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Carp Acoustic Attractants and Repellents

Dr Leigh Thwaites and Josh Fredberg

Invasive Animals CRC

An Australian Government Initiative

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Government of South Australia

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Dr Leigh Thwaites and Josh Fredberg

South Australian Research and Development Institute (Aquatic Sciences)

2013

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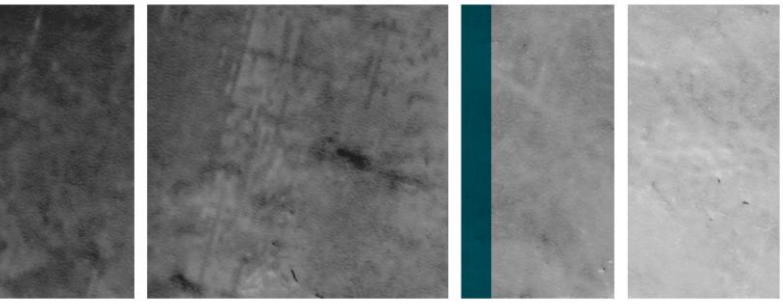

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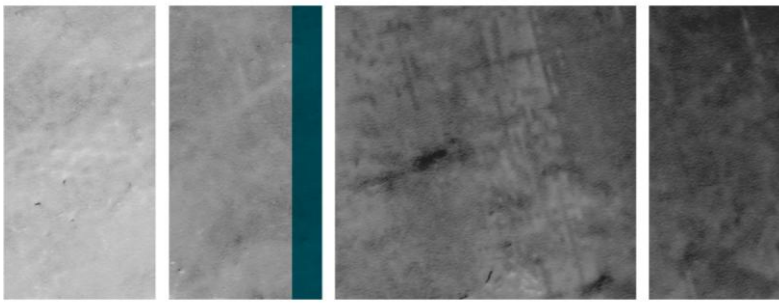
Front cover photo: Various components of the acoustic experiment (SARDI Aquatic Sciences and Google Earth)



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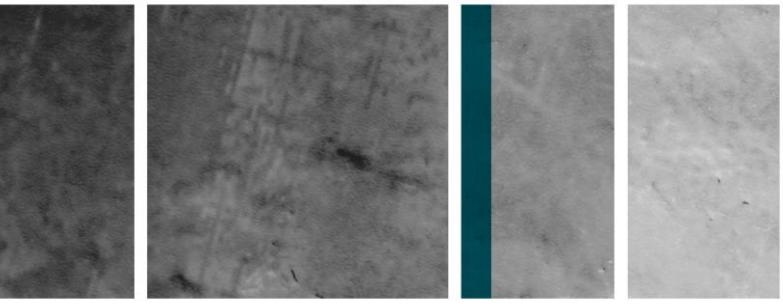

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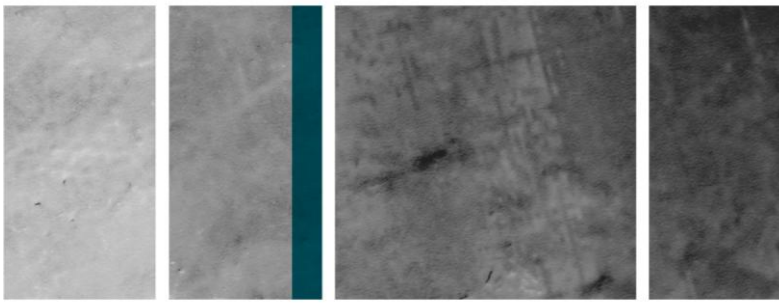

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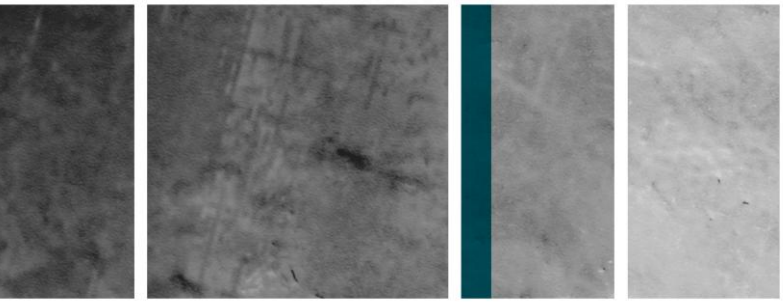
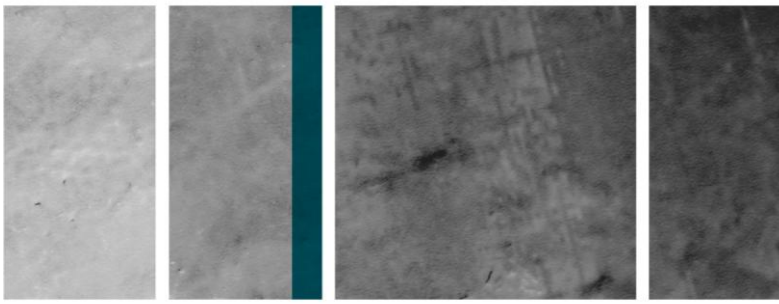
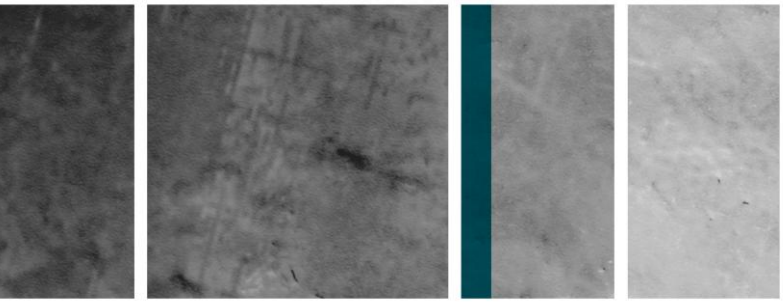




Executive Summary

Common carp (*Cyprinus carpio* L.) are hearing specialists and can detect the pressure component of sounds over a broad frequency range (up to several KHz) and at low sound intensities. Experimentally, the application of underwater acoustical equipment to reproduce 'fish' sounds has been tested on cyprinids to elicit trained responses, restrict movements and most notably, to attract and concentrate dispersed populations. Regarding the latter, carp feeding sounds were successfully used to lure carp to specific locales within baited and unbaited lakes. This behavioural response was often immediate and resulted in large aggregations of carp at the sound projector. Further, carp are positively rheotactic and will actively seek the source of flowing water. While there are several potential sensory triggers for this movement (i.e. flow, entrained scent, sound), sound can travel vast distances underwater and is therefore a key sensory component that is likely to initiate exploration for the source of flow, particularly in fish at larger distances from the source that may not yet "feel" or "smell" the flow. Notwithstanding, an attractive sound can be a repulsive sound if not played back at natural levels. While this requires careful experimentation in order to capture and replay attractive sounds at appropriate sound pressure levels (SPL) it also opens up the possibility of using acoustic repellents to dissuade fish from entering spawning grounds or to help herd fish to areas where they can be captured easily. Thus, when used in conjunction with current integrated pest management technology, acoustics may increase carp harvesting success; particularly in lentic systems (i.e. wetlands) where traditional olfactory cues (pheromones, amino acids) that rely on dispersal by flow are not effective.

The specific objectives of this study were to determine the utility of underwater sounds for attracting and repelling carp for management purposes. Two attractant sounds (carp feeding and flowing water) and one repellent sound (high, low/mid and very low frequencies coupled with explosion sounds) were tested over a series of 28 experiments at three different locations within an experimental lake. A VEMCO VPS array was used to monitor the response of eight acoustic tagged carp. This system provided positional data of each tagged carp approximately every 90 seconds. As a measure of attraction or repellence, Eonfusion 2.2 geospatial software was used to determine the time each tagged carp spent within four distances from the playback system (5 m, 10 m, 25 m and 50 m) both before and during each experimental period. Although the frequency range and calculated sound pressure levels (SPL) confirmed that all experimental sounds were played at biologically relevant levels, the results indicate that feeding and flowing water sounds have a limited effect and therefore do not appear suitable for aggregating carp for harvesting purposes. As previous successful attraction experiments on carp were conducted in clear lakes, it is hypothesised that the reported attraction could be partly attributed to the visual stimuli provided by the researchers standing at the lakes edge or sitting within a boat during the experiments. There were no visual stimuli offered during the current experiments as they were conducted in a turbid lake and care was taken to stand away from the lakes edge during experimental periods. Interestingly, the "assumed repellent" sound seemed to act as an attractant. Even though tagged carp were aggregated near the speakers by broadcast feeding prior to the repellent experiments there were distinct behavioural differences between feeding and experimental times. During feeding, carp displayed exploratory movements while during the experimental period all tagged carp formed a tight aggregation directly at the speaker. This indicates that the repellent sound or a component of the sound (i.e. mid/high frequencies) may be a useful attractant and this warrants further research.



