Acoustic modification of tilapia behaviour

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ABSTRACT

Cichlid fish utilise sound to dominate conspecifics. The aggressive behaviour is thought to induce stress in males reducing reproductive success. A pilot project was developed to assess if sound could modify the behaviour of male Mozambique tilapia (*Oreochromis mossambicus*). 'Mouth fighting' (brief encounters involving the grasping of combatants jaws, a brief push-pull swimming behaviour associated with sound production) were observed and acoustically monitored in a small lake in the centre of Cairns, North Queensland. The exchanges were part of longer term agonistic chorusing between males defending adjacent territorial areas that were concluded by a 'terminating sound' from one male (the last sound in a series that was substantially greater magnitude than any other) that stopped sound production in the other male fish for several minutes. Agonistic exchanges could begin again although between different adjacent males defending territories. A 'terminating' sound generated by a male that was a clear winner of an agonistic exchange was used in a single playback experiment using a 50 watt amplifier and 10" subwoofer set in an air tube extending into the water. Communication by males over a wide area of adjacent territories immediately ceased yet a male *O. mossambicus*, larger than any previously observed, responded with physical confrontation to the sound source and generated agonistic sounds of shorter duration yet comparable intensity to the amplified sequence. The waveform envelope of the response sound was substantially different suggesting capability for variable responses to sounds. Potential exists for exploring the possibility of population control of this feral fish by utilising acoustic calls to interrupt social and reproductive behaviour. The project objective was to search for a sound that could be used to interfere with male social and reproductive communication and behaviour, as an attractant to males / females with relevance to an acoustic baited trap.

INTRODUCTION

The utilisation of sound to modify the behaviour of fish was reviewed by Popper & Carlson (1998). Applications included exclusion from volumes of water associated with water intakes or to mitigate movement of invasive species

The cichlid fish the Mozambique tilapia (*Oreochromis mozambicus*) is recognised as a feral species throughout Queensland (Webb 2008). Extreme concern exists for infestations spreading throughout the Murray Darling drainage and drainages into Northern Territory. Currently poisoning and electrofishing are used as mitigation schemes with significant cost and collateral damage issues to native fauna.

Cichlids demonstrate the widespread use of sounds during courtship and social interactions (Myrberg, Kramer & Heineke 1965, Lobel 2001). Amorim & Almada (2005) noted territorial males produced sounds during male–female and male–male courtship interactions, and during nest related activities.

Marshall (1972) investigated relating sound to modification of reproduction of cichlids, namely *the role of male Tilapia mossambica* sound production in stimulation of oviposition where females were exposed to playbacks of male courtship sounds or to a control of white noise. Females exposed to control sounds took days longer to mature and lay eggs than the females exposed to male courtship sounds.

Shortly after *O. mossambica* was introduced as a feral species in Australia, Lanzing (1974) noted tonal short duration sounds with harmonics at least extending 1-16 kHz and reported sound production by fry 2-3 weeks of age in aquaria. Human approaches to the proximity of the aquarium housing the fish resulted in a cessation of acoustic behaviour.

Canfield & Rose (1996) demonstrated that a cichlid species responded to sounds that featured an onset of either a com-

pressive or rarefying signal pressure or particle velocity. The direction of an initial avoidance response was shown to depend on the time and distance between the source generating either compressive or rarefying signals. A laboratory outcome for tilapia individuals, irrespective of sex, could be an initial response direction by sound type.

Amorim & Almada (2005) examined short aggression contests between male *O. mossambicus* no larger than 15 cm in Total Length (TL) and described agonistic behaviour between males including mouth fighting (brief encounters involving the grasping of combatants jaws, a brief push-pull swimming behaviour) although no sound was described associated with this behaviour. The winners of aggression encounters when transferred to a tank with a ripe female fish immediately commenced spawning activity involving sound production, courting poses and participation in spawning activity. The losers of the contests engaged in courtship activity with greater latencies and definably different sound characteristics. Amorim & Almada (2005) did not record acoustic activity during the initial male aggression encounters although Brown & Marshall (1978) had described both mouth fighting and its associated sound production.

This project was a pilot study to investigate the potential for an acoustic-based mitigation strategy for *O. mossambicus* within the shallow drains and lakes in the North Queensland region. The project proposition was that exposure of male fish to "winning" type aggression sounds often in the absence of visual aggression inputs could influence reproductive capability.

The objective was to search for a sound that could be used to interfere with male social and reproductive communication and behaviour and subsequently between females / juveniles as appropriate. Developments of an acoustic baited trap could be an additional component for tilapia mitigation.

METHODS

Study site.

The site for this specific study was the freshwater lake of the Centennial Lakes in the city of Cairn's Botanical Gardens (Queensland, Australia, 16º54' 10.41E; 145º44' 56.73E).

Opportunistic sampling occurred between August 2007 and September 2008. Approximately 300 hours of multi channel hydrophone data were obtained.

