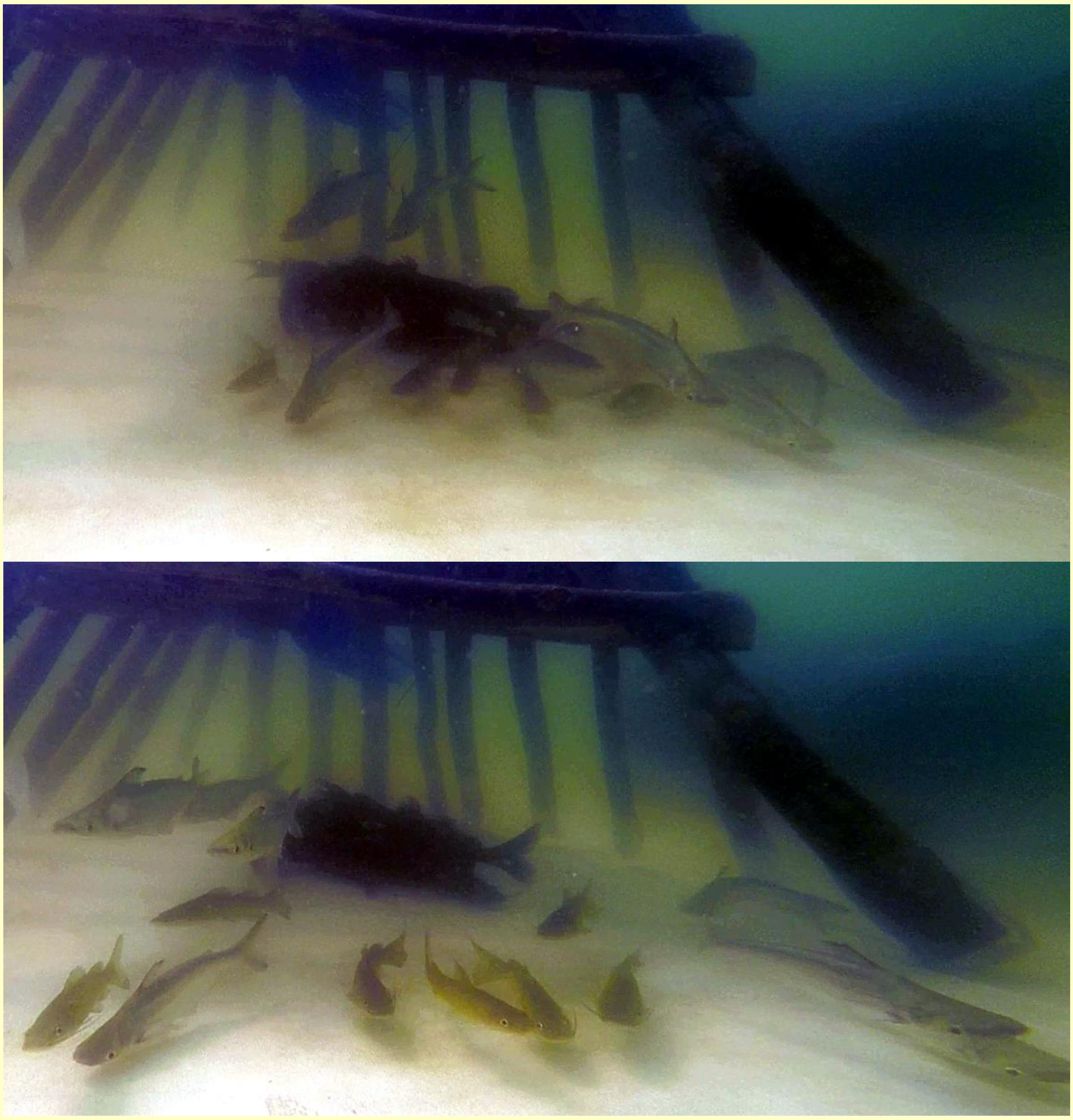
Acoustic Fish Deterrence System Preliminary Trial



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1. Summary

The Don Sahong Hydropower Plant (DSHP) is being constructed from 2016 to 2019 on one channel of the Mekong River at Khone Falls in southern Laos. Once the project is completed, fish which are migrating downstream may pass through the turbines of the DSHP where they are at risk of being injured or killed. Mitigation of this impact entails either excluding fish by screens, deterring them by behavioural barriers, or by some combination of screening and deterrence. Acoustic fish deterrence (AFD) systems are behavioural barriers which have been applied at several projects elsewhere, and in the Mekong fishers use various devices to scare fish into their gears, so acoustic deterrence of fish into alternative channels has potential at this site.

This brief study tested the response of fish to underwater sound during March 2015 in a disused pool at Phapheng Resort, near Khone Falls in Laos. Underwater speakers were powered via a control box to produce a rising and falling output (siren) at 160 dB re. 1 µPa, within pre-set frequency ranges. Three common species of Mekong catfishes and four species of cyprinids (carps) were tested, as well as Nile tilapia. The catfishes showed clear responses to sound between 20-1000 Hz, with one species showing strong avoidance, one species showing moderate or weak avoidance and one species showing increased activity without swimming away from the sound source. The four carps clearly avoided sounds within the range 20-500 Hz. These results are much as expected, as catfishes and carps generally have good hearing abilities and many species are likely to be sensitive to and avoid loud sounds within the ranges observed. In the Mekong River a good sense of hearing would generally be an advantage for survival of fish. By contrast with the catfish and carps, Nile tilapia were almost non-responsive to sound, probably because they originate from relatively clear waters, where they may utilise other senses (sight and smell) to a greater degree than hearing.

Based on these results, development of an AFD system should be further investigated by pool-based testing of captive fish and by field testing as follows.