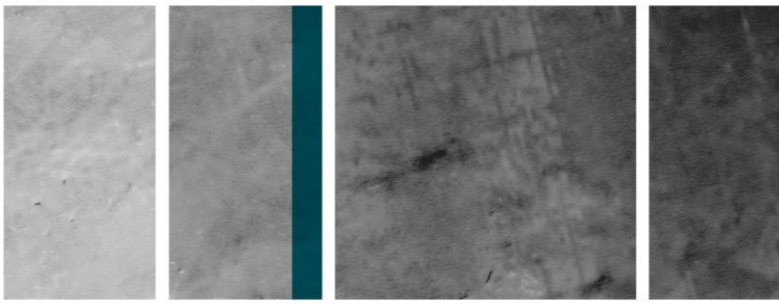
Introduction

Common carp (*Cyprinus carpio* L.) is a successful invader and a declared pest fish in several countries including Australia, New Zealand, Canada and the United States (Koehn 2004). The success of carp stems from their high fecundity (100,000 eggs.kg^{-1}; up to 1 million eggs.y^{-1}), high level of recruitment, longevity (28+ years), ability to occupy a broad range of habitats and tolerance to extreme environmental conditions (Smith 2005). When in high abundance, carp cause detrimental changes to benthic habitats, water quality and the distribution and abundance of native flora and fauna (Gehrke and Harris 1994; Miller and Crowl 2006; Matsuzaki et al 2009). These impacts stem largely from carp's bottom-feeding behaviour (Sibbing et al 1986) and are most commonly reported in shallow off-stream habitats (Parkos et al 2003) where carp congregate annually to feed and breed (Smith and Walker 2004; Stuart and Jones 2006).

Outside their native range, significant resources have been invested to develop and evaluate cost-effective and lasting strategies for their management and control. Internationally, current strategies include physical removal (Stuart et al 2006; Inland Fisheries Service 2008; Thwaites et al 2010), physical exclusion (Verrill and Berry 1995; French et al 1999; Hillyard et al 2010), bio-manipulation (Shields 1957; Yamamoto et al 2006) and chemical piscicides (Clearwater et al 2008). Genetic ('daughterless' carp; Thresher 2008) and biological (Kio herpes virus; McColl et al 2007) control technologies are also in development but they are still some years away from deployment. Despite this suite of management/control strategies, the development of new technologies is also desirable as the eventual control of carp will rely on an integrated approach (Brown and Walker 2004).

Key to the success of physical control strategies is an understanding and subsequent exploitation of innate carp behaviour. In this regard, physical control options such as carp separation cages are designed to intercept and harvest carp during their annual migration between river and off-stream habitats (i.e. Stuart et al 2006). As this migratory behaviour can result in aggregations of carp at flow control structures, river fishways and wetland inlets/outlets, large tonnages of carp can be removed cost-effectively and on an annual basis (Conallin et al 2008; Stuart and Conallin 2009). Given this success, other strategies which seek to create aggregations by exploiting the sensory ability of carp are under examination. Chemical stimulants such as pheromones (Sorensen and Stacey 2004) and environmental odours (Elkins et al 2009) have shown potential to attract and aggregate carp for the purpose of trapping. However, these olfactory attractants generally require flowing water to be effective (Smith et al 2005) and may therefore have limited application within lentic systems. Indeed, many fishes simply do not appear capable of tracking diffuse odour plumes and those that can rely on kinesis (undirected changes in movement pattern stimulated by changes in concentration), which is typically inefficient (Fraenkel and Gunn 1961; Dusenbury 1992). In this regard, a sensory ability which promises to operate independently of flow is hearing.

Teleost fishes can be categorised as hearing specialists or hearing generalists. Common carp belong to the family Cyprinidae, who are hearing specialists (Popper and Carlson 1998). Their hearing apparatus includes three pairs of otoliths (primary sound receptors in fish) (Hawkins 1986) and their accessory structures, the Weberian ossicles and swim bladder (Chardon and Vandewalle 1991; Amoser and Ladich 2005). The utricular, saccular and lagenar otoliths, with excitable mechano-receptive hair cells, perform several functions common to all teleost fishes including balance and the perception of movement and sound pressure (Hawkins 1986; Chardon and Vandewalle 1991). The Weberian ossicles are unique to hearing specialists (Berra 1981). The ossicles are a chain of moveable bones connecting the anterior chamber of the swim bladder with the paired inner ears, particularly the saccular otoliths (Hawkins 1986).



This enables hearing specialists to detect the pressure component of sounds over a broad frequency range (up to several KHz) and at low sound intensities (Popper and Carlson 1998; Amoser and Ladich 2005). Thus, carp are highly tuned to most biological noises (Hawkins 1986) and can detect the lowest abiotic (wind, waves) and biotic (conspecifics, feeding) noise levels encountered in low flow or stagnant freshwater habitats. This sensitivity could assist in prey detection and predator avoidance, and is especially useful in turbid water where vision is impaired.

Experimentally, the application of underwater acoustical equipment to reproduce 'fish' sounds has been tested on cyprinids to elicit trained responses (e.g. Willis et al 2002; Mahoney 2012), restrict movements (in conjunction with air curtains e.g. Taylor et al 2005) and most notably, attract dispersed populations and initiate a flight response (e.g. Hashimoto and Maniwa 1966). Regarding the latter, the authors successfully used carp feeding sounds to lure carp to specific locales within baited and unbaited lakes. This behavioural response was often immediate and resulted in large aggregations of carp at the sound projector. Interestingly, Hashimoto and Maniwa (1966) also reported that a 20 dB increase in the playback intensity of 'attractive' sounds initiated a flight response suggesting sound as a lone stimulus could be utilised to restrict movements or to herd carp to specific areas for capture. Indeed, several studies of marine species have shown this technique to have varying degrees of success (Wahlberg 1999).

While feeding sounds may attract and aggregate carp, other sounds regularly encountered within natural systems may also stimulate a similar response. Carp are positively rheotactic and will actively seek the source of flow (Smith et al 2005). Although this behavioural response can be stimulated by several physical (Montgomery et al 1997) and chemical (Elkins et al 2009) cues, sound is rapidly transmitted over long distances (Popper and Carlson 1998) and is therefore a key sensory component that may initiate exploration for the source of flow-particularly in fish at larger distances from the source that may not yet "feel" or "smell" the flow.

It is often not clear whether an audible sound really has an alluring/repelling effect or whether the vibrations received by the tactile senses initiate a response (Gabriel et al 2005). Regardless, carp have a highly developed hearing ability and appear reactive to various forms of acoustic stimuli. When used in conjunction with current integrated pest management technology (i.e. trapping), acoustics may increase carp harvesting success; particularly in lentic systems (i.e. wetlands) where traditional olfactory cues (pheromones, amino acids) that rely on dispersal by flow are not effective.

Objectives

The objective of this study was to determine the utility of underwater sounds for attracting and repelling carp for management purposes. Specifically, the study aimed to investigate the fine scale response of common carp in an enclosed (man-made) water body to two acoustic attractants (carp feeding and flowing water) and one repellent sound (high, low/mid, and very low frequencies coupled with explosion sounds). It was hypothesised that the percentage of carp and time spent by these carp within 10 m from the sounds' source would increase significantly during the playback of attractant sounds and decrease significantly during the playback of the repellent sound.

Methods

Study Site

The Botanic Gardens main lake is situated in the Adelaide Botanic Gardens, central Adelaide (34°55′05.88″S, 138°36′36.45″E) (Figure 1). The present form of the lake was constructed c.1950 when the earthen banks were replaced by concrete banks. The lake is 150 m long and 70 m wide at its widest point and varies in depth from 0.6 m to 1.2 m. It is sparsely vegetated, contains a series of islands and is surrounded by gardens and urban development. The lake is predominately fed by urban stormwater run-off but can also receive bore water in-flows. Mean salinity (ppm) and water temperature (°C) during the experimental period were 159.05 ± 6.61 S.E. and 17.43 ± 0.45 S.E., respectively. The lake is characterised by low levels of ambient background noise. Common carp are highly abundant and dominate the fish biomass with eastern gambusia (*Gambusia holbrooki*) the only other species present.

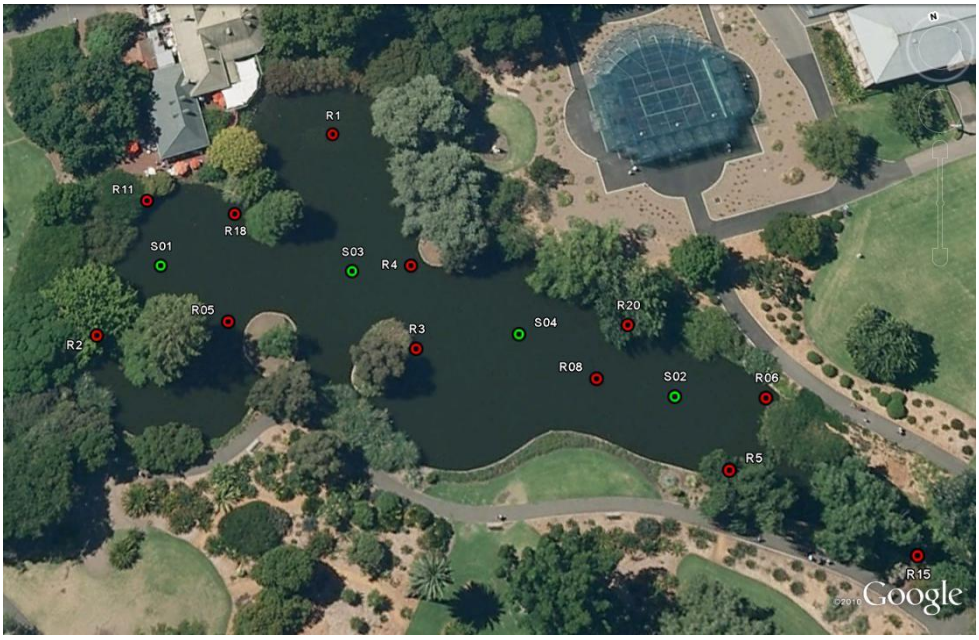


Figure 1. Google Earth image of the Botanic Gardens experimental lake showing VEMCO VR2W receiver and synchronization tag locations.

