschenaultia, Glen Brook Dam and Blue Gum Lake in Perth, Western Australia and to determine if there were temporal and spatial differences in the sound field and if differences occurred between wetlands. Comparisons have been drawn with the marine environment in some instances in order to place freshwater ambient sound into some contextual framework.

Methods

The Wetlands

Blue Gum Lake is an enriched urban wetland which lies on the Swan Coastal Plain. Blue Gum is characterised by large dead trees in the central body of water and has a small terrestrial buffer of native vegetation on the eastern aspect. It is a shallow (1-2m) seasonal wetland dominated by submerged macrophytes with a small section of emergent macrophytes and has a predominantly mud / silt substrate with a sand mix. Lake Leschenaultia and Glen Brook Dam are located approximately 38 km and 26.5 km respectively, inland from the coast. These wetlands are deeper waterbodies and less nutrient-enriched than Blue Gum Lake. Both waterbodies are surrounded by forested areas of Marri (*Eucalyptus calophylla*), Jarrah (*Eucalyptus marginata*) and Wandoo (*Eucalyptus wandoo*). Lake Leschenaultia is dominated by submerged and emergent macrophytes and is a permanent waterbody with shallow and also relatively deep (max. depth ~9m) sections. The substrate is largely gravel and sand with an organic mix. Glen Brook dam is a steep-sided and also relatively deep (max. depth ~8m) permanent waterbody. There are no submerged macrophytes but is dominated by benthic algae with only a small section of emergent vegetation. There are large granite boulders within this waterbody, providing a complexity of habitat in contrast to that seen at the other two wetlands. The substrate is largely gravel and sand with some clay content.

Equipment

A Cetacean Research Technology (CRT) C53 hydrophone was used with a frequency response of 14Hz to 60KHz (±4.5 dB) and was omnidirectional below 10 kHz. The C53 had a sensitivity of -165 dB, re 1V/µPa (this included the gain from the hydrophone preamplifier). Analog recordings were made on a TASCAM DA-P1 DAT recorder, using a sampling rate of 48 kHz in the short play mode. The specifications of the tape deck were: a linear frequency response of 20 Hz – 20 kHz ± 0.5 dB (in short play mode); a 16 bit resolution; a tape speed of 8.15 mm/s. The input level was set at '8' and the analogue input was set on PAD 20 dB.

Recorded sounds were digitised using a Sound Blaster Audigy DE 24-bit/96kHz stereo sound card with a noise level of 100 dB SNR in an Intel Pentium 4 PC running SpectraPLUS version 2.32.04 and Adobe Audition version 1.0.

Graphs were produced in SigmaPlot 2002 version 8.0.

The Recording Regime

Recordings were undertaken over a four week period in summer from February to early March 2003. Recordings were made every week at the three wetlands within the time periods: dawn (5am-7am), midday (11am-1pm), dusk (5pm-7pm) and midnight (10.30pm-12.30am) (The 2-hour time blocks were necessary to accommodate the time taken to walk around the perimeter of each wetland). Recordings occurred at locations north, south, west and east around each wetland and lasted for approximately five minutes at each location.

The hydrophone was deployed from the shoreline to a distance that was accessible in wading gear to facilitate the invertebrate sweeps. In total, 25.4 hours of wetland noise recordings were made with 192 separate recordings.

Invertebrates

Invertebrate samples were taken over a period of a fortnight, at each recording session at each location. Sweeps for the invertebrates were made in accordance with the wetland macroinvertebrate rapid bioassessment protocol (Davis *et al*., 1999) using a fine mesh sweep net (250µm) which was moved around the hydrophone in a zig-zag manner from surface to the bottom sediments – this method approximates 1m^3 of water sampled for invertebrates. In total, 96 samples were collected. Invertebrates were identified using Gooderham and Tsyrlin (2002); Davis and Christidis (1997) and only the macroinvertebrate data is presented here. Statistical analysis was performed by PRIMER 5 version 5.2.2.

