Measurements of Snapping Shrimp Noise along the Cooks River, Sydney

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ABSTRACT

The Cooks River is a 23-km meandering urban waterway of south-western Sydney, and empties into Botany Bay. The tidal section is around 11 km long and supports significant numbers of mangroves, birds, and fish. Due to the tides, the salinity fluctuates but falls off slowly with distance upstream. Underwater ambient noise has been measured from 18 bridges over the lower 12 km of the river. Apart from occasional traffic noise that transmits into the river from some bridges, the only sounds heard underwater have the characteristics of (saltwater) snapping shrimp. The Peak Sound Pressure Level of the strongest snaps is in the neighbourhood of 180 dB re 1 μPa^2 at positions up to 3 or 4 km upstream from the river mouth, but then falls steadily as the measurements are repeated further upstream, although a previous survey of snapping shrimp distribution with a dipnet found a population 9 km upstream. The present finding is however consistent with previous findings for benthic life generally, which suggests that the snapping shrimp distribution may be limited by available food. The quieter sounds upstream are due to propagation of sound from the shrimp within 4 km of the mouth rather than more local shrimps, even though there are three 90-degree bends in the river course upstream of 4 km. Previous work has found that much of the riverbed is mostly sand, and should thus be a good reflector of sound.

INTRODUCTION

The Cooks River is a 23-km meandering urban waterway of south-western Sydney, and empties into Botany Bay. Due to pollution, it is all unsafe for swimming and the upper reaches are unsafe for boating. The water quality is monitored by Sydney Metropolitan Catchment Management Authority ("Sydney Metro CMA") as a check on the integrity of the sewerage system, and by the voluntary Cooks River Valley Association (CRVA) of local residents. Thus there is ample information available on water temperature and salinity, the properties that affect sound propagation. According to Dahlenburg (2011):

> Habitat for small animals (invertebrates) is influenced by water quality (and quantity). … invertebrate sampling is used to get an idea of how healthy (ecologically) a system is. (Sampling surveys have shown) a decreasing trend of invertebrates up the River … which is a good indicator of the impacts of poor water quality, high stormwater flows and riparian disturbance of the system.

Sydney Metro CMA and CRVA are thus interested in the nature of the aquatic animals that live there.

The questions that are addressed in this paper are as follows: what is the underwater ambient noise in the Cooks River, what causes it, where are the noise sources located, and how strongly do the sounds they make propagate upstream? To answer these questions, the author recorded underwater noise from 18 bridges on 49 occasions (34 during summer, and 15 during autumn). The locations of these bridges ranged from near the river mouth to an upstream distance of 12 km. In this paper, the distance of a location on the river (also known as "chainage") will mean the distance along the middle of the river from the mouth to that location.

There have not been any previous measurements of ambient noise in the Cooks River. The only non-ocean water in eastern Australia where noise has been reported is Sydney Harbour, where snapping shrimp were identified as the major source of noise (Ferguson & Cleary, 2001).

As well as presenting acoustic data, this paper also presents a relatively large amount of data on the physical environment of the river. The purpose is to establish a basis for future investigations into relationships between the acoustic data and the environment.

ENVIRONMENTAL CONDITIONS

The course of the river

A satellite photograph of the lower 13 km of the Cooks River is shown in Figure 1 (Google Imagery). Two significant waterways join the river: Wolli Creek, which heads toward the bottom left-hand corner; and Alexandra Canal, which heads toward the mid-point of right-hand side. The tidal section extends 11 km upstream. Between the mouth and a distance of 12 km upstream (where it is a stormwater canal), there are 18 accessible bridges over the river, which are referred to here as A to R. The approximate locations of the bridges, and their distances upstream, are listed in Table 1. For bridges D to J these distances were obtained from chainages relative to Bridge C reported by a Hydrographic Survey of the Cooks River (Public Works, 1989). For bridges A, B, and C the distances were read by rolling a graduated wheel along a map of the river from the mouth (UBD, 2009). The same method was used for K to R, using J as the starting point.

The river width is 135 m at bridge A, 42 m at M, 11 m at Q, and 1 m at R.