VEMCO Positioning System (VPS)

To monitor movements of carp in response to acoustic stimuli, a VEMCO positioning system (VPS) was utilised. The system consisted of twelve omni-directional VR2W acoustic receivers (VEMCO, AMIRAX Systems Inc., Halifax, Canada) which were deployed to ensure overlapping detection ranges on at least three neighbouring receivers (Figures 1 and 2). This non-real-time underwater acoustic fine-scale positioning system uses the principle of hyperbolic positioning or time-difference-of-arrival (TDOA) positioning. Essentially, the technique

converts differences in arrival times of a transmission from a tagged carp to range (distance) differences using the speed of sound in water, and then solves for the transmitter location using these range differences and the known locations of the detecting VR2W receivers (VEMCO 2008). For a fish location to be calculated the transmission must be received by at least three synchronised VR2W receivers. Four synchronization transmitters or "sync tags" (V9-2x-R69K, 69 kHz; nominal code transmission delay of 300 seconds) were deployed to synchronise the internal clocks of the receivers. To ensure the best possible time synchronisation, sync tags were positioned so their transmissions were detected consistently by at least three neighbouring receivers. The system provided approximately 90% coverage of the lake as areas behind the islands mitigate signal reception on three synchronised receivers. Despite this, the tracking system was designed to provide appropriate coverage of locations where experimental playback was conducted.

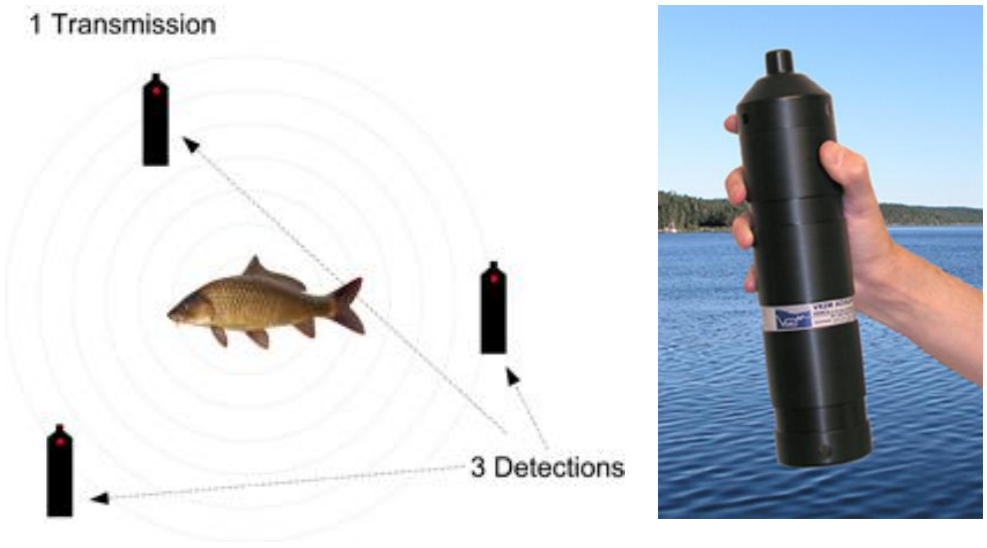


Figure 2. Schematic representation of VR2W acoustic tracking system function (left) and VEMCO VR2W acoustic receiver (right) (Photos: http://vemco.com).

VEMCO V9 Coded Acoustic Transmitters

In January 2011, 8 carp (636 mm Total Length ± 17 S.E.; 3561 g ± 290 S.E.) from the Botanic Gardens Lake were surgically implanted with VEMCO V9-2x low power coded acoustic transmitters (nominal delay of 90 ± 40 seconds around the ping train; VEMCO, AMIRAX Systems Inc., Halifax, Canada) (Figure 3). The surgical procedure utilised was adapted from the methods prescribed by Zampatti and Leigh (2011). Carp were captured from within the Botanic Gardens Lake by hook and line, with all fish captured immediately prior to surgery and held in aerated lake water. Carp were then anaesthetised (Stage III- loss of reflex reactivity, surgical anaesthesia; MacFarland 1960) in a 50 L fish bin containing AQUI-S® (AQUI-S®, New Zealand Ltd) at a concentration of 35 ppm (time taken- 363.4 seconds ± 153.4 S.E.). Length (mm) and weight (g) were recorded before each carp was inverted in a v-shaped PVC fish cradle (Figure 3). During surgery, gills were irrigated with an aerated 50% dilute solution of AQUI-S® (17.5 ppm). Each tag was implanted by first removing six adjacent scales from an area 3 scales posterior to the right side of the pelvic fin. This area was swabbed with Betadine® (Faulding Pharmaceuticals, Salisbury, S.A., Australia) and absolute ethanol before a

1.5-2 cm incision was made through the ventral wall. The tag was inserted into the abdominal cavity anterior to the incision. The incision was closed using one external suture (Ethicon Inc. Somerville, New Jersey, USA) and sealed with Vet-bond™ (3M Animal Care Products, St. Paul, MN, USA). To permit visual identification of carp implanted with transmitters, two external dart tags (Hall Print, Hindmarsh Valley, S.A., Australia) were inserted between the dorsal pterygiophores. Carp were then injected in the dorsal musculature with a long-term (2 weeks) antibiotic (Baytril®, Bayer Australia, Pymble, NSW, Australia) at a rate of 0.1 ml kg^{-1} body weight. At the completion of surgery, carp were transferred to a fresh water recovery tank and monitored until they regained equilibrium. All surgical instruments and equipment were sterilised with Betadine® and absolute ethanol and air dried before each surgery.

Figure 3. VEMCO V9 acoustic tag being inserted into abdominal cavity of carp. Insert shows a carp in the v-shaped PVC fish cradle post-operation after insertion of visual identification dart tags (Photo: SARDI).

Experimental Sounds - Attractant Sounds

Carp feeding and flowing water sounds were captured using a 9V powered AQ-18 hydrophone (sensitivity: -171 dB re 1 µPa @ 20°C; frequency response: 1 Hz-10 KHz; Teledyne Benthos Inc. North Falmouth, MA, USA) and a digital Zoom Handy Recorder H2 (© Zoom corporation, Chiyoda-ku, Tokyo, Japan) (Figure 4). All sounds were recorded at the highest sample rate (96 kHz, 24 bit depth in 2 channel stereo mode) and captured on SD card. To ensure both feeding and flowing water sounds were recorded at their natural levels, during each recording event the hydrophone was submerged approximately 1 m from the sound source and recording gain adjusted to maintain sound peaks just below 0 dB (clipping) on the digital recorders' multi-meter display. To capture feeding sounds, Botanic Lake carp were enticed into a feeding frenzy adjacent to the duck platform by adding a mixture of bread, cornflakes, nutrigrain™, corn and vanilla essence (see Smith and Thwaites 2007). Approximately 10-15 minutes of recordings were taken on three separate occasions whilst feeding activity peaked (December, 2010). Flowing water sounds were recorded from below the inlet culvert at Lake Bonney (Barmera, South Australia) during an environmental water allocation (October, 2010) and from below the inlet weir of the Botanic Lake during a pulse flow event (February, 2011).

Figure 4. The underwater sound recording system. Zoom digital recorder (centre), 9V power supply for hydrophone (left) and AQ-18 hydrophone (right) (Photo: SARDI).

Recorded sounds were transferred to iMAC for editing using Logic Pro 9 (Apple Inc.®, Cupertino, CA, USA). All recordings were arranged and engineered to promote both feeding and flowing water sounds at their natural biological levels, whilst discarding sounds that caused clipping (i.e. when the hydrophone was bumped). The best feeding and flowing water sounds were then collated and looped onto individual 30 minute tracks. Each individual track was exported at the highest possible sample rates (320 Kps; 24 bit depth) and converted to MP3 format to allow for playback (see playback system below). No effects were used to enhance the dynamics of the recordings, however the tracks were equalised in order to dull out the background (ambient) noise associated with the slight feedback caused when recording with an ultra-sensitive hydrophone (-171 dB re 1 µPa @ 20^{o}C).

Experimental Sounds - Repellent Sounds

Repellent sounds were collated from the Logic Pro 9 soundbank (Apple Inc.®, Cupertino, CA, USA). Ambient low, mid and high frequency sounds were over-laid with explosion sounds and looped into an individual 30 minute track. The track was mixed to provide a relatively constant sound and maintain sound peaks just below 0 dB (clipping) before being exported at the highest possible sample rates (320 Kps; 24 bit depth) and converted to MP3 format for playback (see playback system below).