Water depth varied 0.2 to 0.5 m in the immediate study site, dropping off to at least 3 m in the centre of the lake 10 m from the bank. Most sounds were <100 Hz where wavelength would be ≈15 m. Sound propagation was poor with most wavelength and depth combinations well below the cut-off frequency of propagation (Urick 1983; Forrest, Miller & Zagar 1993). Water clarity was usually <0.5 m cm based on underwater camera object resolution. Fish detection from the surface was limited to a water depth of 0.5 m along a shelf around the rim of the lake. No detection was possible in the deeper areas of the lake covered with water lilies. Around the lake rim *O. mossambicus* males constructed shallow nests cleared in the flocculent vegetable material substrate. Hydrophone cables through the study site had 5 cm graduation marks to assist with fish size estimation.

Equipment.

Recordings were made using High Tech Inc HTI-MIN-96 hydrophones (30 kHz dynamic range with manufacturer's hydrophone sensitivity of -165dB re 1 μPa/1 Volt). Two to four track recordings were made Zoom H2 and Edirol R4 recorders sampling at 48 kHz with a bit depth resolution of 24. Acoustic analysis was performed using Cooledit ver.2 software, RavenPro ver.1.3 software, SpectraPro software and Matlab based noise reduction routines written by Craig McPherson (JASCO Applied Sciences). Temporal features of signals were measured from oscillograms and sound peak frequencies from power spectra based on 512 to 4096 point FFT with a Hamming window applied. Relative Sound Pressure Level data are given in units of dB re 1μPa (rms units).

Sound types recorded

Sounds generated by large males approximately 30-35 cm TL were matched whenever possible in real time to gross body movements such as rapid orientation to the direction of a stimulus, physical body contact such as mouth fighting and abrupt changes in position around a nest by territorial males. These sounds were acoustically comparable to the agonistic 'thumps' described for the rainbow cichlid by Brown & Marshall (1978) with comparable behaviour although for fish <10 cm in TL.

Sounds associated with males clearing nest substrates or chewing vegetation were recorded but not included here. Smaller males and females were rarely seen at this site during agonistic bouts between males although some sounds comparable to male-female courtship sounds of Brown & Marshall (1978) and Amorim & Almada (2005) were detected.

Playbacks

For playbacks, a 10" sub-woofer speaker was placed in an enclosure of 25 mm thick timber with sealed joins following manufacturer's instructions for optimum backing air volume. The sub-woofer cone was placed over an open 225 mm

diameter PVC pipe (Figure 1). The complete speaker box weighed 8 kg.

Figure 1. Playback study site water depth approx. 30 cm. Sound source is within green box and projects into the PVC tube pushed into the water and substrate. Tilapia are shown (solid arrows), nests (dashed arrows) and hydrophone positions (#1 and #2 as circles).

The PVC pipe was pushed into the substrate until the open face of the speaker cone was directly above the water surface inside the pipe. The speaker was wired to a 50 Watt 12 volt amplifier on the bank then to a laptop driving the playback.

The *O. mossambicus* sound selected for playback had been associated with an acoustic and behavioural bout involving mouth fighting territorial males. The sound was high pass filtered at 500 Hz, background noise reduced, digitally amplified by 10 dB and saved as a wav file (48 kHz, 24 bit). The playback sequence was 10 repeats of the 1 second long signal with 900 msec between the 'thump' sound. The playback was constrained to a single playback.

Sound Transmission Loss was assessed from trials to be in the order of 60 log R. The loss rate was not unexpected based on the predictions of Urick 1983 and Forrest, Miller & Zar 1993 for shallow gas laden substrates.

RESULTS

Male agonistic 'thump' sounds.

The 'thumps' from the Cairns wild fish were visually associated with males on adjacent nests and surrounding substrate around nests. In this study wild fish varied in length 25-35 cm TL and the nests they defended could be up to 1 m apart. Males were observed to immediately respond to a 'thump' from a male on an adjacent nest by orienting longitudinally in that direction at well above underwater visibility range. Some males would slowly approach each other directly until final orientation would most likely have been visual. At this stage fish would slowly make a final close approach with open mouths and touch or clasp mouths briefly. At this stage a single 'thump' would often be detected. Few, if any, instances occurred for two 'thumps' closely coinciding in time suggesting simultaneous generation from two fish.

Wild fish at a size 25-35 cm TL displayed a keen perception of observers walking on the bank. Sounds of footsteps of observers on the bank would immediately modify *O. mossabicus* behaviour. As the purpose of this project was acoustic and not behavioural, observation obtaining uninterrupted acoustic data was vital. An unobstructed view of a field association between acoustic activity and observed behaviour was often not possible due to the need for observer to remain hidden, and the availability of abundant vegetation to

the fish for cover. These constraints would not occur in aquarium conditions yet fish to 35 cm TL could not be maintained in aquaria.