Acoustic Signals

Acoustic signals are presented as narrow-band spectra produced from the Fast Fourier Transforms. They were digitised at a sampling rate of 48 kHz, FFT size 1024 points, an averaging of 4 with a 75% overlap and a Hanning smoothing window was used. For each distinct signal presented, four main parameters were measured from the spectrograms: 1.) frequency range in kHz (from the lowest to the highest measurable frequency), 2.) average duration of the signal in seconds, 3.) the dominant frequency in kHz (frequency of that harmonic with the greatest amplitude) and 4.) for those signals with measurable pulses – the average inter-pulse interval (IPI) in seconds. The IPI was measured from the end of one pulse to the beginning of the next pulse (using the spectrograms). Examples of each call were selected to show them at their maximum level with well-defined spectral contours and are named according to their aural character.

Ambient Noise and Wind

Ambient noise was recorded at Blue Gum Lake and Glen Brook Dam at locations north, south, west and east for four different wind speeds – Beaufort Wind Scale (BWS) 0,1,2 & 3. Recordings were made in the absence of biologics and occurred in the morning during the winter months.

The ambient noise spectra were obtained from ⅓-octave band measurements made using SpectraPLUS software, which synthesised ⅓-octave bands from FFT's of 4096 points with an averaging of 700 samples per minute (with no overlap), which gave a frequency resolution of 11.7 Hz and a time resolution of 85.3 msec. The recorded signal spectrum was converted to pressure and were bandwidth corrected by subtracting the appropriate ⅓-octave bandwidth correction (see Beranek, 1988), to give received sound levels in dB re 1µPa^2 / Hz.

Results

The Biologics

There were seven distinctive calls recognised in the recordings. The frequency bandwidth most utilised by organisms was between 3 kHz up to around 14 kHz, with the exception of the 'bird-like song' which extended from 500 Hz up to around 10 kHz.

'Tick, tick' Call

Pulse-trains of the 'Tick, tick..' call ranged in frequency from around 3-4.5 kHz with some extending up to 6 kHz. Pulse-trains had an average duration of 1.34 sec (SD=0.28, n=103), and had no discernible dominant frequency i.e.frequency use was equal throughout the call (Figure 1). From a randomly selected pulse-train of 10 pulses, the average inter-pulse interval was 0.12 seconds (SD=0.014). Number of pulses in a pulse-train ranged from 5-18. This organism was only heard at Glen Brook Dam and Lake Leschenaultia, with midnight being the period of greatest sonic activity.

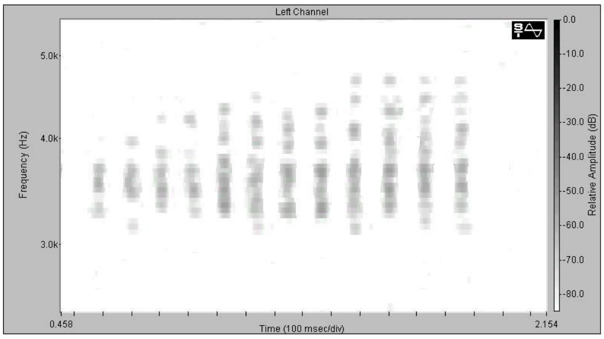

Figure 1. The 'Tick, tick…' call heard only at Lake Leschenaultia and Glen Brook Dam. Summer, 2003. Water temperature 27ºC.

'Cork on Glass' Calls

The 'Cork on Glass' call consisted of either a single pulse, or two pulses made rapidly together. These pulses ranged from 4.5 kHz - 10 kHz, and had dominant frequencies between 7-8 kHz. Pulses had an average duration of 0.13 sec (SD=0.21, n=20) (Figure 2). Isolated calls were heard at Glen Brook Dam, but were prolific at Blue Gum Lake with chorusing activity at dusk and to a lesser extent at midnight.

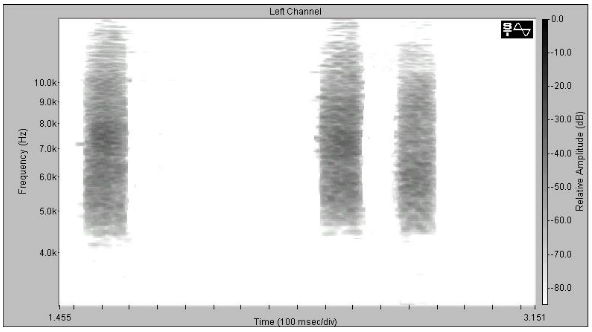

Figure 2. Spectrogram of the 'Cork on Glass' call which dominated all the time periods at Blue Gum Lake and was heard in a continous chorus at dusk. Summer 2003. Water temperature 23ºC.