Playback System

To play back recorded sounds, a GME GR9000 Series marine stereo system (frequency range: 20 Hz-20 KHz; Standard Communications Pty Ltd, Melbourne, Victoria, Australia) and two Electro-voice omnidirectional UW30 underwater loudspeakers were used (frequency range: 100 Hz-10 KHz, 30 Watts, Impedance: Nominal 8 ohms; EVI Audio Pty Ltd, Silverwater, NSW, Australia). The frequency specification of the playback system was flat to within ± 1 dB from 100 Hz-10 KHz. To monitor the playback of underwater sounds a GME SPK003 marine stereo speaker (Standard Communications Pty Ltd, Melbourne, Victoria, Australia) was externally mounted on the case of the stereo system (Figure 5).

Figure 5. Acoustic sound playback system housed in a pelican case and the UW30 underwater speaker (left). Characterising the frequency response of the playback system (right) (Photo: SARDI).

Experimental Protocol

Playback of Attractant Sounds: Carp attractant sound experiments were conducted in the Botanic Gardens Lake between March 18th and May 19th 2011. A total of six feeding sound replicates (3 morning and 3 afternoon) were conducted at both the duck platform and the island (Figure 6) and six flowing water sound replicates (3 morning and 3 afternoon) were conducted at the willow tree (Figure 6). The duck platform was chosen as Botanic Lake carp are regularly fed by the public at this location, while the island was chosen as the public cannot access this location to feed carp. The willow tree was chosen for the flowing water sound experiments as it was at the outer limits of the VPS array and in close proximity to the lakes weir where carp would aggregate during actual flow events. Prior to playback at each location, a VEMCO VR100 monitoring receiver (VEMCO, AMIRAX Systems Inc., Halifax, Canada) was used to ensure tagged carp were not already in close proximity (i.e. low or zero signal strength). The UW30 underwater speakers were then submerged side by side 50 cm below the water surface and orientated toward the centre of the lake. To ensure experimental sounds were played at their natural biological levels, a headroom reference track consisting of peak sounds (no headroom) captured during recording was first played into the water and monitored using the digital recorder and hydrophone (positioned 1 m in front of the speaker). The gain of the digital recorder was set to the level used during recording before the gain (volume) of the playback system was raised until sound peaks matched those obtained during recording (sound peaks just below 0 dB- clipping). Once sound levels were matched, experimental sounds were played for the duration of one hour. A total of 7 tagged carp were present within the system during these experiments as one tagged carp had been removed by illegal fishing.

Playback of Repellent Sounds: Carp repellent sound experiments were conducted from the Botanic Lake duck platform on the 9th (11.40 am), 11th (1.45 pm) and 12th (12.05 pm) of August, 2011. Prior to playback, the UW30 speakers were submerged and carp were aggregated at the platform by broadcast feeding the same berley mixture used while conducting the feeding sound recordings (see above). The VEMCO VR100 monitoring receiver

was used to confirm tagged carp were within close proximity to the platform before playback. Once confirmed, playback of repellent sounds commenced at the highest possible gain for a period of 50 minutes. Feeding also continued for the first 30 minutes of the experimental period. A total of 7 tagged carp were within the system during the first experiment however, due to further illegal fishing, only 6 tagged carp were present for the final two replicates.

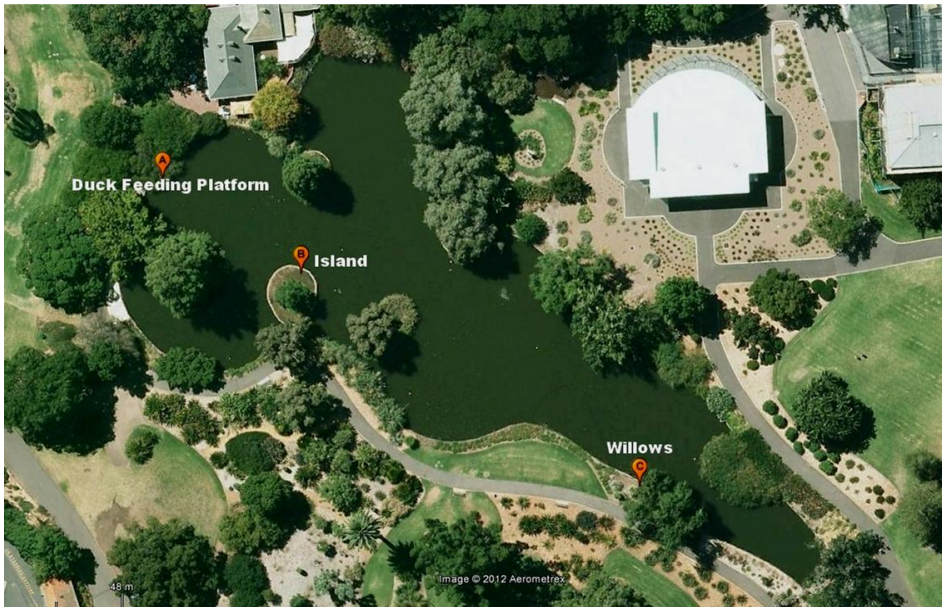


Figure 6. Google Earth image of the Botanic Gardens experimental lake showing the locations for each of the acoustic experiments; Duck feeding platform- feeding attractant sounds and repellent sounds, Island- feeding attractant sounds and, Willows- flowing water attractant sounds.

Sound Pressure Levels and Frequency Range

The measure of sound pressure level (SPL dB re 1 µPa) at 1 m from the sound source was used to describe how "loud" each experimental sound was during playback (Equation 1; adapted from Kinsler et al 2000).

$$SPL(dB\ re\ 1\mu Pa) = 20\ log\left({V^*}/{1V}\right) - \left(-171\ \text{dB}\left(re\ \frac{1V}{1\mu Pa}\right)\right)$$

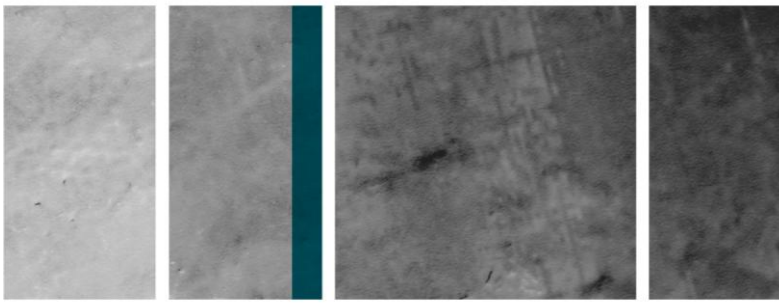
Equation 1. SPL (dB re 1µPa) is the calculated sound pressure level, V* is the voltage of the hydrophone measured at the output terminals, 1V is the reference voltage and -171 dB (re 1V/1µPa) is the hydrophones' sensitivity.

The frequency range of all experimental sounds was determined using channel EQ (Logic Pro 9, Apple Inc.®, Cupertino, CA, USA) and the individual frequencies associated with the repellent sounds were assessed using standard methods on an oscilloscope (Poteck, 6502A, 20 MHz, China).

Data Analysis

At the completion of all experiments the VR2W receivers were downloaded and data sent to VEMCO for VPS processing. Fish positional data were then analysed using Eonfusion 2.2 geospatial software (Myriax Pty. Ltd., Hobart, Tasmania, Australia). As a measure of attraction or repellence, the analytical model was used to determine the percentage of tagged carp present and percentage time that each of these carp spent within four distances from the playback system (5 m, 10 m, 25 m and 50 m) both before and during each experimental period (Figure 7). It was hypothesised that the percentage of carp and time spent by these carp would increase in the zones closest to the sound source (5-10 m) during playback of attractant sounds (i.e. >80% carp present for >80% of time) and decrease during playback of repellent sounds (i.e. 0% carp present). Box and whisker plots were used to describe the data and Mann-Whitney tests were used to determine significant differences between medians (XLStatistics, 2008). These non-parametric procedures were used as: 1) there were a limited number of replicates per treatment, 2) the same carp were used in each experiment, 3) the data were not normally distributed with unequal variances and, 4) proportions were used to summarise the movement data.

Figure 7. Eonfusion 2.2 geospatial software image showing red circles which represent four distances (5 m, 10 m, 25 m and 50 m) distances from the underwater speaker at the duck platform.



Results and Discussion

Attractant Sound Experiments

The equipment and procedures utilised during recording and playback of the attractant sounds ensured that the frequency ranges and sound levels were within the hearing capabilities of carp and therefore biologically relevant. Carp are hearing specialists and can detect the pressure component of sounds over a broad frequency range (up to several KHz) and at low sound intensities (Popper and Carlson 1998; Amoser and Ladich 2005). The frequency range of the feeding and flowing water sounds were 100 Hz-10 KHz and 500 Hz-10 KHz, respectively (Table 1; Figures 8 and 9). As the frequency response of the recording/playback system was flat to within ± 1 dB from 100 Hz-10 KHz (limited by the underwater speakers), the entire frequency range of the attractant sounds were represented during playback. The calculated sound pressure levels (SPL dB re 1 µPa @ 1 m) of the feeding and flowing water sounds were 117 ± 1.60 S.E. and 125 ± 0.75 S.E., respectively. Only one previous study has attempted to evaluate the utility of underwater acoustics for attracting carp (see Hashimoto and Maniwa 1966). However, the authors did not report the frequencies or Sound Pressure Levels (SPLs) of their feeding sounds and therefore provide no scope for direct comparison with the present study. Notwithstanding, Wahlberg (1999) reports several successful attraction experiments on various marine species of hearing generalists and hearing specialists. While these experiments evaluated a variety of different sounds (i.e. trawling noise, swimming sounds, pure tones, buzzers) the reported SPLs ranged from 100-187 (dB re 1 µPa @ 1 m) which encompass the SPLs used in the current experiment. In addition, successful acoustic feed conditioning experiments on cultured and wild carp utilised pure tone frequencies and SPLs of 400-1000 Hz and 80-145 dB re 1 µPa @ 1 m, respectively (Kojima et al 2005; Zion et al 2007; Mahoney 2012).

