A COMPARISON OF TECHNIQUES FOR RANGING CLOSE-PROXIMITY MULLOWAY *(ARGYROSOMUS JAPONICUS)* CALLS WITH A SINGLE HYDROPHONE

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The accurate ranging of sounds produced by fish can provide valuable information on species ecology, and fish calls are being increasingly used to delineate and evaluate spawning grounds. In 2008, a single hydrophone was deployed on the riverbed of the Swan River, Western Australia, to assess the most effective technique for ranging mulloway (*Argyrosomus japonicus*) calls. During this experiment, the ranges of a calling mulloway were calculated using four techniques. These techniques involved comparing the characteristics of the direct and surface -reflected paths using: 1) arrival-time difference; 2) the pressure-amplitude ratios; 3) pulse sound-pressure-level ratios and; 4) a combination of techniques 1) and 2). Technique 1 proved the most consistent ranging technique, with accuracy limited by wave-motion-induced variation in water depth. However, a combination of the tested techniques is recommended when ranging fish.

INTRODUCTION

Overfishing has led to the collapse of numerous fish stocks around the world. It is a particular threat to species prone to exploitation, such as those of the Sciaenidae, known as drums or croakers, e.g. mulloway (*Argyrosomus japonicus*), black jewfish and (*Protonibea diacanthus*) teraglin (*Atractoscion aequidens*) [1-3]. The recent collapse of a black jewfish spawning aggregation in northern Queensland has highlighted the susceptibility of Sciaenidae in Australia and the need to develop more accurate monitoring techniques for sustainable management of the fishery [4, 5].

The observation of fine-scale movement of individual fish facilitates the understanding of interaction within the spawning group and the spatial extents of aggregation movement. For example, some species exhibit mobile spawning rushes where multiple males follow a female in a vertical movement, while other species take part in near stationary pair spawning [6-9]. However, many fish spawn during hours of darkness or in estuarine waters of high turbidity, which can affect the ability of visual techniques to observe behaviour [5, 10]. In addition, some methods of observation may induce behavioural bias (e.g. baited remote underwater video), while extractive techniques such as tagging and biological sampling may not be appropriate for species which are susceptible to barotrauma (over-expansion of the swimbladder) or exhibit high catch-mortality rates. Such species include black jewfish, mulloway, and West Australian dhufish (*Glaucosoma hebraicum*), which are key species of commercial importance in Australia [11-15].

One alternative method of observation is the remote recording of fish calls (passive acoustics). For centuries traditional fishermen around the world have known that many species of fish produce sound, listening to the noise through the hulls of their wooden boats to locate aggregations [16]. Over the past five decades, more than 800 different fish species have been reported to be soniferous [17]. Sounds associated with reproductive behaviour are being increasingly reported [18-24]. Winn [25] and Fine *et al*. [26] summarised these sounds as associated with one of several behavioural functions including: aggressive encounters (usually territorial); reproduction; echolocation; schooling; recognition; feeding; migration; exploration; and distress.

Sound production by fishes can eventuate from diverse methods, such as bubble release from the mouth or vibration of bubbles at the anal cavities [27]. Some species use stridulation, which is the rubbing or knocking of body parts together, creating a noise similar to that of marine invertebrates. This stridulation (high frequency, wide-bandwidth, usually of short duration) may be from pectoral fins (e.g. catfish [28, 29]) or skeletal bones (e.g. pipefish, *Syngnathus louisanae* [30]), but the chief mechanism of fish sound production is via the vibration of the swimbladder (an enclosed gas chamber within the body cavity) [25]. To vibrate the swimbladder, fish contract fast or superfast twitch (“sonic”) muscles, which may or may not be connected to the swimbladder [31, 32]. Since the acoustic impedance of the gas inside the swimbladder differs greatly from the surrounding water, the swimbladder is highly effective at generating sound [33] and is therefore an effective means of communication (and observation) over great distances.

Mulloway is a commercially and recreationally important species in Australia [34]. Individuals aggregate during spawning, often in estuaries at night-time high tide, which restricts many traditional data sampling methods [5]. Mulloway produce tonal sounds of varying length, comprising a train of swimbladder pulses [35, 36] (Figure 1). Close-proximity ranging of fish can be achieved non-invasively by recording these calls with a hydrophone [5, 20, 35]. Fine-scale localisation of individual fish from their calls has been achieved [37], but this is non-trivial because it requires an array of hydrophones and regular array synchronisation [35, 37]. Single hydrophones are often used to identify broad-scale movements of cetaceans [38], and on occasion the position of fish [20], but rarely to observe the small-scale movement patterns of individuals.