The 'Ratchet' call

The 'Ratchet' call spans a broad spectrum from around 1.6 kHz extending above 20 kHz; with a dominant frequency of around 3 kHz and a lesser peak at around 8.6 kHz. Average duration was 0.72 sec (SD=0.39, n=12) (Figure 3). This organism was more active at midnight and only heard at Blue Gum Lake.

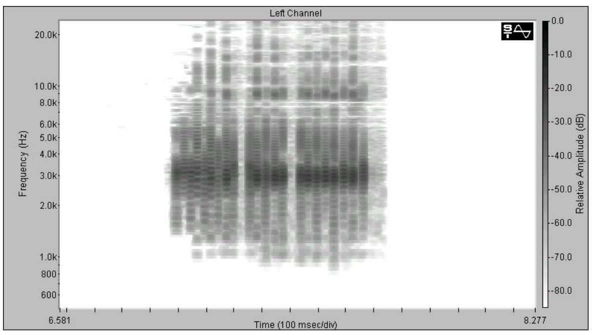

Figure 3. Spectrogram of the 'Ratchet' call only heard at Blue Gum Lake. Summer, 2003. Water temperature 29ºC.

'Bird-like song'

Spectral components in the 'Bird-like song' ranged from around 500 Hz to nearly 10 kHz with a dominant frequency around 1.8 kHz to 2 kHz (Figure 4). This organism was an intermittent caller, with some preference for midnight for sonic activity and was only heard at Glen Brook Dam and Lake Leschenaultia.

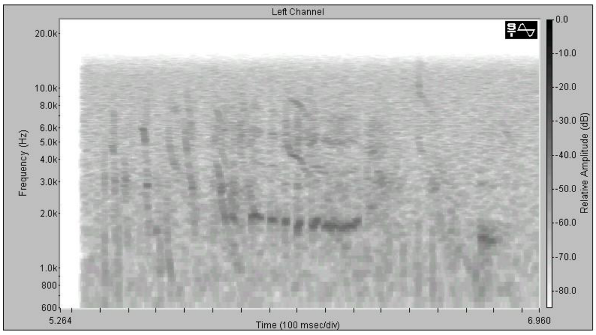

Figure 4. Spectrogram of the 'Bird-like song' only recorded at Lake Leschenalutia and Glen Brook Dam. Received levels for this call gave a low signal to noise ratio. Summer, 2003. Water temperature 27ºC.

The '12 / 6 kHz rattle'

The frequency range for the '12/6 kHz rattle' extended from around 5.8 kHz to around 13.8 kHz. The greatest output was between 10.6 kHz – 13.8 kHz with a lesser peak at 6 kHz - thought likely to be the opposite stroke as the organism stridulated. Each rattle lasted more than 35 seconds punctuated with silent intervals lasting around 1 second (Figure 5). This organism was mostly active at midnight and only heard at Blue Gum Lake.

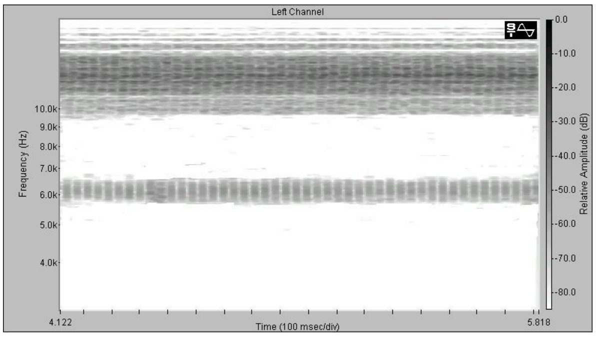

Figure 5. Spectrogram of the '12/6 kHz rattle' only heard at Blue Gum Lake. Summer 2003. Water temperature 27ºC.

The '5.5 kHz rattle'

The frequency range for the '5.5 kHz rattle' extended from around 5 kHz up to around 6.8 kHz, with the greatest output around 5.5 kHz. This caller along with the 'Tinsel caller' were frequent callers at midday; at Blue Gum Lake. Each rattle lasted 35 seconds or longer punctuated by silent intervals of varying duration (Figure 6).