Table 1. Sound pressure levels (SPL) and frequencies of experimental attractant sounds.

Sound	SPL (dB re 1 µPa) (±S.E.)	Frequency range
Feeding sounds (@ 1m)	117 ± 1.60	100 Hz - 10 KHz
		Peak Frequency ≈ 750 Hz
Flowing water (@ 1m)	125 ± 0.75	500 Hz - 10 KHz
		Peak Frequency ≈ 1 KHz

While the attractant sounds were recorded and reproduced at biologically relevant levels, the results of the attraction experiments indicate that feeding and flowing water sounds used in the present experiments have a limited effect and therefore do not appear suitable for attracting and aggregating carp for harvesting purposes. Although it was hypothesised that the percentage of tagged carp and time spent by these carp would increase significantly within the 5 m and 10 m zones during the playback of attractant sounds, this response was not observed. There was no significant difference in the behavioural patterns of carp in response to the playback of feeding sounds from the duck platform (Figures 10, 11 and 12). While there was a slight increase in the percentage of tagged carp present and time spent by these carp within the 5 m and 10 m zones during the playback of feeding sounds at the island, these percentages were not significantly different from the pre-experimental period (Figure

13). The response to the flowing water sounds was also minimal with no difference between behaviour patterns before and during playback (Figure 14).

In that minimal response was observed during playback of the feeding sounds at natural levels, a pilot trial was conducted to evaluate the response of carp to the feeding sound at the maximum gain of the playback systems. While this strategy increased the SPL (dB re 1 µPa @ 1 m) of the feeding sound to 130 ± 1.81 S.E., no attraction or repulsion was observed (SARDI unpublished data).

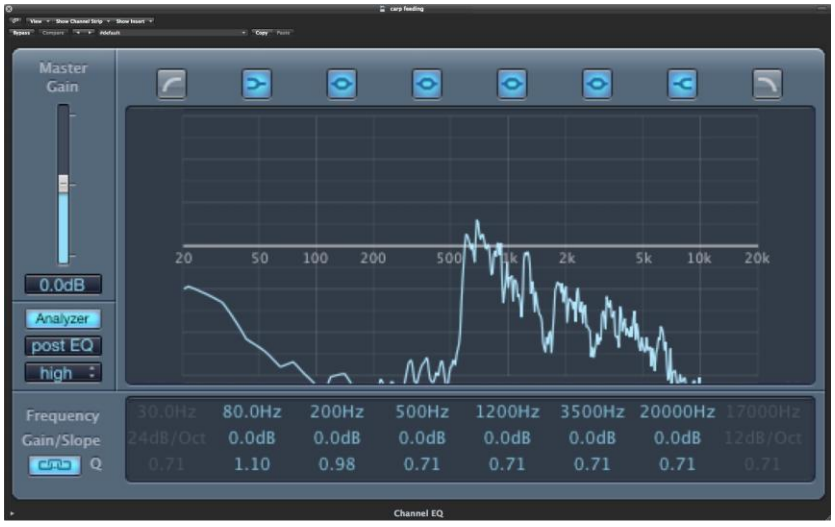


Figure 8. Channel EQ (Logic Pro 9) output showing frequency range of the carp feeding sounds.

Figure 9. Channel EQ (Logic Pro 9) output showing frequency range of the flowing water sounds.

Hashimoto and Maniwa (1966) noted an immediate response by carp to the playback of their experimental sounds. However, as they conducted some of their feeding sound experiments in previously baited clear lakes; it is hypothesised that the attraction they reported could be partly attributed to learned behaviour and the visual stimuli provided by the researchers standing at the lakes edge during the experiments. Further, the attraction they noted during playback from a boat within a previously un-baited clear lake may be partly due to the presence of a visual stimulus (i.e. the boat). There were no visual stimuli offered during the current experiments as they were conducted in a turbid lake and care was taken to stand away from the lakes edge during experimental periods and this may explain the limited attraction observed. Interestingly, Hashimoto and Maniwa (1966) also noted attraction to a recording of tapping the edge of a boat and showering bait into a wooden trap net. Given that these are not "natural" sounds it is possible that the exploration for the sound source in their experiment may also be associated with curiosity. Regardless of the mechanism for attraction, these behaviours were not observed in the current experiment.

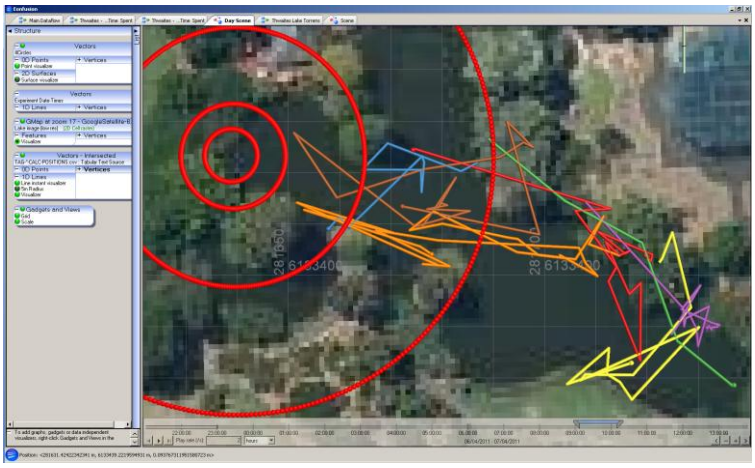


Figure 10. Eonfusion 2.2 geospatial software output showing typical movement patterns of each tagged carp (coloured lines) for 60 minutes prior to the on-set of the feeding sound experiment (red circles represent 5 m, 10 m, 25 m and 50 m distances from the underwater speaker at the duck platform).

Figure 11. Eonfusion 2.2 geospatial software output showing typical movement patterns of each tagged carp (coloured lines) for the 60 minutes duration of the feeding sound experiment (red circles represent 5 m, 10 m, 25 m and 50 m distances from the underwater speaker at the duck platform).

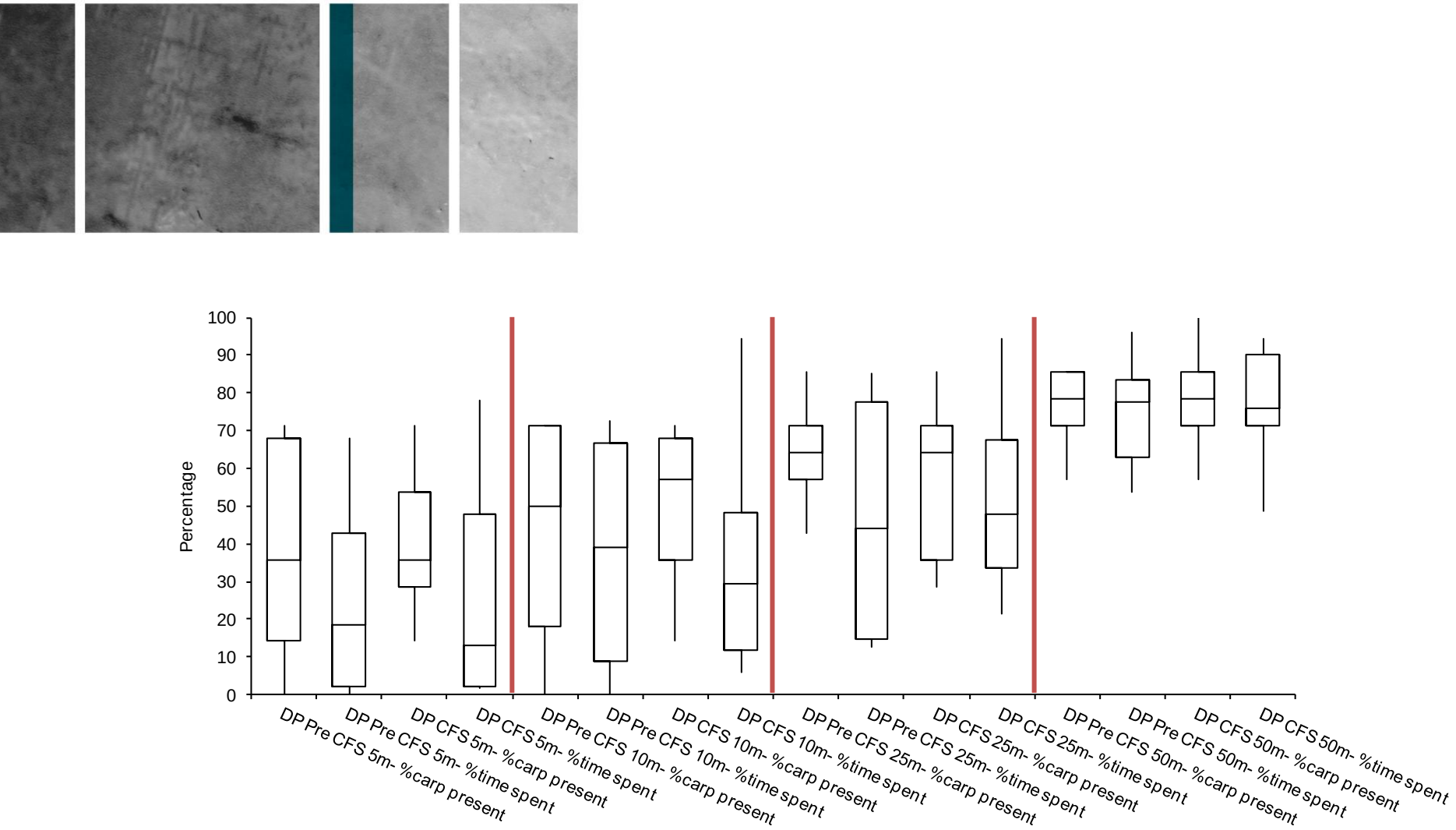


Figure 12. Results of the duck platform (DP) carp feeding sounds (CFS) experiment showing the median percentage of carp present (%carp present) and time spent by these carp (%time spent) within 5 m, 10 m, 25 m and 50 m from the sound source both before (Pre) and during the experimental period (boxes = upper and lower quartiles, whiskers = maximum and minimum values).