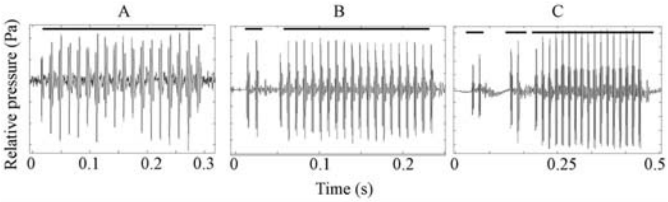

Figure 1. Waveforms of example mulloway (*Argyrosomus japonicus*) calls. Black lines above waveforms denote periods of audible tone.

Understanding local sound-propagation characteristics (e.g. transmission loss) is one of the initial steps towards assessing the numbers of calling fish by comparing the sound-pressure levels (SPL) produced by a single fish with the overall received SPL from the entire chorus [20, 39]. Given that estuarine tidal range, salinity and temperature all vary at different temporal scales (ranging from hours to months), the propagation of sound in estuaries can change significantly over a matter of hours, with considerable effect on the received SPL of fish calls [31]. The ability to range fish calls using a single hydrophone aids the characterisation of local transmission properties at the time of recording, and therefore the contribution of an individual call to the overall SPLs [20, 35]. Once local transmission properties have been determined and accounted for, it is then possible to compare the SPLs of fish calls recorded at different times and potentially to compare estimates of abundance.

The aim of this study was to assess the most appropriate passive-acoustic technique for localising fish under survey conditions by calculating the range of calling mulloway in Mosman Bay, Western Australia using four different techniques.

METHODS

Data collection

A hydrophone array was deployed in Mosman Bay on 8th March 2008 to localise individual mulloway calls. The Mosman Bay channel varies in depth between approximately 18 and 21 m and comprises a sand/silt substrate with a number of artificial reefs (Figure 2).

An HTI-90U hydrophone (Hi-Tech Industries Inc., MS, USA) was attached to a custom-made autonomous sea-noise logger (www.cmst.curtin.edu.au/products/usr.html) developed at Curtin University of Technology and Defence Science and Technology Organisation (DSTO) and deployed on the riverbed at approximately 32° 0.57’ S, 115° 46.43’ E. The noise logger recorded for twenty five minutes of every half hour at a sampling frequency of 10.416 kHz with a flat (± 1 dB re 1 V^2/Hz) frequency response between ~20 Hz and 1 kHz (confirmed using a -90 dB re 1 V^2/Hz white-noise source).

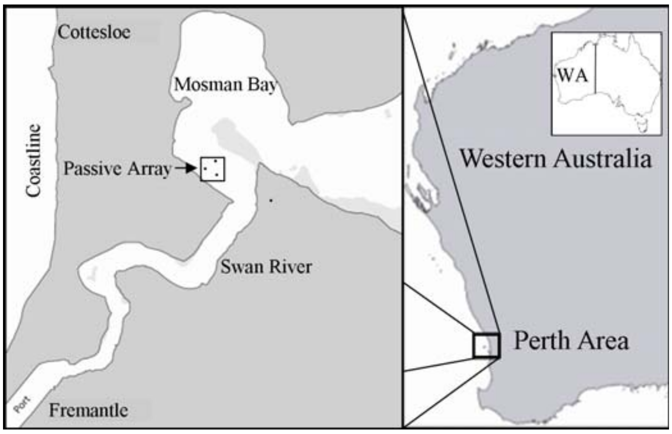

Figure 2. Map of the Swan River in Western Australia and the location of a hydrophone array in the Mosman Bay area.

At the time of the reported calls the hydrophone was positioned in 18.3 m of calm water. The greatest variation in water depth was due the wake of passing vessels, estimated at a maximum of ± 30 cm [40]. Over large distances, the effects of ray bending on path distance and transmission loss can have considerable impact on source-range estimates. However, at the ranges in this experiment (<50 m), the effects of ray bending on source range were considered negligible compared to those of depth variation caused by vessel-generated surface waves [37, 41].

Data analysis

Waveforms and spectral content of the recorded calls were analysed using a suite of Matlab© programs developed by the CMST. The received SPL refers here to root-mean-squared (RMS) pressure measured in dB re 1μPa.