Table 1. Locations and distances upstream of the 18 bridges

Bridge	Approximate location	Distance, km
A	Near mouth into Botany Bay	0.20
B	South of Alexandra Canal	2.10
C	South of Wolli Creek	3.00
D	North of Wolli Creek	3.54
E	East end of large southward meander	4.89
F	West end of large southward meander	5.72
G	East of large northward meander apex	6.51
H	West of large northward meander apex	6.89
I	West of the gentle southward meander nadir	7.51
J	Apex of gentle northward meander	8.08
K	The wide road indicated by a line of white marks, 30 mm east of left side	8.64
L	South of the railway bridge visible 29 mm east of left side	9.00
M	(no distinctive reference)	9.96
N	Visible bridge at meander apex, 22 mm east of left side	10.32
O	(no distinctive reference)	10.72
P	(no distinctive reference)	11.12
Q	(no distinctive reference)	11.66
R	Visible bridge 6 mm east of left side	12.30

Regarding the upstream propagation of sound that will be discussed later, it is of interest that the river course contains six bends around which the course changes by around 90 degrees: (1) a third of the way from A to B (2) before C (3) after D (4) before F (5) between F and G, and (6) between G and H. The radius of curvature of these bends is typically around 150 m.

Figure 1. Satellite photograph of the Cooks River. Mouth is in bottom right-hand corner, upstream heads toward top left-hand corner. Width of photograph is 8.6 km. (Copied from Google Imagery)

Riverbed bathymetry

Two profiles of the mid-tide (mean sea level) depth of the river, as functions of distance upstream from the mouth, are shown in Figure 2. One curve applies to depth at mid-river, and the other is the maximum depth. These depths were obtained as follows:

(1) for distances between 3.0 and 8.0 km, the 87 cross-sections obtained by the Cooks River Hydrographic Surveys (Public Works, 1990b)

(2) for distances between 0 and 3 km, and also between 8 and 11.4 km, depths were read at selected distances from the bathymetric database produced by AWT Survey Pty Ltd (Yagoona, Sydney). The smooth appearance of the bathymetry at these distances is due to these depths being read at large spacings.

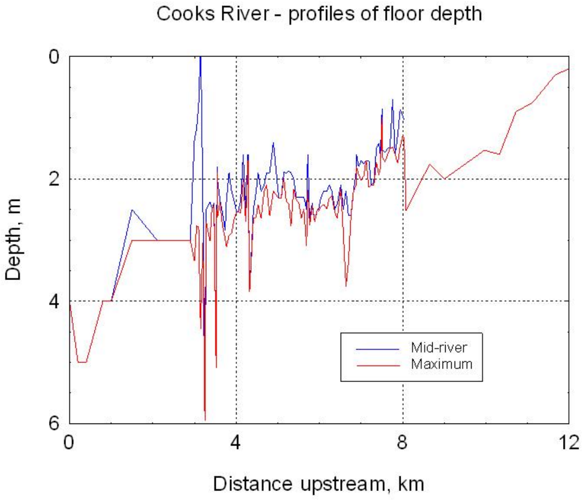

Figure 2. Profiles of the mid-river and maximum depths along the Cooks River at mean sea level. Data density is higher between 3 and 8 km than at other distances.

Riverbed geology

Upstream from a distance of around 10 km from the mouth, the riverbed is concrete. For the natural riverbed, it can be seen from a chart of surface geology in Cooks River Project (1976, page 38) that it consists of mud alluvial deposits except for distances between 5 and 6 km, where it is on the boundary between mud and Hawkesbury sandstone. According to Clarke & Hardie (1988), as cited by Kollias (2005), the sediment in the lower Cooks River is silty sand which is fine to medium grained and poorly graded, and the river banks in this material are easily eroded. Deposits of organic clay, silt and peaty sands may also be found. The results of two geological surveys conducted in 2002 and 2004 have been reported by Albani (2005). The data for average and standard deviation of the grain size at 20 positions have been read off, and combined with estimates of the distances of those positions. The results, in phi units, are shown in Figure 3 [Phi = $-\log_2$(grain diameter in mm)]. Since physical grain size increases with decreasing phi, the ordinate has been reversed so that larger grains are represented near the top of the plot. The boundary between sand and silt occurs at 4 phi, and the boundary between sand and granules occurs at -1 phi. Of the 20 average grain sizes, 16 correspond to sand rather than silt. From empirical results for porosity vs. average grain size presented by Richardson & Briggs (1993), it can be seen that the riverbed porosity will therefore range between 35 and 50% at 16 positions, and between 50 and 60% at the remaining four positions.