The 'thump' sounds displayed a complex variation of signal envelopes with most energy <200 Hz. A variety of 'thumps' were recorded from the same hydrophone over a 10 second time period (Figure 2). It is likely that more than one animal made the sounds as most nests were adjacent to others, each with an attendant male. Background energy is from an airport 1500 m away.
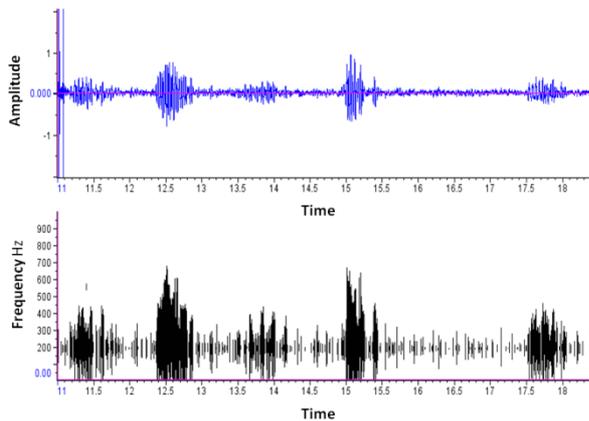

Figure 2. Examples of 'thump' sounds. Upper panel is time domain Y-axis relative amplitude: Lower panel is frequency domain Y-axis: X-axis time).

While females did not remain in nest areas for long periods they would, on occasions, move past or briefly toward a nest with an attendant male (Figure 3). Fish interactions around nests occurred but were rarely monitored closely.

Figure 3. *O. mossambicus* male (left, with pale lower jaw and red margins to fins) and female (centre right, dull markings) adjacent to the nest defended by the male.

In observed cases where females were in close proximity to males defending nests a short pulsed male-female courtship sound was recorded (Figure 4). Agonistic 'thumps' could not be confused with courtship sounds.
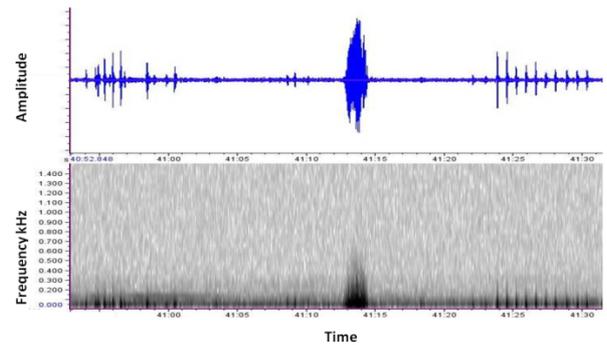

Figure 4. Example of 'thump' (centre) and male-female courtship sounds. Y-axis relative amplitude in time domain and frequency in frequency domain; X-axis time.

The signal envelope of the 'thump' signal demonstrated considerable variability from a symmetrical to an asymmetrical waveform envelope structure including variable rise times and highly variable trailing fall times including isolated highlights. The time and frequency analysis domain parameters of the 'thumps' from this study are compared to the 'thump' pattern published for the convict cichlid of Brown & Marshall 1978 (Table 1). The mean duration of the sounds for *O. mossambicus* from the present study are more than twice those of Brown & Marshall 1978 for much smaller average length convict tilapia. The *O. mossambicus* featured a longer minimum observed time and a maximum time more than three times longer. While data are not fully comparable, the 'thump' frequency is substantially lower.

Table 1. Comparison of 'thumps' of convict cichlid of Brown & Marshall 1978 with *O. mossambicus* 'thumps' for the present study.

Parameter	Brown & Marshall (1978)	This study
No. Sampled	100	100
Duration of sound		
- mean in msec	93	246
- range in msec	27-225	112-775
Frequency (Hz)		
- mean in Hz		40-60
- range in Hz	85-1250	<300
Fish size (est. cm TL)	9-12	30-45

Sound chorusing

Males defending nests conducted a continuous acoustic chorusing campaign against individuals on adjacent nests. Nest substrate positions tended to present a close packed type configuration with variations dictated by aquatic vegetation and bottom topography. Two hydrophones were usually positioned within 20 cm of each of two nests of interest, and often two others were placed further from the nests and potentially closer to other nests. It was never clear which nests would be defended when the hydrophones were being deployed. Up to four hydrophones were recorded simultaneously. Once hydrophones were deployed, recordings did not commence for at least 1 hour.

These 'Thumps' sounds would be attributed to the nearest hydrophone based on recorded intensity. Sounds were rarely detected on the more remote third and fourth hydrophones. A 'thump' would be attributed to a channel based on intensity

and marked with a pale blue identification on the oscillogram recording in Figure 5 and 6.

Chorusing males would spasmodically generate agonistic threats from the vicinity of their nest. In Figure 5 the male near hydrophone #1 generated a few 'thumps' in the five minutes prior to the loudest recorded 'thump' A few low amplitude 'thumps' were generated immediately prior to the highest amplitude 'thump' as an apparent response to a cluster of 'thumps' shortly before. The generation of the high amplitude 'thump' appeared to coincide with mouth fighting behaviour.