In addition to long calls (Figure 1), mulloway also emit short calls of one or two pulses. These short calls look similar to the first two pulses of the call in Figure 1B. The waveform of an example single pulse mulloway call together with the waveform characteristics of importance to each ranging technique are highlighted in Figure 3A, including the call initiation peak (CIP), peak-peak amplitude of the first pulse cycle and the pulse duration used in analysis. Using these waveform and call spectral-content characteristics, four techniques were applied to determine caller range [20, 37, 42]. These techniques are summarised in what follows.

Technique 1: Arrival-time difference

The difference in distance between the direct path (r_1) and that of the surface reflected path (r_2) is equal to that travelled by the signal during the arrival-time difference (ΔT) at sound speed under survey conditions (c), given as ΔTc. If the caller and the hydrophone are positioned at the same depth (see results section for estimate of caller depth) the path distance difference, combined with the hydrophone depth (d) can be related to the source range in the form of:

$$r_1 = \frac{4d^2 - (\Delta Tc)^2}{2\Delta Tc} \qquad (1)$$

where $\Delta T = T_{r2} - T_{r1}$.

Technique 2: Pressure-amplitude ratio

For each call the absolute difference between the first positive and negative peaks in waveform amplitude were measured for the direct (V_1) and surface reflected (V_2) signals. Range was calculated from the ratio of these two pressure differences, combined with the known hydrophone depth and assumed caller depth in the form of:

$$r_1 = \sqrt{\frac{(2d)^2}{\left(\frac{V_1}{V_2}\right)^2 - 1}} \qquad (2)$$

Technique 3: Energy ratio

The received SPLs of the direct (SPL_1) and surface-reflected (SPL_2) pulses were calculated as per the techniques standardised in McCauley [20] and Madsen [43]. In this technique, transmission loss for both paths was assumed to be close to spherical spreading 20log(r). Therefore the two calculated SPLs were related by:

$$SPL_1 + 20(\log(r_1)) = SPL_2 + 20(\log(r_2)) \qquad (3)$$

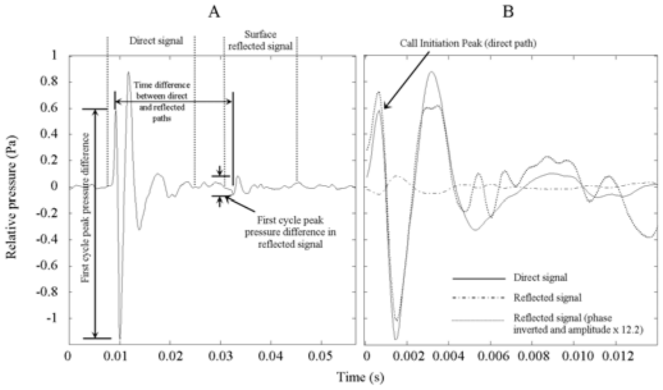

Figure 3. Waveform of an individual *A. japonicus* single pulse call with the direct signal, reflected signal, time difference and pressure amplitude points taken in analysis (A). An expansion of the direct (continuous line) and reflected (dotted line) pulse waveforms from A with the reflected waveform phase inverted and scaled to match the amplitude of the direct waveform (dot-dash line) with both waveforms synchronised to the call initiation peak (B).

Technique 4: Arrival-time difference + pressure-amplitude ratio

Range was calculated using a combination of techniques 1 and 2 by:

$$r_1 = \frac{\Delta Tc}{\frac{V_1}{V_2} - 1} \qquad (4)$$

This technique removed the assumptions of caller depth. To confirm position in the water column, the azimuth of the fish from the vertical and centred at the hydrophone was given by:

$$\cos\theta = \frac{r_1^2 + 4d^2 - r_2^2}{4r_1 d} \qquad (5)$$

where ghost range, r_2 was calculated by:

$$r_2 = r_1 \frac{V_1}{V_2} \qquad (6)$$

Assumptions

The carrier frequency of Mosman Bay mulloway calls ranges between 175 and 350 Hz [35, 36]. The height and period of waves generated by passing vessels typically varied by ±30 cm and ~4 s [40]. As such, the acoustic Rayleigh parameter has been considered to be low (P<<1) and direct energy was assumed to be reflected in the specular direction as a coherent wave, with the reflection coefficient taken as -1 [44]. To provide maximum and minimum range estimates, the variation in water depth (d) due to wave height and possible losses in the reflected signal due to scattering (arbitrarily taken as ±10%) was applied to each applicable technique.