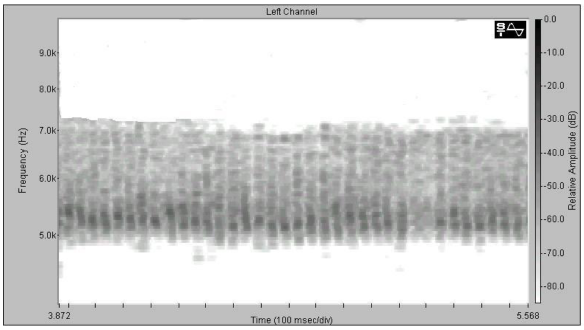

Figure 6. Spectrogram of the '5.5 kHz rattle' only heard at Blue Gum Lake and was a frequent caller at midday. Summer 2003. Water temperature 30ºC.

The 'Tinsel Caller'

The frequency range for the 'Tinsel caller' extended from around 7 kHz up to 9 kHz with the dominant frequency around 7.5 kHz. This organism was a frequent caller at midday and only heard at Blue Gum Lake with this call lasting 35 seconds or longer punctuated by short silent intervals (Figure 7).

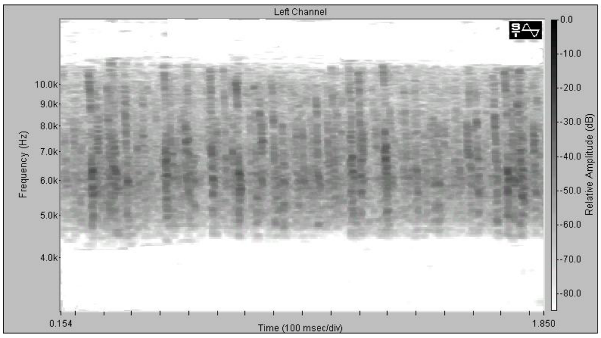

Figure 7. Spectrogram of the 'Tinsel caller' only heard at Blue Gum Lake and was often heard with the '5.5 kHz rattle' at midday. Summer, 2003. Water temperature 29ºC.

The Invertebrates

The entire data set (using both micro and macroinvertebrates) was analysed using the Bray-Curtis similarity clustering and was transformed by 4th root transformation. At about 15% similarity, two broad groups were present: 1.) Blue Gum Lake and 2.) a mixed grouping of Lake Leschenaultia and Glen Brook Dam. The average dissimilarity values between the groups were high (>90%), indicating a distinct difference between: Blue Gum Lake; and both Lake Lescehnaultia and Glen Brook Dam.

Greater diversity and abundances of macroinvertebrates were found at Blue Gum Lake (7 families) compared to Lake Leschenaultia and Glen Brook Dam (4 families & 3 families respectively). Only the Caenidae and Ceinidae were found at Blue Gum Lake and Glen Brook Dam; with Palaemonidae only found at Lake Leschenaultia and Glen Brook Dam. Generally, dusk and midnight were the time periods in which greater diversity and abundances of organisms were present for all wetlands – although given the paucity of families found at Glen Brook Dam, this trend was not so obvious here. Unlike the paucity of organisms present at midday at Glen Brook Dam and Lake Leschenaultia; biologics were well represented at midday at Blue Gum Lake (Figures 8-10).

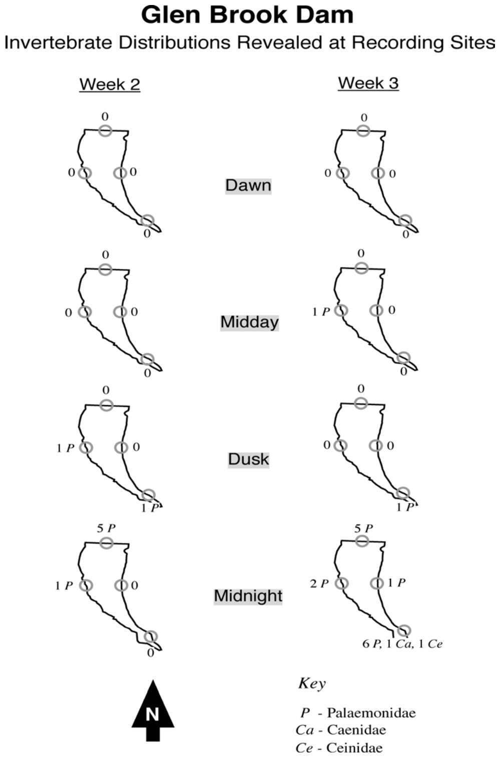

Figure 8. Macroinvertebrate distributions found at Glen Brook Dam at dawn, midday, dusk and midnight. Numbers represent actual numbers of macroinvertebrates found in a sweep sample which is the equivalent to 1m^3 of water. Summer 2003. (Graphics by Steven Goynich)