Figure 5. Time domain views of two hydrophone channels (#1 above, #2 below) of the 5 minute period prior to, and including, an exceptionally high amplitude 'thump' at the end of the 5 minute period. 'Thumps' are assigned to hydrophone channels based on received Sound Pressure Level.

The five minutes of acoustic data after the highest intensity 'thump' is shown in Figure 6. The male that generated the most intense 'thump' engaged in a bout of lower intensity 'thumps'. The receiving male generated a few scattered 'thumps' over the next few minutes.
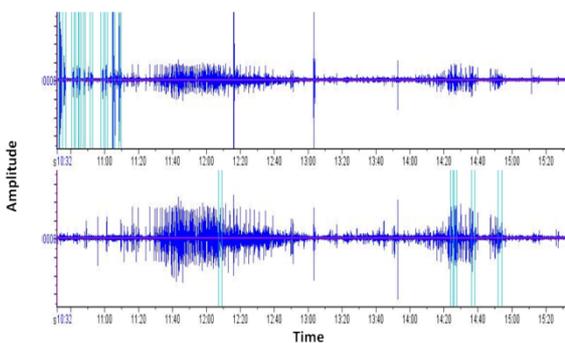

Figure 6. Time domain views of two hydrophone channels of the 5 minute period after, and including, an exceptionally high amplitude 'thump' at the start of the 5 minute period. 'Thumps' are assigned to hydrophone channels based on received Sound Pressure Level.

The second hydrophone channel recorded a few isolated 'thumps'. It was not determined if the 'thumps' were generated by the loser of the acoustic bout and directed towards another male on another nest or if the 'thumps' were generated by a male on a remote nest directed toward the loser of the previous bout.

The most intense 'thump' in this event and for other commonly detected events for *O. mossambicus* is referred to here as a 'terminating thump'. While 'terminating thumps' were

not uncommon in this study several general waveform envelopes were observed. Waveform envelopes varied considerably in duration by a factor or at least three, asymptotic to asymmetrical with multiple isolated trailing highlights. Three general 'terminating thumps' are presented in Figure 7.
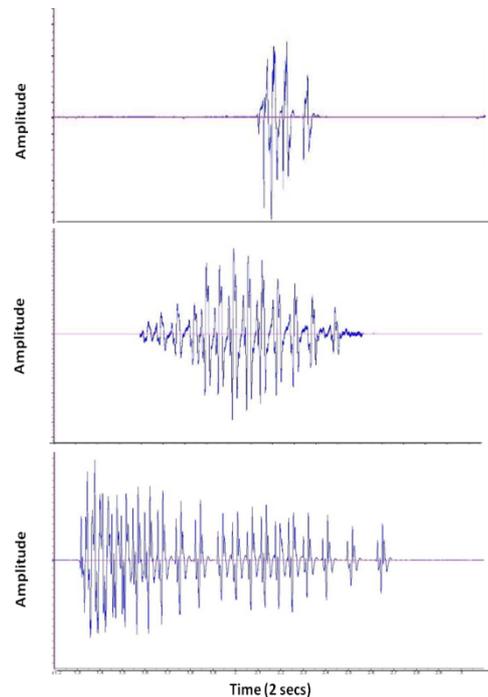

Figure 7. Examples of *O. mossambicus* 'terminating thump' sounds. Sounds varied in waveform envelope and additional isolated highlights. Amplitude levels and time units have been standardised. (Y-axis relative voltage, X-axis 2 secs time)

Sound playback – 'terminating thump' selected

An assumption was made that a 'terminating' thump' may provide potential in playbacks for acoustic modification of tilapia reproductive behaviour. The second 'terminating thump' signal in Figure 7, the symmetric 'thump' was selected. The thump was further noise filtered and digitally amplified 10 dB.

Sound playback - acoustic activity before initiation of playback sequence

The playback arrangement described in Figure 1 was established at a site where no acoustic monitoring had occurred for at least a week. The observer left the immediate area for an hour returning to the cover of a bank of shrubs some time before the commencement of playback.

Acoustic recording commenced when acoustic exchanges between two males adjacent to each hydrophone at nest/hydrophone #1 and #2 respectively were detected. The five minute period prior to the initiation of the playback signal is shown and the 10 playback sequences shown. As per Figures 5 and 6 the most intense 'thump' sound was attributed to the channel of recording based on received amplitude and marked in blue. The intensity of the playback sequence is slightly higher in channel #2 indicating that the hydrophone #2 was slightly closer to the playback source as shown in Figure 1. The distance differential would have been no more than 20 cm.