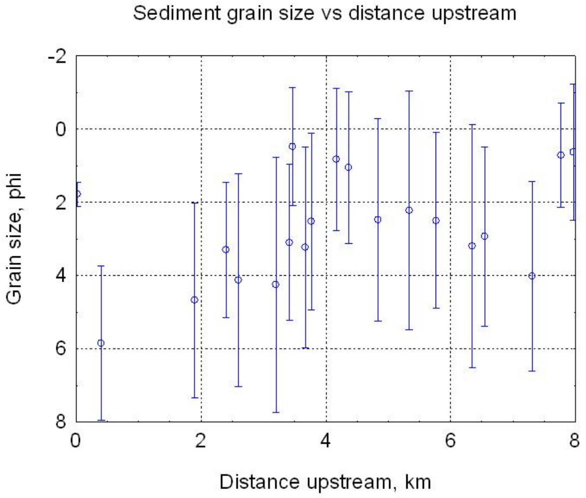

Figure 3. Average and standard deviation of riverbed grain size at 20 positions along the Cooks River (Albani 2005), shown as a function of distance upstream. Phi = $-\log_2$(grain diameter in mm).

The river water

The 11-km tidal section supports significant numbers of mangroves, birds, and fish.

Electrical conductivity and temperature are monitored continuously (every 15 minutes) by instrument buoys commissioned by the Sydney Metro CMA at two locations on the Cooks River. These buoys are named CMABOT01 and CMABOT 02; the former is upstream of H at a distance of 7.2 km, while the latter is downstream of B at a distance of 1.9 km. These buoys are remote from stormwater drains. Records covering the 6-month period from 2010 August to 2011 February have been provided by Dahlenburg (2011) and analysed. Additional records that span single weeks during February and March were downloaded from the CMA website. The results have been converted to salinity using the UNESCO routine described by Fofonoff & Millard (1983). An example of the time series from both buoys for December 7 is shown in Figure 4.

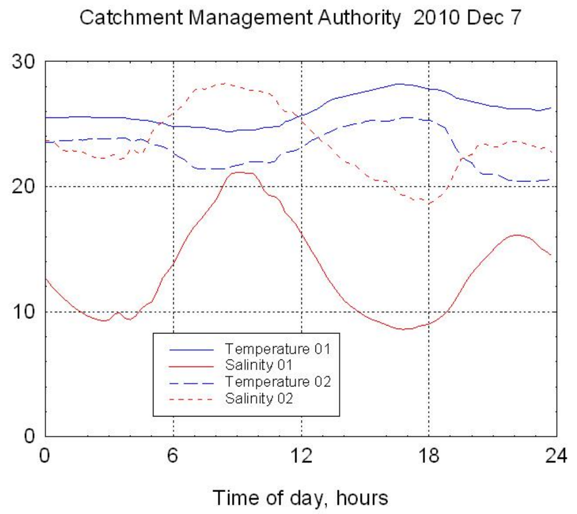

Figure 4. Time series of temperature and salinity from the buoys CMABOT 01 (near H) and 02 (near B), on 2010 December 7. Ordinate is in degrees C for Temperature, and parts per thousand (by mass) for Salinity.

As expected, the buoy closer to the ocean (02) had the higher salinity. The two maxima in salinity at buoy 02 were a little earlier than the ocean high tides at 9 hours (1.9 m) and 22 hours (1.3 m) on that day, while the maxima at buoy 01 were a little later.

Histograms of the derived salinities in 5-unit bins are shown in Figure 5. For BOT 01, 17238 records cover the 180 days from 2010 July 29 to 2011 January 24. For BOT 02, 16993 records cover the 177 days from 2010 Aug 1 to 2011 January 24. Salinity varies with time due to tides and rainfall, and tends to be higher at the downstream location.

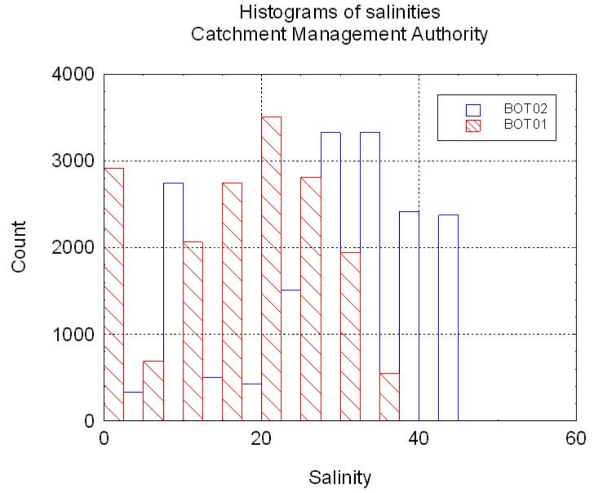

Figure 5. Histograms of salinities derived from temperature and conductivity recorded continuously for nearly 6 months by two buoys of the Sydney Metro CMA. Bin width is 5. Abscissa is in parts per thousand.