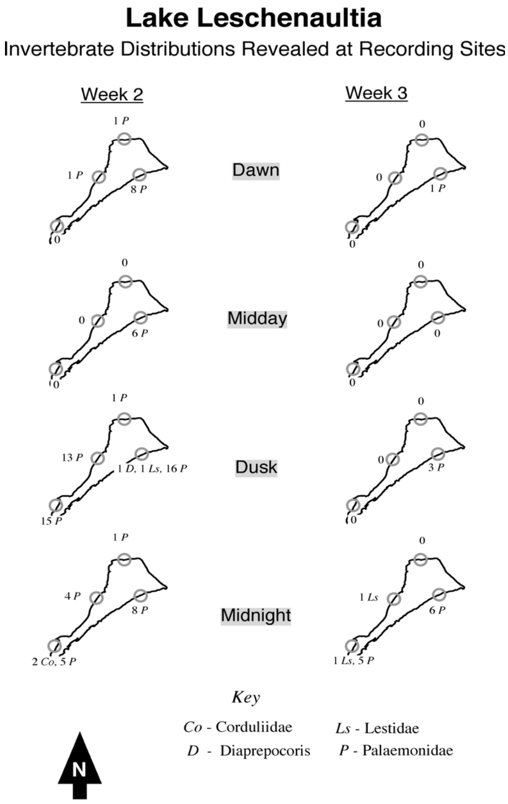

Figure 9. Macroinvertebrate distributions found at Lake Leschenaultia at dawn, midday, dusk and midnight. Numbers represent actual numbers of macroinvertebrates found in a sweep sample which is the equivalent to 1m^3 of water. Summer 2003. (Graphics by Steven Goynich)

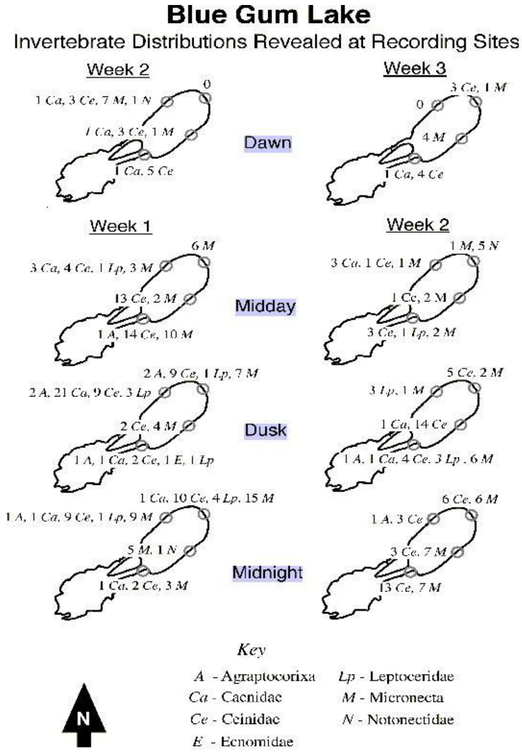

Figure 10. Macroinvertebrate distributions found at Blue Gum Lake at dawn, midday, dusk and midnight. Numbers represent actual numbers of macroinvertebrates found in a sweep sample which is the equivalent to 1m^3 of water. Summer 2003. (Graphics by Steven Goynich)

Background Ambient Noise

At Beaufort Wind Speeds of 0, 1 and 2, there was no difference overall to ambient noise in Blue Gum Lake or Glen Brook Dam at any recording site. The data was averaged to give a single spectra of ambient noise at these wind speeds (Figure 11). It was difficult to record in the complete absence of biologic activity and a small peak between 6-8 kHz is evident in the spectra for Blue Gum Lake. At wind speeds of BWS 3 and above; extraneous noise was evident.