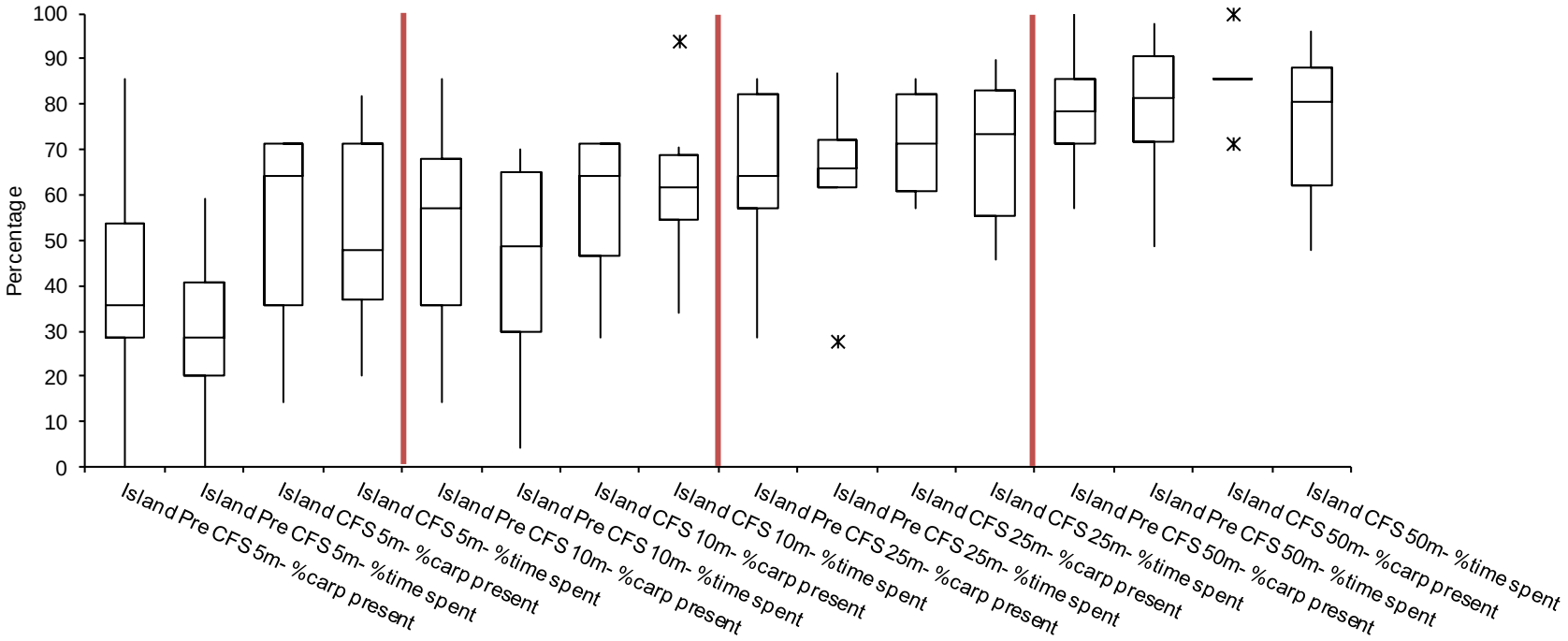
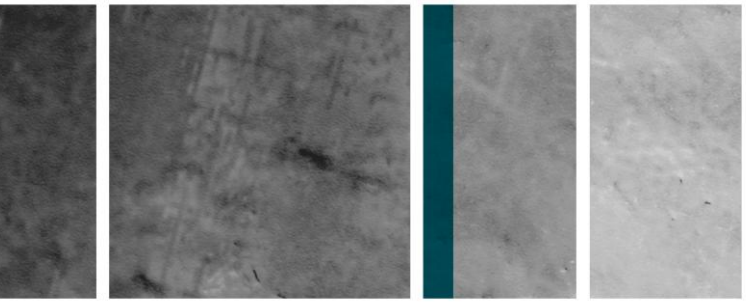


Figure 13. Results of the island carp feeding sounds (CFS) experiment showing the median percentage of carp present (%carp present) and time spent by these carp (%time spent) within 5 m, 10 m, 25 m and 50 m from the sound source both before (Pre) and during the experimental period (boxes = upper and lower quartiles, whiskers = maximum and minimum values, stars = outliers).



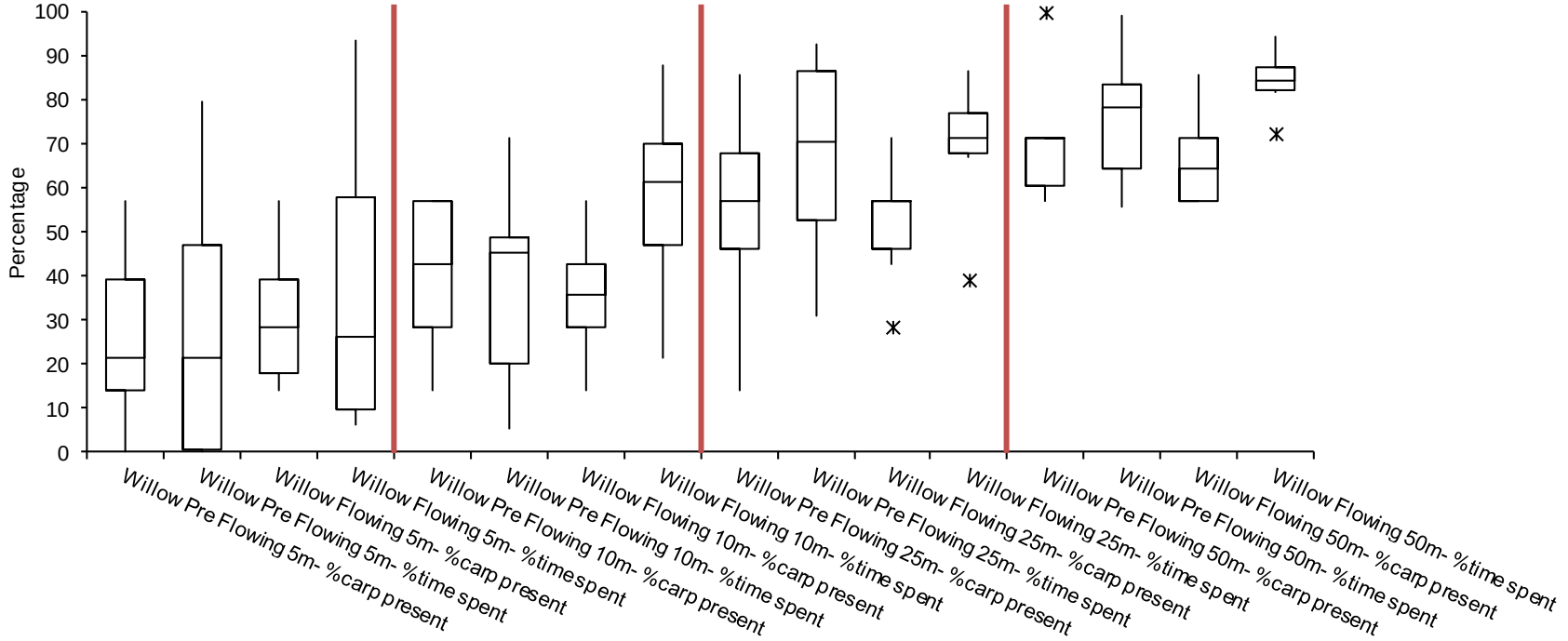


Figure 14. Results of the willow tree (Willow) flowing water sound (Flowing) experiment showing the median percentage of carp present (%carp present) and time spent by these carp (%time spent) within 5 m, 10 m, 25 m and 50 m from the sound source both before (Pre) and during the experimental period (boxes = upper and lower quartiles, whiskers = maximum and minimum values).