The SPL for each complete call was calculated as per methods outlined in Coates [45], McCauley [20]. In previous studies, for a particular call type, source levels of calls from an individual fish have been considered to remain constant [20, 46]. As such, the relative received SPL of a complete call was taken as indicative of the relative caller range. At ranges approximately equal to the water depth, spherical spreading provides a reasonable estimate of geometric losses [38, 39], thus a doubling in range would result in an equivalent decrease in received SPL of approximately 6 dB re 1µPa [47].

RESULTS

A series of short calls (1-5 swimbladder pulses) were observed during the recording period (Figure 3A). Based on the rate of call emission, the similarities of spectral peak frequencies of the calls (Figure 4B) and the similarity with calls of the same type emitted in aquaria by an individual fish [35], it was determined that these calls originated from a single fish. The fish emitted a total of 114 calls over a 32 s period. Due to interference from overlapping calls or surface reflected pulses, not all calls in the series were suitable for analysis with all four ranging techniques (Table 1).

Table 1. Breakdown of short calls in the analysed call series by the number of pulses within a call and the number of calls used in each localisation technique

	Number of calls analysed				
Number of pulses in call	Total	Technique 1	Technique 2	Technique 3	Technique 4
1	37	19	16	16	16
2	41	24	16	16	16
>2	36	n/a	n/a	n/a	n/a

Swimming behaviour

Initial calculations using arrival-time differences (ΔT) of the call initiation peak between the direct and surface waveform for the most intense call (Figure 4A, 15.4 s) showed that for the call to be emitted from within the water column (and not beneath the riverbed) the fish must have been within 1.6 metre range of the hydrophone. At this point the fish must therefore have been swimming on, or close to, the riverbed. It was assumed that the fish behaved similarly to those reported by Parsons *et al*. [37] and continued swimming along the riverbed remaining at the same depth as the hydrophone.

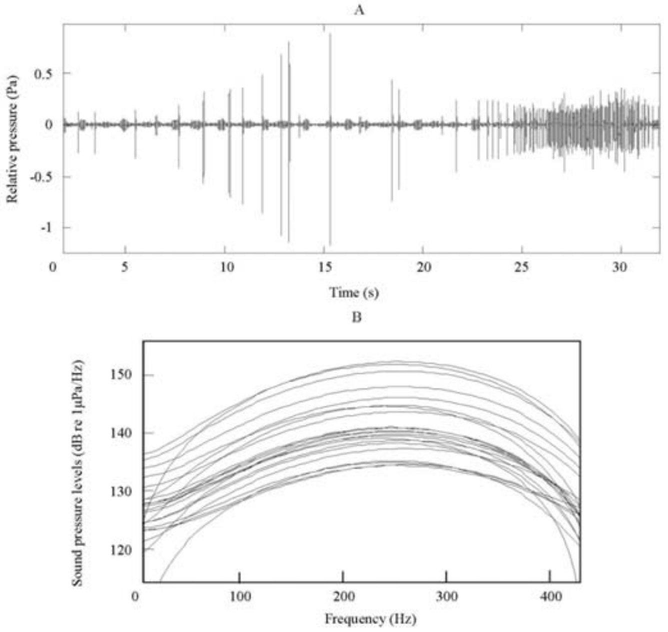

Figure 4. Waveform of a series of short calls recorded in 18.3 m of calm water at 19:35 on March 8th, 2008 (A). Example frequency spectra of the first two waveform cycles from 22 calls to highlight the likelihood of an individual caller (B).

Caller range

Figure 5 displays the caller range as determined by the four techniques, together with the maximum and minimum estimated ranges due to varying water depth from surface waves and possible pressure variation due to scattering. The received SPL of each call are also shown for comparative purposes as an indication of relative range, assuming calls were of constant source level [46]. With the exception of two calls ranged by technique 3, the four ranging techniques positioned the fish between 1 and 16.5 m from the hydrophone (Figure 5). All techniques ranged the fish as approaching and then departing from the hydrophone over time at a comparatively constant rate. Additionally, the mean water-column elevation of the caller to the receiver from the vertical was 96.9° (±7.1° s.d.), confirming that the caller was positioned on or very near the riverbed.