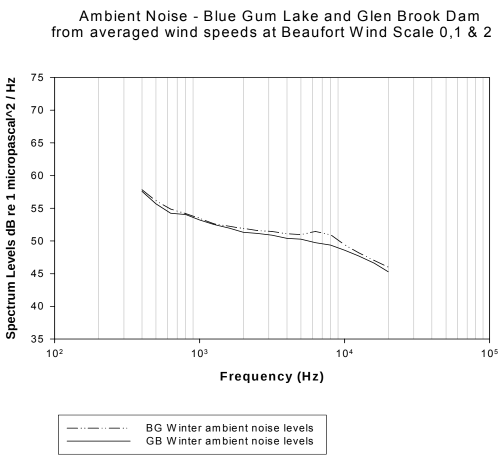

Figure 11. Averaged spectra for wind speeds at Beaufort Wind Scale 0, 1 & 2 at Blue Gum Lake (water depth 1-2m) and Glen Brook Dam (water depth 1-8m). Note the small peak at 6-8 kHz due to biologic activity at Blue Gum Lake.

Spectrum Levels at Blue Gum Lake

Noise spectrum levels are presented when chorus and/or persistent non-chorus calls were evident in the time periods:

midday, dusk and midnight. Each call is revealed at its maximum and is superimposed on the ambient background noise (Beaufort Wind Scale between 0-2). Midday recordings revealed a distinct peak between 5 kHz – 6 kHz which was produced by the '5.5 kHz rattle' with a lesser peak from the 'Tinsel caller' which is around 12 dB below the '5.5 kHz rattle' (Figure 12). At dusk, the continuous 'Cork on Glass' chorusing dominated this time period producing a dominant peak at 6 kHz - 8 kHz, which was slightly higher – around 8 dB above the maximum spectra at midday and around 3 dB above the midnight maxima (Figure 13). Midnight recordings revealed two dominant spectral peaks: one at a frequency of around 6.3 kHz and the other peak around 12.5 kHz which were produced by the '12 /6 kHz rattle'. This organism occasionally called with the dis continuous 'Cork on Glass' chorus appearing between these two frequency bands. The 'Cork on Glass' calls had largely subsided into dis continuous chorusing by midnight, with noise levels dropping from around 72 dB at dusk to 62 dB by midnight (Figure 14).

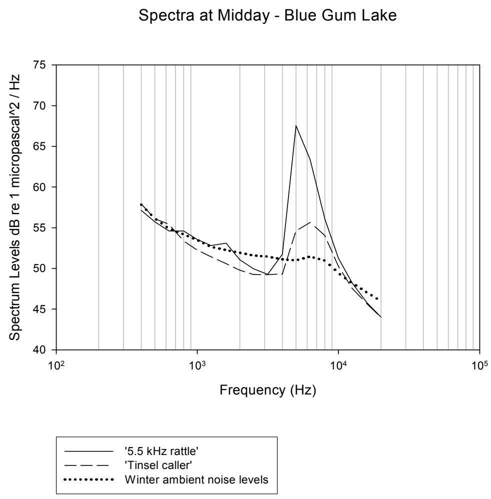

Figure 12. Spectrum levels at midday when the '5.5 kHz rattle' and the 'Tinsel caller' were present. These calls were only heard in the midday recordings. Water temperature 30ºC.

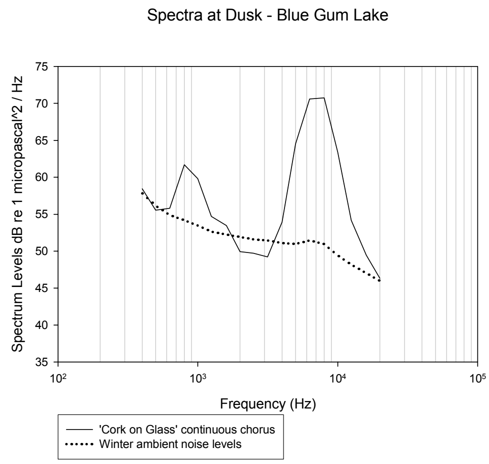

Figure 13 Spectrum levels at dusk when the 'Cork on Glass' were in continuous chorus. The smaller peak at 900 Hz was from a bubble released from the sediments. Water temperature 28ºC.