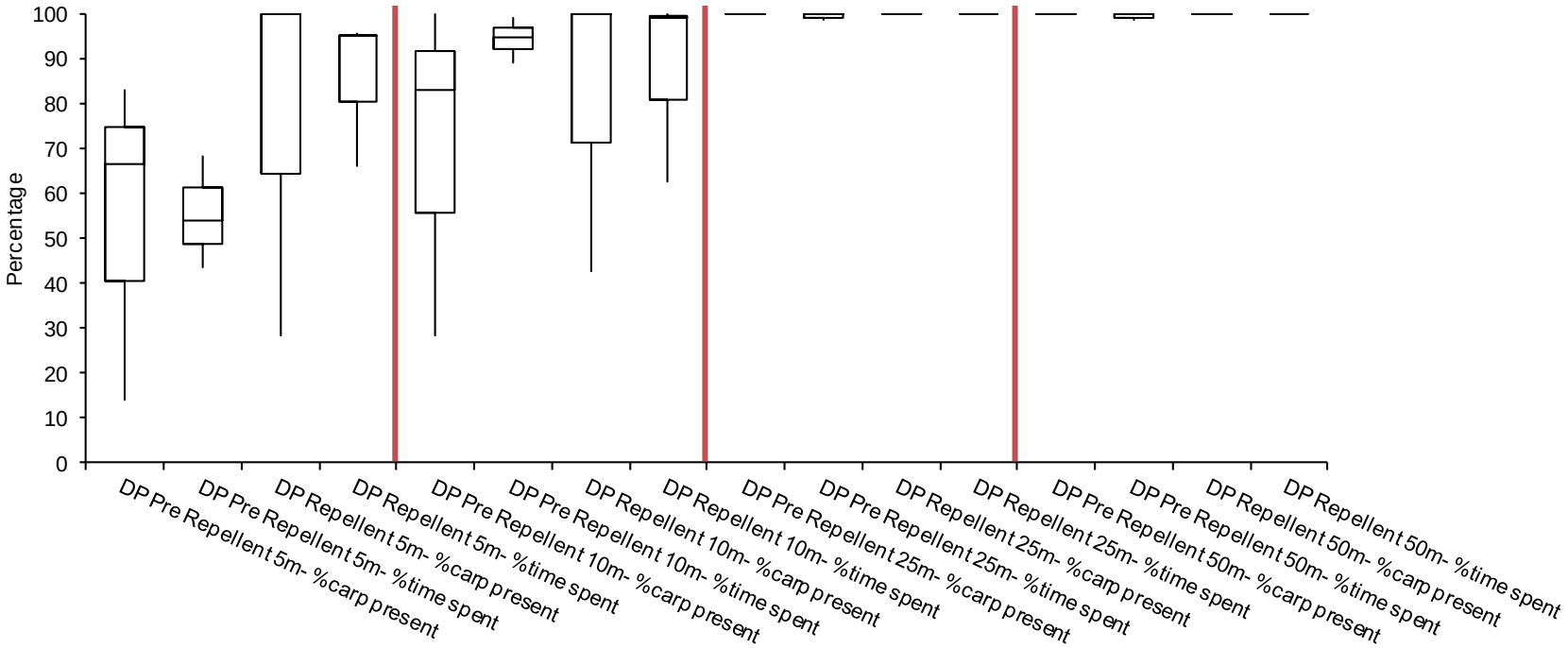


Figure 15. Results of the duck platform (DP) repellent sound (Repellent) experiment showing the median percentage of carp present (%carp present) and time spent by these carp (%time spent) within 5 m, 10 m, 25 m and 50 m from the sound source both before (Pre) and during the experimental period (boxes = upper and lower quartiles, whiskers = maximum and minimum values).

Repellent Sound Experiments

The frequency range and the SPL (dB re 1 µPa) of the repellent sound trialled on carp (which were ≈ 1 m from sound source) were 20 Hz-12 KHz and 142 ± 0.42 S.E., respectively (Table 2; Figure 16). Previous successful studies of herding or scaring other species of hearing specialists utilised SPLs (145 ± 7 dB re 1 µPa) and frequencies (1-60 Hz) which are similar to, or incorporated by, the repellent sound used in the current experiment (Wahlberg 1999). However, given the frequency response of the recording/playback system (100 Hz-10 KHz) and frequency range of the repellent sound (20 Hz-12 KHz; Table 1) there is a possibility that frequencies at the lower and higher end of this range were not represented due to roll-off or distortion. Notwithstanding, the vast majority of frequencies associated with the repellent sound were within the range of the system and within the hearing capabilities of carp.

Table 2. Sound pressure levels (SPL) and frequencies of experimental repellent sounds.

Sound	SPL (dB re 1 µPa) (±S.E.)	Frequency range
Repellent in front of speaker (@ the carp)	142 ± 0.42	20 Hz - 12 KHz
Repellent sound in alcove behind speaker (@ 0.5 m)	153 ± 0.85	Peak frequencies: High ≈ 9500 Hz Low/mid ≈ 220 Hz Low ≈ 47 Hz
Repellent sound in alcove behind speaker (@ 1m)	143 ± 1.07	
Repellent sound right in front of speaker (@ <0.1m)	165 ± 0.36	

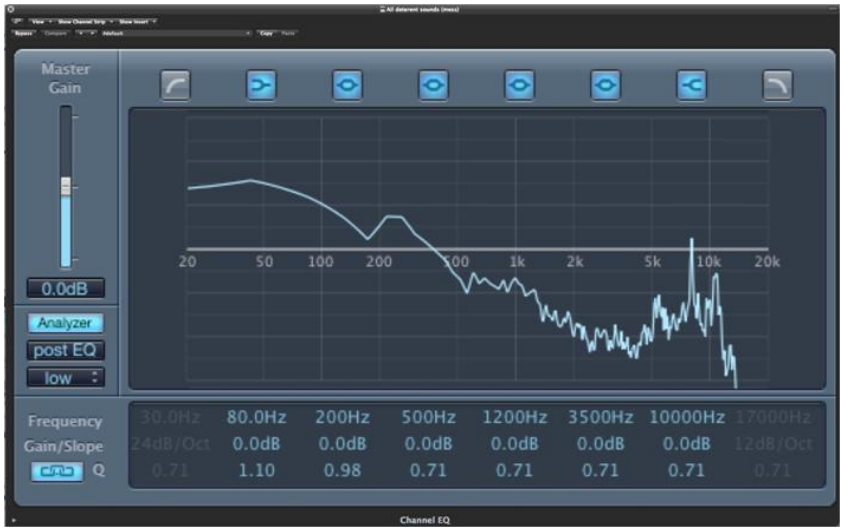


Figure 16. Channel EQ (Logic Pro 9) output showing frequency range of the repellent sound.

Although it was hypothesised that the proportion of carp and time spent by these carp would decrease significantly within the 5 m and 10 m zones during the playback of the repellent sound, this response was not observed and the sound actually appeared to act as an attractant. Although not significantly different, there was an increase in the percentage of carp present and percentage time spent by these carp within the 5 m zone during playback (Figure 15). Even though tagged carp were aggregated near the speakers by broadcast feeding prior to the on-set of the repellent experiments, there were distinct behavioural differences between feeding and experimental times. During pre-experiment feeding, carp displayed exploratory movements (Figure 17) while during the experimental period all tagged carp formed a tight aggregation directly at the speaker; even though food remained widely broadcast in the surrounding area (Figures 18 and 19).

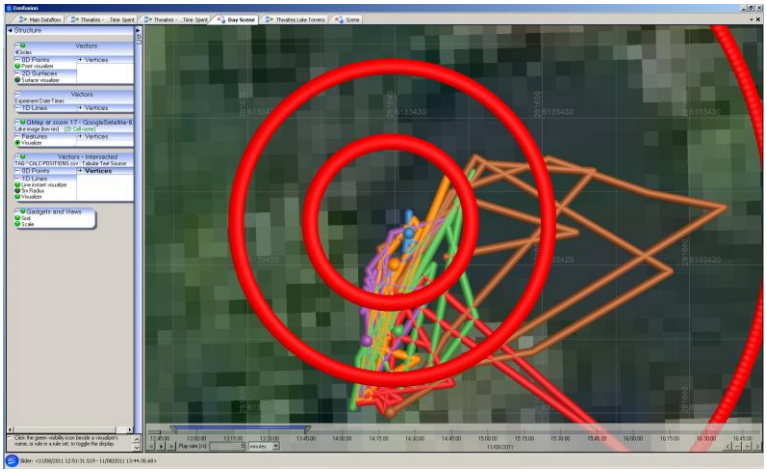


Figure 17. Eonfusion 2.2 geospatial software output showing typical movement patterns of each tagged carp (coloured lines) over a 1 hour period (including feeding) prior to playback of the repellent sound (red circles represent 5 m, 10 m, and 25 m distances from the underwater speaker at the duck platform).

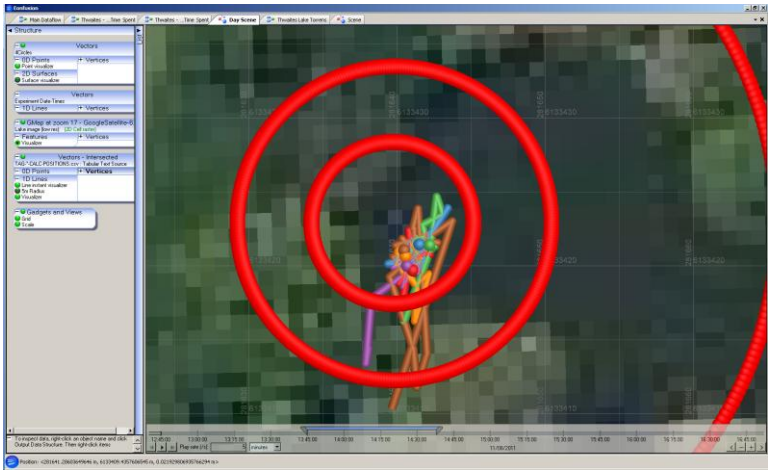


Figure 18. Eonfusion 2.2 geospatial software output showing typical movement patterns of each tagged carp (collared lines) over the entire 50 minute playback of the repellent sound (red circles represent 5 m, 10 m, and 25 m distances from the underwater speaker at the duck platform).