The fish nearest hydrophone #1 appeared to be a little more agonistic over the five minute period although the fish near hydrophone #2 did make a burst of some agonistic 'thumps'. No mouth fighting was observed during this period. Both fish were estimated to be 30-35 cm TL.
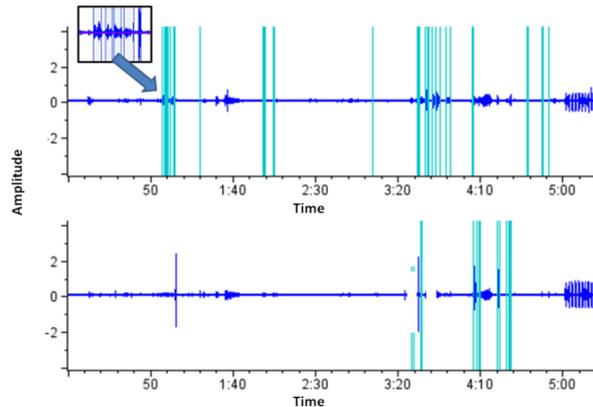

Figure 8. Time domain views of 'thumps' from two hydrophones of the 5 minute period prior to, and including, the playback sequence. Thumps are assigned to hydrophone channels are based on received Sound Pressure Level.

Sound playback - acoustic activity after initiation of playback sequence

As with normal chorusing events in following initiation of a 'terminal thump' in Figure 6 the playback sequence was followed by a number of 'thumps' recorded by one hydrophone and a marked decline in 'thump' events recorded by the other hydrophone (Figure 9). Behaviourally, following the playback sequence, both male fish retreated immediately to their nests.
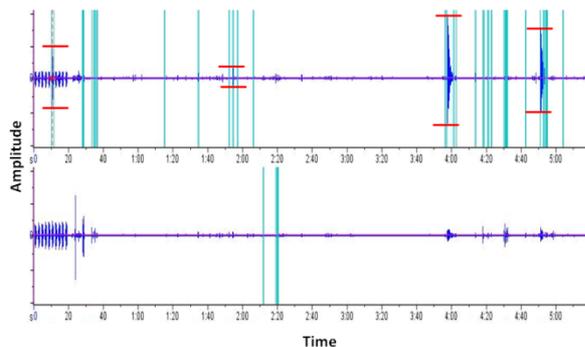

Figure 9. Time domain views of two hydrophone channels of the 5-minute period after, and including, the playback sequence. 'Thumps' are assigned to hydrophone channels based on received Sound Pressure Level. The extent of the acoustic responses of the higher amplitude 'thumps' are shown by red horizontal marks.

'Thump' sounds were effectively restricted to one channel. In the other channel a scant two 'thumps' were recorded and at such low amplitude that the source may well have been from a nest further away in the lake.

The playback sequence itself was profoundly dominated by a single immediate acoustic response during the playback, and two delayed higher amplitude delayed acoustic responses some minutes later. The delayed acoustic responses at least were associated with the sudden arrival between the nests and

hydrophones of a fish larger than any other seen over the one-year monitoring period. The fish was estimated to be approximately 40-45 cm TL. Fish of this size were locally reported from the study site where Cairns residents had caught and filleted fish overnight leaving the fish frames available for opportunistic length assessment. *O. mossambicus* is anecdotally known to occur to 50 cm in Queensland lakes.

A numerical summary of the sound generation behaviour of all three fish in the five minutes before and the five minutes after the initiation of the playback sequence registered in both hydrophone channels (‖) is presented in Table 2. 'Thumps' are assigned to hydrophone channel. The three dominant responses are also included although they do not influence the overall number of acoustic bouts.

Table 2. Thumps recorded on two hydrophones in the five minutes prior to, and after, initiation of the playback sequence (‖). Thumps are assigned to hydrophone channel based on highest SPL.

Channel	5 minutes BEFORE playback sequence by 1 minute period					
	5	4	3	2	1	
1	2	6	1	8	4	
2	0	0	0	2	6	‖
Channel	5 minutes AFTER playback sequence by 1 minute period					
		1	2	3	4	5
1		9	5	0	6	13
2	‖	2	0	2	0	0

Most 'thumps' in the period before the playbacks were attributed to the male near nest/hydrophone #1 with a burst of 'thumps' from the male near nest/hydrophone #2 immediately before the playback. Following the playback sequence of the 'terminating thump' further generation of 'thumps' were almost entirely restricted to a single channel. However, at the initiation of the playback sequence both males had immediately retreated to their nests and away from both hydrophones.

With the original two male fish retreating to their nests the high amplitude initial response during the playback, and definitely the two high amplitude 'thumps' recorded some minutes after the playback were most likely from another source. The arrival of the third fish approximately 40-45 cm TL between both hydrophones (closer to #1) was the most likely source of the high amplitude 'thumps'.