Transmission loss

During the call series, the trend in received call SPL declined by approximately 30 dB re 1μPa. If transmission losses were due only to spherical spreading, this difference in SPL would imply that the range of the farthest call was approximately 30 times that of the nearest. The relationships between the received call SPL and the caller range, as determined by each technique, are shown in Figure 6. This figure displays the least-squares-regression fit curves (and 95% c.l.) for call SPL and log(r) relationships for each technique in the form of:

$$RL\ (\text{dB re } 1\mu\text{Pa}) = SL\ (\text{dB re } 1\mu\text{Pa}) - TL \tag{7}$$

where RL is the received SPL, SL is the source level and TL is the transmission loss.

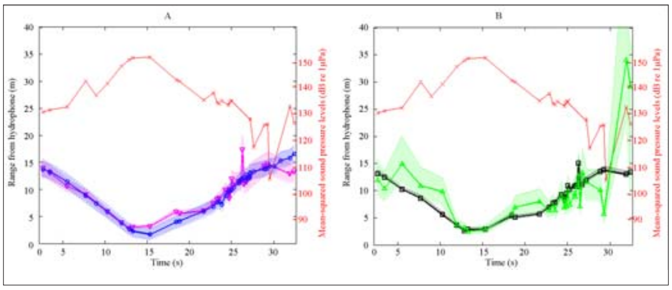

Figure 5. Range variation of recorded calls against time, as calculated by time-arrival differences (○, blue line, A), combined time-arrival/pressure amplitude ratio (△, magenta line, A), pressure amplitude ratios (□, black line, B) and mean squared SPL ratios of direct and surface reflected pulses (▽, green line, B). Maximum and minimum determined ranges caused by variation in water depth (time-arrival, pressure amplitude and SPL methods) or 10% variation in surface reflected pressure amplitude (combined time-arrival/pressure amplitude method) are shown by the shaded regions. SPLs of each call with time are also shown (x, red line).

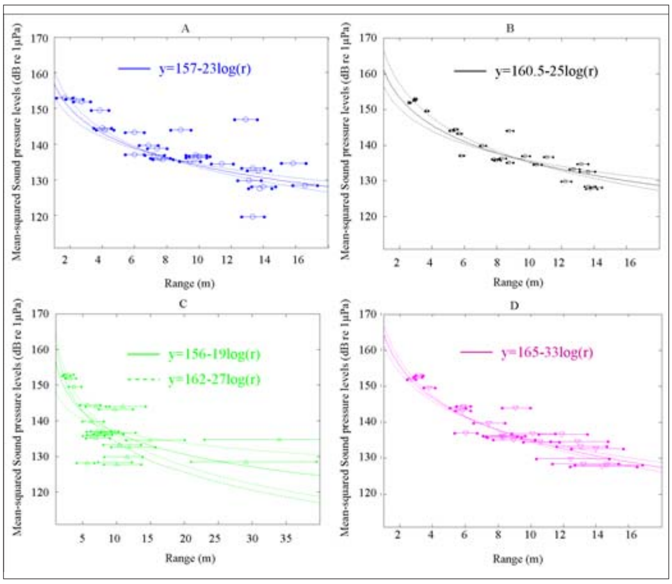

Figure 6. Relationship between mean-squared SPLs and range as calculated using time-arrival differences (A, ○), waveform amplitude ratios (B, □), mean squared SPL ratios of direct and surface reflected pulses (C, ▽) and combined time arrival/pressure amplitude ratio (D, △). Continuous lines show the least squares regression fit (with 95% c.l., dotted lines) for received SPLs with range to illustrate the transmission losses estimated by each technique. Dashed line in C represents the least squares regression fit with two calls of possible interference removed.

These plots illustrate that the relationship between call SPL and range calculated from technique 1 (Figure 6A) displayed the greatest similarity to spherical spreading (20log(r)). Although technique 3 estimated similar losses of 19log(r), once the final two call-range estimations were removed this changed dramatically to 27log(r) with an improved Pearson correlation (r^2 = 0.65, compared with 0.50). Estimated ranges using technique 2 and 4 produced transmission losses of 25log(r) and 33log(r) respectively (Figure 6B and 6D).

Technique 1 positioned the fish at minimum and maximum ranges of 1.6 and 16.5 m, compared with 1.3 and 13.6 m for technique 2, 1.2 and 32.2 m for technique 3 and 2.6 and 14.6 m for technique 4. All techniques displayed estimated transmission losses of greater than spherical spreading, however, only the arrival-time and pressure amplitude methods were within practical limits displaying transmission loss curves of less than 25log$r$ [45].