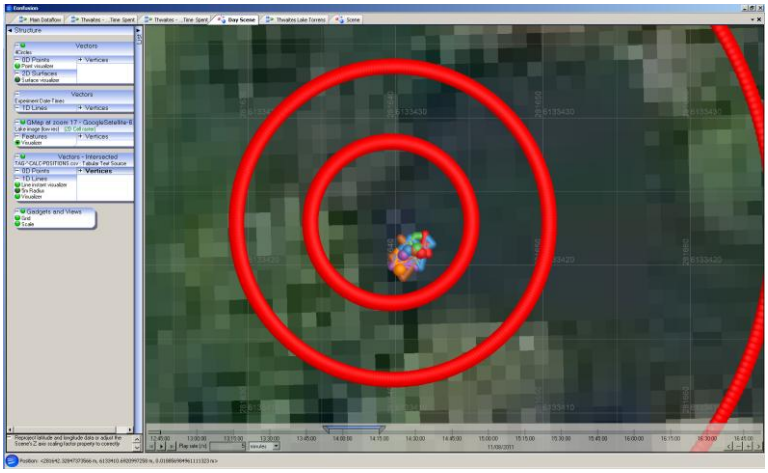


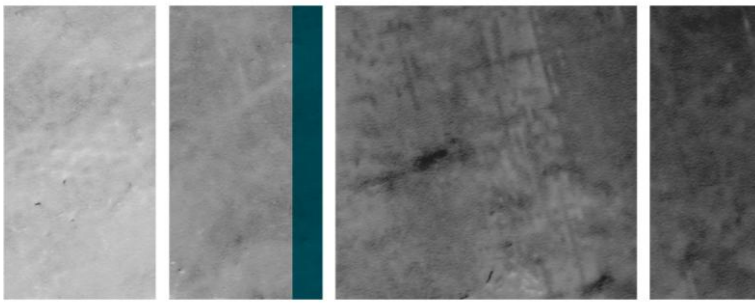
Figure 19. Eonfusion 2.2 geospatial software showing each tagged carp (coloured lines/dots) aggregating for a 20 minute period during the playback of the repellent sound (red circles represent 5 m, 10 m, and 25 m distances from the underwater speaker at the duck platform).

As a result of this unexpected response four alternative explanations were initially proposed;

1. the repellent sound masked carp transmitter reception on the VPS array;
2. carp attempted to hide behind the speaker;
3. the aggregating behaviour was a flight response;
4. carp were attracted to the sound.

After considerable consultation with VEMCO, which included spectral analysis of the repellent sound, it was confirmed that the VPS array was not affected during playback and that the positional data were correct. While possible that carp may attempt to hide from the repellent sound by moving into an alcove underneath the duck platform directly behind the speaker, calculated SPLs (dB re 1 µPa) immediately in front of the speaker, directly behind the speaker and within the alcove were 165 ± 0.36 S.E., 153 ± 0.85 S.E. and 143 ± 1.07 S.E., respectively (Table 2). Given that these SPLs are louder than the SPL 1 m in front of the speaker, hiding behind the speaker would not provide refuge from the sound source and is therefore considered an unlikely explanation. The repellent sound may have initiated a flight response that stimulated carp to seek protection by forming a tight aggregation (pers. comm. Paul Brown, Freshwater Ecologist), however as carp actually moved toward, and aggregated at the sound source this is also considered unlikely. Given that the above explanations are unlikely it appears that carp were actually attracted to the "assumed repellent" sound.

While no studies have specifically attempted to repel carp using underwater sounds, Hashimoto and Maniwa (1966) report that a 20 dB increase in the sound intensity of an attractant sound stimulated a flight response in carp. Wahlberg (1999) reports 17 successful herding/scaring experiments on other species of hearing specialist fish and provides the frequency range for six (1-60 Hz) and the SPLs for two (145 ± 7 dB re 1 µPa at the fish). Although the SPLs used in the current experiment were ≈20 dB louder than the attractant sound and similar to those reported for other successful herding/scaring trials, frequencies <100 Hz were not represented or misrepresented (i.e. distorted) due to playback system limitations (frequency range of the playback system was flat to within ± 1 dB from 100 Hz-10

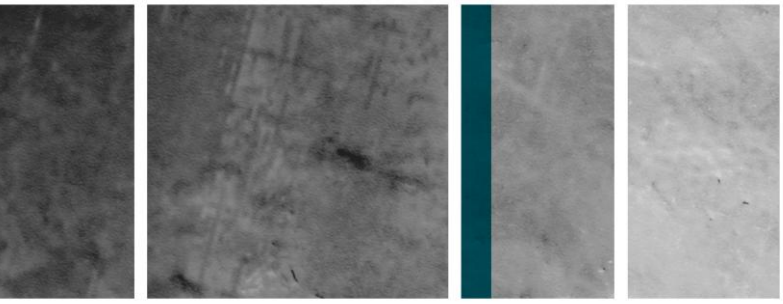


KHz). Even though all frequencies between 100 Hz and 10 KHz were represented in the repellent sound, previous studies suggest these frequencies may be too high to act as an effective repellent. Interestingly, Wahlberg (1999) reports three failed attempts to herd or scare hearing specialists. While no SPLs are provided for these experiments, the reported frequency range was higher than the successful trials (100 Hz-20 KHz). Further, successful attractant sounds used on hearing generalists and non-specialists were also characterised by higher frequencies (100 Hz-5 KHz). Thus, it is hypothesised that the higher frequencies used in the current experiment stimulated exploration for the sound source and therefore acted as an attractant. Similar high frequencies were represented in the attraction experiments (see Table 1 and Figures 8 and 9), however these frequencies fluctuated due to inherent variability associated with feeding and flowing water sounds (i.e. peaks and troughs) and were therefore less consistent than the frequencies of the repellent sound. This suggests that an attractant sound consisting of pure tones (frequencies) similar to those used for the current experiment may prove to be a useful attractant. In addition, an attractant sound comprising more constant feeding sounds may also increase attraction.

Conclusions and Recommendations

This study investigated the response of common carp in an enclosed (man-made) water body to two acoustic attractants (carp feeding and flowing water) and one repellent sound (high, low/mid, and very low frequencies coupled with explosion sounds). Although the frequencies and sound pressure levels were biologically relevant, the results indicate that feeding and flowing water sounds have a limited effect and therefore do not appear suitable for optimizing carp harvesting. Interestingly, the “assumed repellent” sound seemed to stimulate exploration for the sound source which indicates that this sound or a component of it could prove to be a useful attractant.

It is recommended that future research should evaluate the attraction capabilities of this sound, as well as its individual peak frequencies both singularly and in combination. Similar and other pure tones (frequencies) emitted from a sound generator should also be tested. It is recommended that these sounds be tested over a range of SPLs that encompass the SPL (dB re 1 µPa @ 1 m) used during the repellent experiment (i.e. 142 ± 0.42 S.E.). This research should also evaluate the attraction capabilities of these sounds on carp at greater distances from the sound source in both experimental and natural systems. Finally, further research concerning the utility of repellent sounds should focus on low/mid frequencies at high SPLs and employ technologies such as transducers that can emit infrasound (low frequencies).



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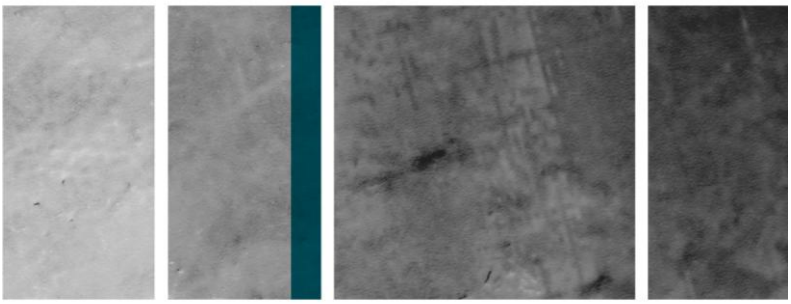

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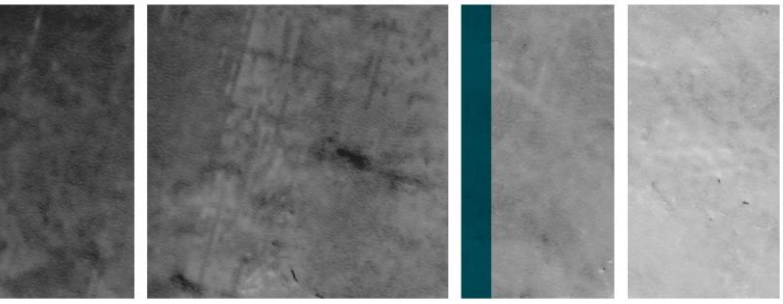

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