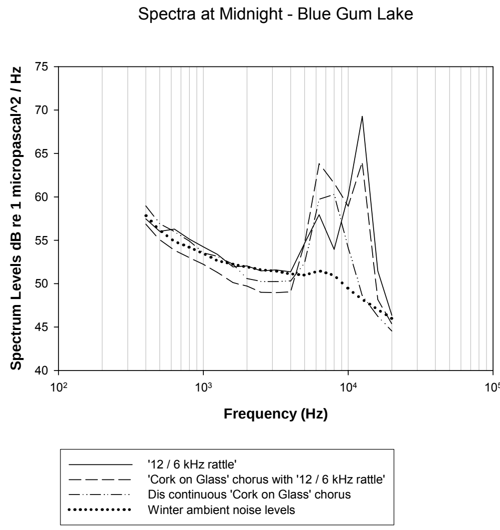

Figure 14. Spectrum levels at midnight when the '12/6 kHz rattle' was present and the 'Cork on Glass' were in a dis continuous chorus. Occasionally, the 'Cork on Glass' callers appeared between the '12/6 kHz rattle'. Water temperatures from 27ºC - 28ºC.

Anthropogenic Noise in Wetlands

There were four sources of anthropogenic noise encountered in the study. Noise was recorded from a helicopter; a speed-boat; water aerators; and road vehicles. Low frequency noise from heavy haulage vehicles were particularly distinctive in the recordings - using a band from around 100 Hz to just over 200 Hz, which was evident even up to 200m away. The helicopter produced distinctive noise in a band up to 2 kHz well above background noise levels.

DISCUSSION

Biological Contribution

Greater diversity and abundances were revealed in the invertebrate samples from Blue Gum Lake (the urban enriched wetland) compared to samples from the less enriched sites - Lake Leschenaultia and Glen Brook Dam. In support of the differences in diversity and abundances of invertebrates; there were variations heard in the recordings. A paucity of calls (two types) were recorded at Lake Leschenaultia and Glen Brook Dam; and these were different to calls recorded at Blue Gum Lake which had a greater diversity of calls (five types) as well as the presence of chorus activity which was not heard at the two less-enriched sites. From the maps of macroinvertebrate distributions, consistent trends of dusk and midnight were generally the periods of greatest diversity and abundance; which was synonymous with the increased sonic activity in these two time periods.

In these clear, freshwater environments; noise levels were greatest at dusk in particular, and to a lesser extent at midnight. Similar trends have been recorded in a marine environment (e.g. Fish, 1964 Clapp, 1964; McCauley *et al.,* 1996), although unlike the freshwater recordings, dawn chorus are also evident at some marine locations (Cato, 1978), with invertebrates and fish appearing to be the main contributors of high amplitude and continuous noise in the marine environment (Fish, 1964).

The bandwidth of greatest output in these shallow freshwater environments was at higher frequencies than that found in the marine environment. In the freshwater environment the greatest output was from around 6 kHz to 14 kHz, while in recordings made in the Timor Sea, East Indian and the West Pacific Ocean, Cato (1978) found the bandwidth of greatest output was from 400 Hz to 4 kHz, with Clapp (1964) reporting most energy between 100 Hz to 1000 Hz in coastal waters off San Diego. The higher frequency use in these freshwater environments is likely to be due to their shallow nature and their fluctuating water levels (i.e. seasonal wetlands have a wetting drying regime and therefore; the organisms present have waterlevels that can range from a few metres, during the wet months, to a few centimetres in summer, in which to signal in). Chorus spectrum levels between dusk and midnight in the Timor Sea were around 10 dB higher than the greatest output revealed in the freshwater dusk 'Cork on Glass' chorus and around 12 dB above the greatest output at midnight from the '12/6 kHz rattle'; but comparable spectrum levels were seen in the West Pacific and East Indian Ocean spectra.

The 'Cork on Glass' dominated the dusk and midnight recordings in summer by their chorusing activity - particularly at the enriched wetland – Blue Gum Lake. Chorusing activity, has been described in only one other Australian freshwater invertebrate: *Micronecta Concordia;* which was distinctive in itself as it was synchronised (King, 1999). The dusk 'Cork on Glass' chorus was an obvious chorus event producing well-defined spectral peaks and dominated Blue Gum Lake recordings. However, the '12/6 kHz rattle', '5.5 kHz rattle' and the 'Tinsel caller' were not strictly a chorus; but due to the energy in the call and their persistence in a recording period, these callers were included in the chorusing section and were defined as 'persistent non-chorus' calls. While most of the calls were percussive and considered produced by invertebrates, the complex 'Bird-like' call was considered to have been produced by a vertebrate animal.