Electrical conductivity and temperature are also monitored by the Cooks River Valley Association at several locations on the river, usually at a rate of once per week for limited periods, supplemented by ad-hoc measurements at locations of interest. The data presented here are from five locations, at the following upstream distances (km): 3.5 (D), 4.2 (between D and E), 5.9 (near F), 6.5 (H), and 7.25 (I). Locations close to and downstream of stormwater drains are excluded here.

The histograms of the derived salinities in 5-unit bins are shown in Figure 6. These histograms give a description of the salinity values to be found at these locations, but since many salinity values occur only a few times, they do not provide robust support for conclusions regarding the dependence of salinity on upstream distance.

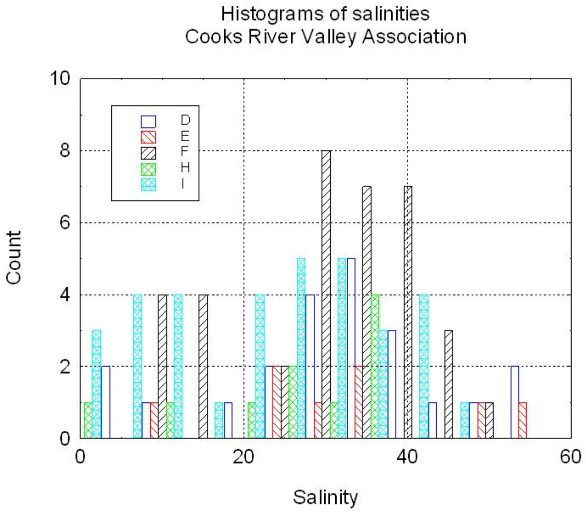

Figure 6. Histograms of salinities derived from temperature and conductivity measured at five locations by the Cooks River Valley Association. Bin width is 5. Values in the legend identify the nearest bridge. Abscissa is in parts per thousand.

Averages and standard deviations of the salinities at each of the seven locations have been computed, and are shown in Figure 7 as a function of distance. For the two CMA buoys as examples, the average salinities at the two locations are 30 and 17, with standard deviations of 12 and 10 respectively.

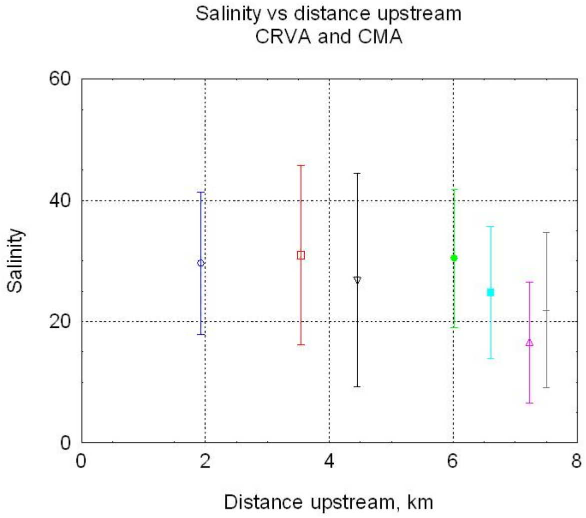

Figure 7. Average and standard deviation of the salinities at each of the seven locations, as a function of distance upstream. KEY: Blue and pink – CMA; others – CRVA. Ordinate is in parts per thousand.

The particular temperatures and salinities that prevailed at CMABOT02 (near B) concurrently with the 49 acoustic measurements are listed in Table 2. The 34 summer temperatures ranged between 19.9 (on Dec 8) and 24.3 (on Dec 15), had an average of 22, and a standard deviation of 1.4. The 15 temperatures observed during March were close to the average summer temperature. The summer salinities ranged between 7.6 (on Dec 14) and 32.9 (on Dec 23); they had an average of 23 and a standard deviation of 7.6. The March salinities ranged between 31.6 and 36.4, and had an average of 34 and a standard deviation of 2.5. The salinities during March were thus significantly higher than those during summer.