Characteristics of the tilapia responses

The initial response to the playback was recorded at relatively high amplitude of shorter duration than any one of the playback 'terminal thumps'. It occurred 12 seconds into the full playback sequence. It overlapped the generation of the sixth replay of the 'terminal thump'. The waveform envelope of this initial response is compared in Figure 10 where the uninterrupted fifth playback sequence is shown followed by the sixth playback sequence being overwhelmed by the fish 'thump'.

The exact source of this sound was not known. The large 40-45 cm fish had not been observed at this stage although it may have been nearby under the cover of water lilies or light reflection off the water surface.
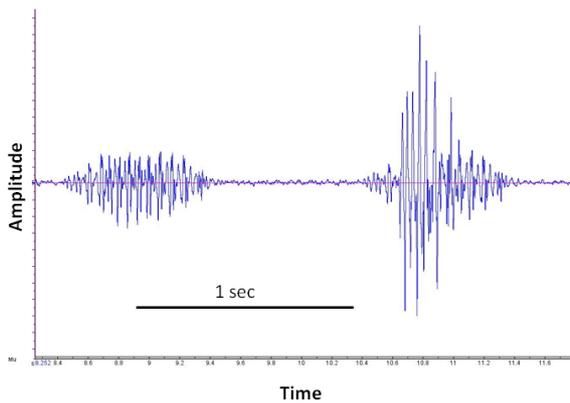
Figure 10. 5th playback sequence 'terminal thump' sound (left) compared to the tilapia initial dominant response overwhelming the playback of the 6th occurrence of the 'terminal thump' in the (right).

The delayed dominant response (first occurrence) from Figure 9 was definitely associated with the observed arrival of the 40-45 cm fish TL between the hydrophones. The fish was noticed in the study area approximately 3 minutes 40 seconds after the playback sequence stopped. The delayed dominant response (first occurrence) was compared in Figure 11 to a normal 'thump' recorded some 10 minutes before the playback routine. Observers had remained hidden for that time which may have also influenced the appearance of that fish in open water between the two nests and in front of the playback source.
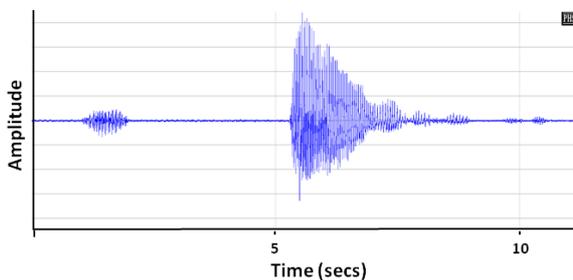

Figure 11. Comparison of the last sound of the playback sequence (left of figure) from Figure 9 channel#1 to the dominant response after the playback sequence from Figure 9 channel #1 (right of figure). Four minutes of time have been removed from the recording.

At 45 seconds after the delayed dominant response (first occurrence) another high amplitude delayed dominant response (second occurrence) 'thump' was detected (Figure 9). Acoustic monitoring for another 5 minutes after this delayed dominant response did not reveal any more 'thump' sounds. The large 40-45 cm TL fish was not observed again and the two smaller 30-35 cm TL fish generally remained in their nests.

Frequency composition of dominant response

A spectrogram view comparison between a representative 'thump' sound (recorded some 10 minutes prior to the playback experiment) and the dominant response thump to the playback (from Figure 11) is shown in Figure 12. Peak power of the response occurred a short time into the response and attained all power at ≤ 300 Hz with a likely peak approximately 40-60 Hz.
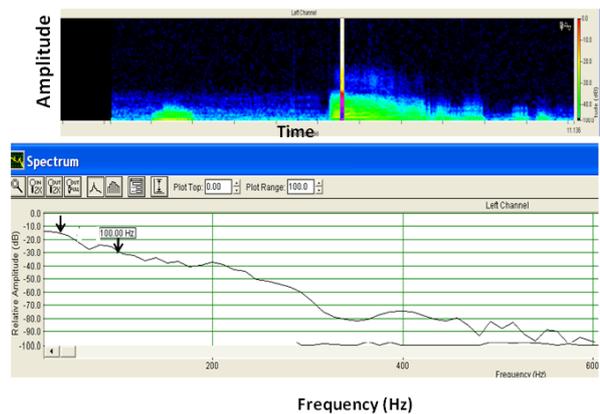

Figure12. Frequency domain Spectrogram (upper panel), comparison of playback and response, and relative Spectrum view (lower panel) of the highest amplitude segment of the dominant sound. Marks at 40 and 100 Hz.

DISCUSSION

The present study determined that the tilapia *O. mossambicus,* a declared feral pest in Australian waters (freshwater and observed in coastal seagrass areas), utilises sound communication in social and reproductive strategies. This in itself was not new for the family of cichlid fishes, nor for this species since its introduction into Austraia waters in the early 1970's (Lanzing 1974).