Anthropogenic Noise

While wetlands on the Swan Coastal Plain and those further inland, are isolated from the types of anthropogenic noise inputs that are experienced in the marine environment(e.g. Epifanio *et al,* 1999; Finneran *et al*, 2000; Thompson and Richardson, 1995; Greene and Moore, 1995, Potter and Delory, 1998; McCauley *et al.,* 2003), wetlands were not without contributions from anthropogenic sources. While most of these sounds were intermittent; inputs from water aerators and from road vehicles using arterial highways (where wetlands lie adjacent to the highway), would contribute more-or-less continuous noise loadings into these freshwater environments, with the impacts on the organisms present unknown.

Ambient Noise

Unlike the ocean, these wetlands have some buffering to the influences of wind as they occur in natural depressions and are often surrounded by terrestrial vegetation and, in some cases urban dwellings. Therefore, wind in these wetlands do not reach the wind speeds that the ocean would be subjected to and consequently only the low wind speeds at BWS of 0,1,2 & 3 were the most relevant speeds (maximum wind speed recorded in the summer recordings was 12.4 km/hr). The contribution to ambient noise in a wetland was negligible at low wind speeds of Beaufort Wind Scale 0,1 & 2 and it appears that water depths from 1-8m did not influence the levels attained at these wind speeds either. Dietz *et al.,* (1960) also found no correlation between wind speed and sound pressure levels in shallow waters (7 fathoms or 12.8m) when wind speeds were lower than 9.76 km/hr; but variations have been found in the noise spectra at these wind speeds in a slightly deeper freshwater system at 15m (see Hawkins and Myrberg, 1983). Wind at speeds of Beaufort Wind Scale of 3 and above produced mechanical noise from action of wavelets on the hydrophone cable and slapping of waves on nearby structures such as: the height datum pole; granite boulders; and deadwood in the wetland, and surface debris washed in-shore which would bump against the hydrophone cable. Therefore, data was unavailable at wind speeds of Beaufort Wind Scale of 3 and above in this study.

The averaged ambient noise spectra revealed that higher noise levels were present in a wetland compared to spectra produced for some northern hemisphere 'shallow' marine environments (see Wenz, 1962). While the definition of a 'shallow marine environment' (< 100 fathoms or <183m) is obviously different to an inland wetland and would be considered deep; this was used as a basis for some comparison. Using Wenz (1962) Beaufort Wind Scale of 2 – Blue Gum Lake and Glen Brook Dam ambient noise levels were around 20 and 22 dB higher at 1 kHz and 400 Hz respectively compared to some marine locations. In general, Wenz (1962) found shallow water seas were around 5 dB higher than deeper water levels; so perhaps then it is not surprising that high ambient noise levels were found in the relatively shallow water environment of Blue Gum Lake and Glen Brook Dam. Surprisingly though, similar spectrum levels were found with those of ambient noise in tropical seas surrounding Australia (c.f. at 500 Hz: freshwater NL is ~57 dB: Cato sea NL is ~58 dB; at 1 kHz: freshwater NL is ~54 dB: Cato sea NL is ~57 dB) (see Cato, 1976). At much lower frequencies still (between 11-45 Hz), investigations by Lomask and Saenger (1960) found at zero sea-state ambient noise was quieter in a deep lake (750 ft or 228m) compared to the marine environment. Noise in the marine environment at low frequencies has been attributed to shipping traffic (Wenz, 1962; Cato, 1976).

CONCLUSIONS

There is a paucity of research on the ambient sound field in freshwater environments and what role sound plays in the ecology of the organisms existing within these systems, remains unknown. The urban enriched wetland revealed greater diversity and abundances of organisms present with a corresponding greater diversity and number of calls; and was the only wetland where chorusing activity occurred. Diversity and abundances of macroinvertebrate organisms were lower at the two less-enriched wetlands and had a corresponding paucity of calls. From the above results; these inland, freshwater environments appear to share some similarities with the marine environment – in particular, the prevalence of sonic activity from dusk through to midnight and the presence of chorusing activity.

The differences encountered in the sound field between the enriched urban wetland and the two less-enriched wetlands, suggesst that sound may have some potential use as a biomonitoring tool. Further studies between a range of inland fresh and saline systems would enable a greater understanding of sound within these environments.

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