Table 2. The times when acoustic recordings were made, the concurrent water temperatures and electrical conductivities (EC) as recorded by CMA BOT02, and the derived salinities.

Date	Time of measurement, hours	Water temperature (C)	EC (mS /cm)	Salinity
Nov 27	18.5 18.5	23.9	44.0	29.1
Dec 3	11.6 12.8 12.8	20.9 21.6	38.3 37.2	26.7 25.4
Dec 6	9.4 10.4 11.2	21.8 22.2 22.5	39.6 38.5 36.7	27.1 26.0 24.5
Dec 7	8.4 9.0 9.5	21.4 21.7 22.0	40.7 40.7 40.5	28.2 28.0 27.7
Dec 8	7.8 8.6 9.2 9.7 10.9	19.9 20.6 20.6 20.7 20.9	29.9 29.5 29.4 29.6 29.3	20.8 20.1 20.1 20.2 19.9
Dec 10	8.7 9.4 10.0	21.7 21.8 21.7	18.2 18.1 18.1	11.6 11.5 11.5
Dec 14	7.9 8.3 8.7	23.2 23.3 23.4	12.9 12.8 13.1	7.7 7.6 7.8
Dec 15	7.7 7.8 8.5 8.9	24.1 24.1 24.3 24.3	41.9 41.9 41.6 41.4	27.4 27.4 27.1 26.9
Dec 23	8.7 8.4 7.8 7.9	20.5 20.4 20.4 20.4	45.8 45.7 45.7 45.7	32.9 32.9 32.9 32.9
Jan 7	11.1 11.1 10.5 11.8 11.9 11.5	23.2 23.2 23.2 23.8 23.8 23.8	41.9 41.9 26.1 41.4 41.2 41.6	28.0 28.0 16.6 27.2 27.1 27.4
Mar 8	11.8 11.9	22.3 22.4	52.1 52.1	36.4 36.4
Mar 22	10.2 10.9 11.3 11.7 – 12.3	22.8 22.7 22.7 22.8 – 22.9	46.6 47.1 46.9 46.4 –	31.8 32.2 32.1 31.6 – 30.3

			44.7	
Mar 28	10.4 10.9 11.5 11.8	21.1 21.1 21.1 21.1	50.1 49.3 50.9 50.9	35.9 35.2 36.5 36.5

Zoology

According to the Cooks River Project (1976, page 17), “Samples of macroscopic animals were collected from the Cooks River and its tributaries during the months of August, September and October 1975”. They had 13 sampling stations at distances between 0 and 12 km. The number of species found decreased from a maximum of 48 at the mouth to three at 12 km. Of the species listed, the one that is known to be a prevalent source of noise is the snapping shrimp (Alpheus sp.). The project found at least 40 specimens at five of their stations, the distances to which were 0, 3, 4, 5 and 9 km. The nearest bridges are A, C, D, E and K respectively. The eight stations at which no snapping shrimp was observed were at distances of 1, 2, 6, 7, 8, 10, 11, and 12 km.

According to Banner & Banner (1973):

> The alpheids are characteristically associated with the complex of tropical coral reefs, from the inshore beaches across the growing reefs to the offshore muddy bottoms. There appears to be a greater penetration of the family into temperate waters in Australia than in the Northern Hemisphere. In Australia we have records of the genus Alpheus reaching up various rivers, for example up the Swan River to Perth, in Western Australia, and rivers in New South Wales and Queensland, but these are evidently brackish waters. While the habitats are undoubtedly washed with fresh water at time of heavy rain, we have no records of further penetration by alpheids into strictly fresh water in Australia.

The Cooks River Advisory Committee (1978), as cited by Kollias (2005), found that benthic organisms were plentiful below bridge D, where the river is regularly flushed by tidal waters. The benthic community consisted of a variety of small crustaceans, worms and molluscs. Benthic organisms were virtually non-existent upstream of E.

EXPERIMENTAL METHOD

On 13 days over the summer and early autumn of 2010/2011, 49 recordings of ambient noise were made with a single hydrophone lowered to the river floor from 18 bridges.