Agonistic sounds defined as 'thumps' were described for north Queensland *O. mossambicus*. The thumps were consistent in waveform envelope shape with those described by Brown & Marshall (1978) for convict cichlids although they were substantially of longer duration and of lower frequency. That may be as the present study was conducted in the wild with fish 2-3 times larger. The 'thumps' were clearly different in character to male-female courtship sounds described by other authors for cichlids.

Male fish defending nests generated 'thumps' when engaged in long distance (at least 1 m) acoustic exchanges between fish on adjacent nests sometimes culminating in brief mouth fighting (physical contact) behaviour. In this preliminary study, it was not always clear which males generated the final acoustic signal in a mouth fighting exchange. It would seem parsimonious to suggest that the winner of the mouth fighting exchange based on its dominant manner was the generator of the sound. That sound is referred to here as a 'terminating thump' of a mouth fighting exchange.

Playback of a dominant 'thump' did at least appear to have an initial terminating effect on the two males previously chorusing adjacent to the sound source. Amorim & Almada (2005) did not investigate sound production during mouth fighting bouts for *O. mossambicus* but did demonstrate that the winners of these agonistic bouts were more successful in subsequent reproductive encounters in the order of days. Potential for playback to influence fish acoustic if not reproductive fitness was identified.

An assumption was made from this investigation that a 'terminating thump' from normal acoustic exchanges leading to mouth fighting might offer best potential as a sound that could generate acoustic modification of tilapia reproductive behaviour. The second 'terminating thump' signal in Figure 7, the asymmetric sound, was selected. The thump was noise filtered and digitally amplified by 10 dB, amplified with a 50 watt amplifier and 10" subwoofer amplifier.

The single playback exposure result provided a dramatic result. A particularly large fish, larger than any fish observed during the one year study, became obvious to observers and made an aggressive behavioural movement and acoustic response in the volume of water immediately in front of the playback equipment and hydrophone. Effectively, a fish of approximately 45 cm TL rushed up to an imposing inanimate object towering over the water surface, much as a two story loud speaker tower would appear to a person, and yelled at it with an overpowering conviction. As a byproduct of this behaviour agonistic interactions involving acoustic exchange and physical behaviour between two males in the same vicinity, was stopped for at some time after the playback.

O. mossambicus of 40-45 cm TL were present in the lake but were rarely seen. It was clear that the acoustic playback attracted an animal of this size to the proximity of the playback source. The fish generated a strong acoustic challenge and physical/approach response comparable to an exaggerated version of normal behaviour between smaller males to a novel and inanimate object. It would appear that the acoustic challenge of the playback appeared to be an acoustic threat worth answering by a male from outside the immediate experimental area, which could respond effectively, and apparently did.

The playback observations of this investigation were based on a single playback event that should attract appropriate caveats. Variation exists in the temporal envelope of the sound type used by chorusing males to settle agonistic bouts. It appears that there may be a degree of variation to the repertoire of agonistic 'thumps' available to *O. mossambicus* used for social and reproductive aggression in *O. mossambicus*.

The playback appeared to exaggerate responses normally observed between normal agonistic chorusing and mouth fighting behaviour where one fish acoustically dominated the other. Taking the observations of Amorim & Almada (2005) into consideration it is most likely those losers of the acoustic 'thump' bouts associated with mouth fighting events would be, temporarily at least, males with reduced reproductive capability.

The long term effect on the cessation of social behaviour could at least be considered as sub-optimal for the species. The potential to reduce male social/reproductive communication so vitally important in the social structure and reproductive biology of *O. mossambicus* using acoustic methods, offers potential for mitigation of infestations of the species in Australian waters as part of a suite of mitigation procedures.

Hearing sensitivity of the electric yellow cichlid was tested to tone bursts and samples of recorded calls using auditory evoked potentials (Higgs, Barkley & Radford 2011). Fish were more sensitive to tones than to playbacks of call segments therefore expanding the potential range of playback sounds to influence tilapia behaviour.

Rollo, Andraso, Janssen & Higgs (2007) recognised the potential for attraction and localisation of invasive round gobies to conspecific calls in Canadian Great Lakes waters. Rollo & Higgs (2008) refined the attraction stimulus determining that playbacks of male and female biologically significant goby signals not only increased speed of approach and reduced proximity of approach but also enhanced localisation capability compared to playbacks of non-biological sounds. Their work was conducted as part of an acoustic trap development programme.

Cordo & Mensinger 2012 used hydrophone arrays to refine the seasonality and acoustic characteristics of round goby communication during spawning periods. Acoustic trapping success approached 87% while there was a differential success in targeting gravid females.

Simões, Duarte, Fonseca, Turner & Amorim (2008) observed that variations in cichlid pulse durations and pulse periods evoked differential responses in male-male and male-female agonistic interactions. The suggestion was that the type of sound used in playbacks would be important.

Amorim, Fonseca & Almeida (2003) noted an slight inverse relationship between *O. mossambicus* fish size (8 to12 cm) with signal frequency. A potential extrapolation to fish 30-40 cm in length would almost certainly make a more significantly difference to the inverse relationship. A full understanding of cichlid sound repertoire by fish size and sex would be required to optimize playback systems.