Surface reflection

The similarity between a swimbladder pulse direct path and the surface reflected signal is shown in Figure 3B by the magnified, phase inverted signal. This similarity indicates that there was no frequency shift in the spectral content of the surface reflection, which was typical of all the analysed calls. However, in calls of greater range there was, on occasion, visible interference between the surface reflection and direct paths of successive pulses.

DISCUSSION

This experiment has shown that for short, close-range (<20 m) signals, which contain a discernible initial pressure peak, all four ranging techniques provided similar estimates of caller range. Over the course of 43 analysed calls, the estimated ranges were similar to that expected by consistent, straight-line movement by an individual fish. The comparison of estimated range and received SPLs of complete calls illustrated that estimated transmission losses, determined using the caller ranges, were within practical working conditions [45].

Technique comparison

The relationship between determined range and complete call SPL illustrated that technique 1 provided range estimates which most closely resembled transmission losses to spherical spreading compared with the other techniques. However, this technique requires an *a priori* estimate of the caller depth not often available when locating fish.

Technique 2 also provided range estimates which varied consistently with time. However, although these ranges displayed high correlation with the least-squares-regression-determined losses (due to interference, likely between the waveform tail of the direct path and the peak of the reflected path), fewer calls could be used to estimate range

Technique 3 displayed greater variation in estimated range from the transmission-loss curve than other techniques, particularly at greater ranges (Figures 5B and 6C, green line). Similar to technique 2, this variation was likely due to interference, with increased effect with range as the path difference between direct and surface reflected paths was reduced.

Transmission loss

McCauley [20] reported minor levels of frequency shift in the surface reflections of Terapontidae calls, possibly due to loss of lower-frequency energy through the reflected path. If present, this scattering or energy loss would have significant effects on the range estimates from the energy techniques, producing a range estimate shorter than the actual position. The similarities between the direct and surface-reflected waveforms (Figure 3B) highlight that frequency shift was not evident in the calls analysed during this study.

Recommendations

Technique 4 eliminates the assumption of caller depth. However, with increased range the likelihood of interference between the direct and surface-reflected paths will still affect the range estimate. Therefore, when using a single hydrophone the authors propose that a number of techniques, applying different acoustic characteristics, are used to estimate the range of fish calls. The inclusion of technique 4 helps provide an estimate of the caller depth to confirm assumptions made using technique 1 alone.

SUMMARY

The calls analysed in this study were produced at close range in shallow water. McCauley [20] employed similar techniques to range the calls of Terapontidae in similar water depths, with sufficient signal-to-noise to estimate range. However, as range or water depth increases it is likely that fish-call signal-to-noise ratios of surface-reflected paths (and possibly the direct path) decrease and are less likely to be sufficient to estimate range. Additionally, the reduced arrival-time difference of calls at greater range results in overlap between the waveform of the direct and surface reflected path of the pulse, causing interference between the two waveforms [35-37]. These limitations mean that the application of ranging fish using call surface-reflection techniques is not only dependent on the call structure and intensity, but also the relative dimensions of caller, receiver and water surface positions.

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Acoustics 2011

BREAKING NEW GROUND

Gold Coast

Australia

The Australian Acoustical Society conference in 2011, ACOUSTICS 2011, will be held from 2-4 November at the Holiday Inn in the heart of Australia's favourite holiday destination on the Gold Coast, Queensland. The conference theme, Breaking New Ground, is based on the recent boom in large infrastructure projects. Major infrastructure for transportation, industry and mining present challenges in noise and vibration, whether these are in assessment, modelling or mitigation or in the need to provide appropriate legislative and regulatory frameworks. This conference will break new ground as delegates review recent developments and address the challenges and opportunities presented by the construction and operational phases of such infrastructure. Other major topics for the conference will include Underwater Acoustics and Architectural and Building Acoustics.

Authors are encouraged to prepare papers from all areas of acoustics and to submit abstracts by the end of March 2011. The Trade Exhibition will provide an opportunity for the latest technology to be displayed and sponsorship opportunities are available. Details can be found on the conference web site at http://www.mech.uq.edu.au/acoustics2011/.

A series of workshops that will focus on aspects of transportation noise and a short course on fundamental acoustics are also planned.

Congress Plenary speakers will include Dr David Hiller (ARUP) and Professor David Thompson (ISVR, University of Southampton). ACOUSTICS 2011 is shaping up to be a very exciting conference.

For further enquiries, contact the conference chair, Matthew Terlich, at mterlich@savery.com.au