The hydrophone was lowered midway between neighbouring pylons, these being selected so that the hydrophone would be near the middle of the river. A photograph of the deployment from bridge Q on December 23 is shown in Figure 8; the depth during this measurement was 0.6 m. The (spherical) hydrophone had an external diameter of 8 cm and a quasi-constant sensitivity up to a frequency of 30 kHz. The hydrophone signals were passed to a Reson 100-MΩ pre-amplifier and then to a Fostex FR-2 field memory recorder set to a sampling rate of 88200 samples per second. The recording duration was generally 1 minute, except for the two recordings on Nov 27, which were a half-minute. For each of the 13 days, the date, time, and position of the measurements conducted on the day are listed in Table 3. Each position is written with a sequence number which indicates the cumulative number of measurements at that position. Also listed are times and heights of either high tide or low tide in the ocean, whichever occurred closer. Tide heights are relative to Lowest Astronomical Tide (LAT), which in the Sydney region is 0.9 m lower than mean sea level.

Figure 8. Hydrophone suspended from bridge Q (distance 11.66 km), on December 23.

Table 3. List of dates on which acoustic measurements were made, with their positions and times. Times and heights of the most coincident ocean tide are also listed. All times are GMT + 10.

Date	Position(s) and sequence numbers	Time of measurement, hours	Ocean tide time, hours	Tide height relative to LAT, m
Nov 27	D1 D2	18.5 18.5	18.8	0.32
Dec 3	A2 B1 B2	11.6 12.8 12.8	12.4	0.34
Dec 6	C1 D3 E1	9.4 10.4 11.2	8.3	1.89
Dec 7	F1 G1 H1	8.4 9.0 9.5	9.0	1.87
Dec 8	I1 J1 K1 L1 M1	7.8 8.6 9.2 9.7 10.9	9.7	1.81
Dec 10	A3 B3 E2	8.7 9.4 10.0	11.0	1.64
Dec 14	M2 N1 O1	7.9 8.3 8.7	8.2	0.73
Dec 15	P1 P2 Q1 R1	7.7 7.8 8.5 8.9	9.4	0.72
Dec 23	P3 Q2 R2 R3	8.7 8.4 7.8 7.9	9.3	1.92

Jan 7	N2 N3 O2 O3 O4 P4	11.1 11.1 10.5 11.8 11.9 11.5	10.0	1.72
Mar 8	D4 D5	11.8 11.9	10.2	1.46
Mar 22	B4 D6 E3 H2-H5	10.2 10.9 11.3 11.7 – 12.3	10.2	1.63
Mar 28	B5 D7F E4 H6	10.4 10.9 11.5 11.8	10.4	0.55

According to Willyweather (2011), high tide at bridges C, E and K are respectively delayed by 13, 23 and 43 minutes relative to the ocean tide. These delays lie on a straight line when plotted against upstream distance, and the slope yields 11.3 km /hour for the speed of the tidal wave. Assuming this speed remains constant, the estimated delay for the furthest tidal position (Q) is 1.0 hours.

EXPERIMENTAL RESULTS

The recordings consistently exhibit the snaps associated with snapping shrimp, and there are no other consistent sounds (traffic passing over the bridge was heard in some cases, and running water from nearby drains was heard once). From the waveform measured in the first measurement on bridge B (B1), a 10-ms segment that contains a snap (and its reflection) is shown in Figure 9. An ADC output of 32000 corresponds approximately to a peak SPL of 180 dB re μPa^2, which occurred frequently at bridges A to D.

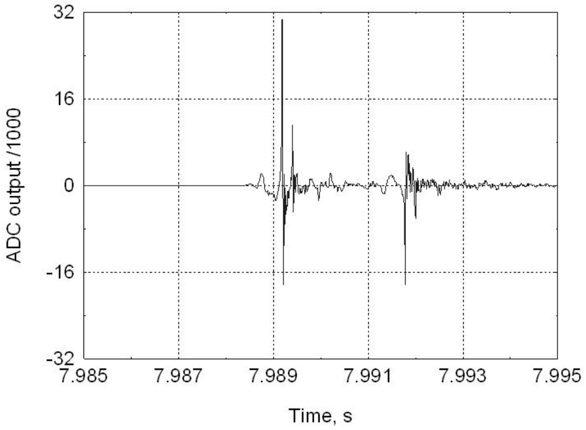

Figure 9. A 10-ms segment of the waveform obtained from a recording at bridge B that contains a snap and its reflection.