Bertucci, Attia, Beauchaud & Mathevon (2012) found that cichlid acoustic features that best distinguished differences between males were the instantaneous frequency of sounds and the modulation of pulse amplitude. These results suggested that acoustic signals could bear information about individual identity and attendance to these features would be relevant to a comprehensive acoustic trap strategy.

RECOMMENDATIONS

Investigation of sound production in Australian feral *O. mossambicus* and other cichlid species in Australian waters would refine the most suitable sounds for use in playbacks to contribute to mitigation techniques. While significant opportunity exists for male-male behavioural modification the potential for male-female, female-female and adult-fry behavioural modification has rarely been investigated. Lanzing 1974 suggested the use of sound for females and fry. Increasing the vulnerability of cichlid fry to Australian native species by engaging adults in 'unnecessary' acoustic disputes induced by playbacks would appear worthwhile investigating.

A directed acoustic approach utilising both dominant and sub-dominant agonistic sounds to subdue and attract size/sex combinations of *O. mossambicus* offers mitigation potential using an acoustic trap approach. This offers reduced environmental risk compared to current chemical methods.

ACKNOWLEDGEMENTS

REFERENCES

Amorim MCP & Almada VC, 2005, The outcome of male-male encounters affects subsequent sound production

during courtship in the cichlid fish *Oreochromis mossambics, Animal Behaviour,* vol. 69, no. 3, pp. 595-601.

Amorim MCP, Fonseca PJ & Almeida VC, 2003. Sound production during courtship and spawning of *Oreochromis mossambicus* male-female and male-male interactions, *Journal of Fish Biology,* vol. 62, no. 3, pp. 658-672.

Bertucci F, Attia J, Beauchaud M & Mathevon N, 2012, Sounds produced by the cichlid fish *Metriaclima zebra* allow reliable estimation of size and provide information on individual identity, Journal of Fish Biology, vol. 80, no. 4, pp. 752-766.

Brown DH & Marshall JA, 1978, Reproductive behaviour of the rainbow cichlid, *Behaviour,* vol. 67, no. 3-4, pp. 299-321.

Canfield JG & Rose GJ, 1996, Hierarchical sensory guidance of Mauthner mediated escape responses in goldfish (*Carassius auratus*) and cichlids (*Haplochromis burtoni*), *Brain, Behavior and Evolution, vol.* 48, no. 3, pp. 137-156.

Cordo EB & Mensinger AF, 2012, Poster – 66. Potential Bioacoustic Control for the Round Goby, *Neogobius melanostomus* , 1442nd Meeting American Fisheries Society, Minneapolis , St Paul, August 19-23.

Higgs DM, Barkley AN & Radford CA, 2011, Acoustic communication in the electric yellow cichlid, *Labiochromis caeruleus, Journal of the Acoustical Society of America,* vol. 129**,** no. 4, pp. 2435.

Forrest TG, Miller GL & Zagar JR,1993. Sound propagation in shallow water: Implications for acoustic communication by aquatic animals,'Bioacoustics vol. 4, pp. 259–270.

Lanzing WJR, 1974, Sound production in the cichlid Tilapia *mossambica* Peters, *Journal of Fish Biology,* vol. 6, pp**.** 341–347.

Lobel PS, 2001, Acoustic behaviour of cichlid fishes, *Journal of Aquaculture and Aquatic Sciences,* vol. 9, pp. 167-186.

Marshall JA, 1972, Sound production by *Tilapia mossambica* (Pisces: Cichlidae), *American Zoologist,* vol. 11, pp. 632.

Myrberg AA, Kramer E. & Heineke P, 1965, Sound production by cichlid fishes, *Science*, vol. 149, pp. 555-558.

Popper AN & Carlson TJ, 1998, Application of sound and other stimuli to control fish behaviour, *Transactions of the American Fisheries Society,* vol. 127, no. 5, pp. 673-701.

Rollo A, Andraso G, Janssen J & Higgs D, 2007, Attraction and localization of round goby (*Neogobius melanostomus*) to conspecific calls, *Behaviour, vol. 144, pp. 1-21.*

Rollo A & Higgs D, 2008, Differential acoustic response specificity and directionality in the round goby, *Neogobius melanostomus*, *Animal Behaviour,* vol. 75, pp. 1903-1912

Simões JM, Duarte IG, Fonseca PJ, Turner GF & Amorim MC, 2008, Courtship and agonistic sounds by the cichlid fish, *Pseudotropheus zebra, Journal of the Acoustical Society of America,* vol. 124, no**.** 2, pp. 1332-1338.

Urick RJ, 1983, Principles of Underwater Sound. (McGraw Hill, Baskerville, New York).

Webb A, 2008, Pest Fish in NE Queensland – actfr@jcu.edu.au.