The Sound Exposure Level (SEL) of the first pulse is 128 dB re μPa^2.s. Its spectrum in third-octave bands is shown in Figure 10. The low-frequency cut-off at frequencies below 1 kHz could be due to propagation in very shallow water. In an example of cutoff discussed by Jensen et al (1994, page 32), a cutoff frequency of 11 Hz occurs for propagation in water 100 m deep over a sand-silt floor. Since the cutoff frequency is inversely proportional to the floor depth, a cutoff frequency of 1 kHz will correspond to a floor depth of around 1 m.

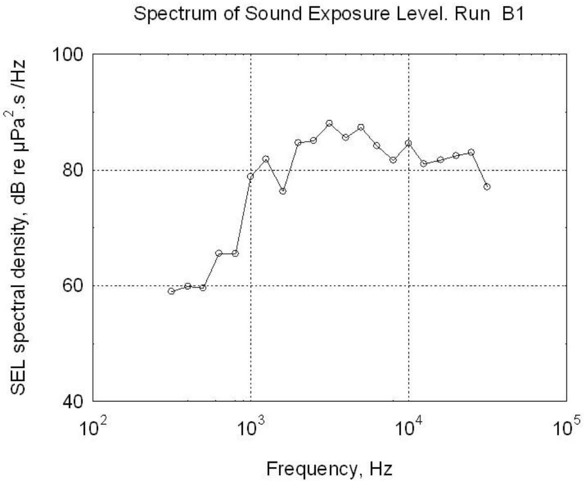

Figure 10. Third-octave spectrum of the first pulse in Figure 9.

The peak SPLs measured in each of the 49 recordings are shown as a function of distance upstream in Figure 11. The results obtained during March are distinguished from those obtained during November to January, and it can be seen that the March data tend to have lower peak SPLs than the remainder.

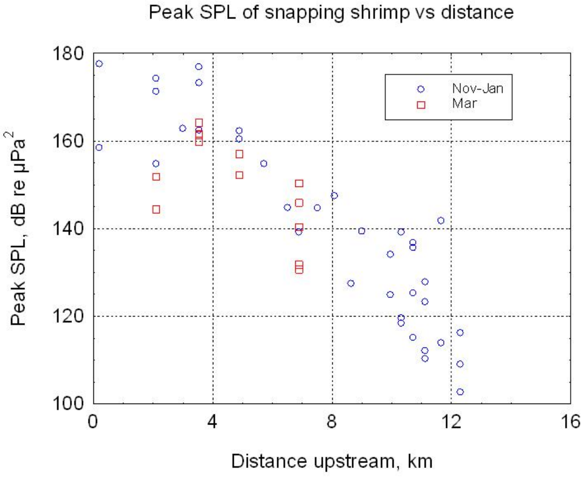

Figure 11. Peak SPL in each of the 49 recordings, as a function of distance upstream.

The highest peak Sound Pressure Level (SPL), which was 178 dB re μPa^2, occurred at A, the closest bridge to the mouth. Peak SPLs of at least 170 dB re μPa^2 occurred only at bridges within 3 km from the mouth. This is consistent with being close to snapping shrimp, in that Ferguson & Cleary (2001) found that "For a sample of 1000 snaps recorded in Sydney Harbour, the distribution of peak-to-peak sound pressure levels (at a standard distance of 1 m from its point of origin) has a mean value of 187 dB re μPa^2 and an interquartile range of 185–189 dB re μPa^2". In view of the small size of this interquartile range, it follows that low peak SPL are not attributable to variation in the Source Level of snapping shrimp, but are due to propagation loss. This loss could be due either to the shrimp being some distance from the hydrophone, or to them being in a shadow zone behind a bridge pylon.

Beyond 3 km, peak SPL decreased with distance upstream at an average rate of 5.6 dB /km. This decrease is attributed to attenuation of sound signals propagating upstream from the shrimp that are located in the first 3 km of the river. The three 90-degree bends in the river upstream of 4 km occur at distances of around 5.5, 6.1, and 6.7 km. It does not appear however that there is a significant change in the rate of attenuation near those distances.

As distinct from peak SPL, the average square pressure that is heard upstream has been computed for each of the 49 recordings, and is plotted in Figure 12. The March data tend to have lower average SPLs than November to January. Beyond 3 km, average SPL decreased with distance upstream at an average rate of 3.7 dB /km, more slowly than peak SPL. This lower rate for the average can be attributed to the peak depending on high-frequency content in the spectrum, whereas energy depends on the whole spectrum; and the former will attenuate more rapidly than the latter.

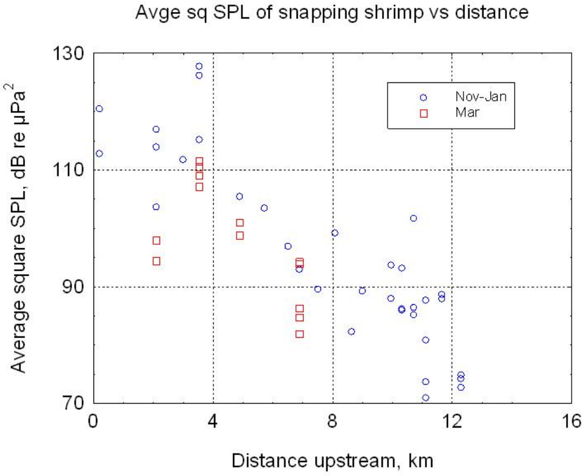

Figure 12. Average square SPL in each of the 49 recordings, as a function of distance upstream.

At the bridges where several recordings were made, there is considerable spread in the results. At bridge B (2.1 km), the peak and average data have ranges of 30 and 23 dB respectively. This bridge has large pylons, as can be seen in Figure 13, and it may be that, relative to the closer noise sources, the hydrophone was in the shadow zone behind a pylon during some recordings.

Figure 13. Bridge B, showing the size of the pylons.

Alternative explanations for the large spread are that (i) shrimp were located near bridges during summer but moved to positions between bridges during March, or (ii) a duration of 1 minute is too short to always capture the maximum signals (the closest sources) that occur at a given location, although this does not account for SPL tending to be lower during March.

For bridges upstream, variations in conditions that affect propagation may have varied from one recording to another; such factors would be water depth and salinity. Greater water depth (high tide) would lower the attenuation, whereas higher salinity would increase it due to increased absorption (assuming that the concentration of magnesium sulphate varies with total salinity as it does in the ocean). An interesting aspect is that due to the tide, greater depth is concurrent with higher salinity, and thus these two factors may (at least partially) cancel each other. A detailed analysis of these effects is however beyond the scope of the present paper.

COMMENTS ON SOUND PROPAGATION

For a point sound source, the propagation loss (PL) from 1 m to a given distance is given by the area of the wave front at that distance (spreading loss) as constrained by any boundaries, augmented by the effect of damping due to imperfect reflection by those boundaries. At a fixed distance of 5 km for example, PL in the open ocean will be around 70 dB or more. It has been found here however that the corresponding PL in the Cooks River (moving upstream from 3 to 8 km) is no more than around 40 dB. The major factor causing PL up a river to be less than in open waters is that, beyond a few metres distance, there is virtually no wavefront spreading. In fact there is a contraction in the area of the wavefront, due to the decreasing river depth and width. The damping component in PL may be significant, depending on the reflectivity of the riverbed. At river bends, the path approaches the bank and is refracted horizontally by the slope in the riverfloor. The fact that snaps were audible at distances of around 10 km indicates that the slope of the river floor as it shallowed to the side was sufficient to refract the signal sideways so that it propagated around each bend without great loss. It could be expected that the attenuation rate would be higher at the bends, since sound propagating in shallower water has a higher damping rate (due to the smaller distances between successive reflections). There is however no evidence of such increases in the observed variation of SPL with distance, suggesting that the riverbed reflectivity is high.

CONCLUSIONS

Underwater ambient noise in the Cooks River consists of random sequences of sharp pulses. Close to the river mouth, the highest wideband peak SPL is 178 dB re μPa^2. There is significant spread in the results, even at a fixed distance. The only other underwater sounds heard are very quiet in comparison: vehicle traffic (on some bridges) and running water from a nearby drain on one occasion.

The pulses have the characteristics of the sounds emitted by the many species of snapping shrimp which, although saltwater creatures, are known to have made significant migrations up Australian rivers in general, and the Cooks River in particular.

Since there is no point in a shrimp snapping quietly, the weaker pulses heard upstream are attributed to propagation of snaps created close to the river mouth, and in particular to the first 3 to 4 km of the river.

Beyond 3 km from the mouth, peak SPL decreased with distance upstream at an average rate of 5.6 dB /km, and the average square pressure decreased at an average rate of 3.7 dB /km.

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Gayle Adams of the Cooks River Valley Association provided data from their readings.

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