1) Pool-based testing is recommended for large, long-lived and high-profile species such as the giant catfish (*Pangasianodon gigas*), giant barb (*Catlocarpio siamensis*) and Jullien's barb (*Probarbus jullieni*), as well as other wild-caught fish. A video should be prepared to demonstrate the potential of acoustic deterrence to mitigate impacts on downstream-migrating fish.

2) Field testing of the sound projector with wild fish moving towards a stationary sound source will provide more realistic results to supplement the pool-based experimentation with captive fish. Field trials should be carried out in October-November when many fish are migrating downstream. It is suggested that DSPC also investigates the feasibility of a mechanical device such as a rotating drum or wheel with attached paddles and internal steel balls positioned underwater, and which could be driven hydraulically to create random clanging or banging noises to deter fish. Such a system would likely be much cheaper, more robust and require less maintenance than high-tech speaker-based systems. A prototype could be field-tested at the same time as the sound projector.

During this brief trial, DSPC staff developed capacity in pool management as well as fish handling and testing procedures, with various improvements made over the course of the testing. Some minor improvements to programming of the sound projector are needed to improve its flexibility and usefulness, especially for field work. DSPC staff need to prepare well in advance for any future work, taking account of the lessons from this trial exercise; for example that fish of good quality need to be purchased and set up on site in floating cages before any testing is planned.
The recommendations are covered in more detail in the Section 5 of this report.

2. Introduction

2.1 Options for mitigation of impacts on fish passage

The Don Sahong Hydropower Project (DSHP is under construction on the Sahong Channel, one of seven main Mekong River channels that cross Khone Falls in southern Laos. Construction began in January 2016 with closure of the channel and will continue until 2019.

Mitigation of the impacts on fish of the DSHP requires consideration of upstream and downstream migration, following the Mekong River Commission's (MRC) Preliminary Design Guidance for Mainstream Dams (PDG) of 2009, Clause 61. Upstream migration by fish is being enhanced by ongoing improvements to natural channels (including Xang Pheuak and Sadam) which provide alternative migration routes, as well as measures to reduce fishing pressure.

Once the DSHP operational, any fish which migrate downstream and continue through the Sahong Channel will pass through the plant's turbines, where they could be injured or killed. As well as designing turbines to be as 'fish-friendly' as possible, the main approach to mitigating this potential impact on downstream-migrating fish is to exclude or deter them from the Sahong channel, so that they will migrate down other channels.

Exclusion would rely upon a system including screen(s) constructed across the Sahong Channel and diversion channel(s). Such a system would be expensive to build and costly to maintain, especially in this environment where large quantities of detritus and algae would impinge upon and tend to block and damage screens.

An alternative or supplement to exclusion is to deter fish by behavioural barriers, which could include electric fields, lights, air bubbles or sound. After reviewing the options, FGS (2014) concluded that sound (acoustic fish deterrents or AFDs) would be the only realistic option that would work in both wet and dry seasons. AFDs have been used in several locations elsewhere with success varying between 60% and 100% deterrence of fish. It is important to note that: 1) mitigation is rarely 100% effective, and 2) an average deterrence rate of even 60% would be very worthwhile, particularly if the rate is higher for the larger long-lived fishes which are most at risk from mainstream hydropower development (Halls and Kshatriya, 2009).

FGS (2014) provided some preliminary design information and costing for an acoustic barrier system for DSPC (estimated at US$5-10M to construct), but there is no precedent in the Mekong region or with Mekong species for such a system. The trial described here is the first step in determining whether such an AFD system is likely to be viable for Mekong fish species in this location.

2.2 Basis for acoustic deterrence of fish

Fish detect sounds mainly by hearing them with their inner ear. Fish do not have external ears, and sound waves in water pass through fish because fish are of a similar density to water. However structures in a fish's inner ear - otoliths - are denser than water, so sound waves cause the otoliths to vibrate at a different frequency to the rest of the fish; the difference is then detected and converted to nerve impulses in a similar manner to hearing in other vertebrates. Gas spaces in a fish, in particular the swim bladder, can act as amplifiers, as they compress and expand in response to sound waves, and these changes in volume can be transmitted to the inner ear.

Most Mekong fishes are within the Otophysi, the major group of freshwater fishes that is characterised by possession of a Weberian apparatus, a structure that connects the swim bladder to the inner ear, and which can greatly enhance hearing. Otophysan fishes generally have excellent hearing and many species communicate using sounds which are produced by movement of the swim bladder and/or bony structures. As well as hearing with their inner ears, fish can also sense water movement and pressure variations caused by low-frequency sound (<200 Hz) with sensory structures on their lateral line and/or on their head. As well as for communication, fish use acoustic information to orient and navigate, and to detect prey and avoid predators which is particularly advantageous in turbid waters and at night.

Generally, freshwater fish are most sensitive to sounds which have frequencies somewhere between 100 and 1000 Hz, and the overall range of hearing sensitivity in some freshwater fish can extend from less than 20 Hz to 3000 Hz or higher (Webb et al., 2008). By comparison, the range of human hearing is about 20 Hz to 20,000 Hz, but we are most sensitive to sounds between 1000 and 4000 Hz, so the sounds that fish generally hear best are at the lower part of the human audible range. Another useful comparison is that the lowest note on an 88-key piano (an A) has a frequency of 27.5 Hz and the highest note is a C, at 4186 Hz.

3. Objectives

The overall objective of investigating acoustic effects on fish is to develop a system to mitigate the impact of the DSHP on downstream-migrating fish.

The main objective of this trial was to test the response of fish to sound under controlled conditions, which is the first step in evaluating the viability of an AFD system at the DSHP project site.

A secondary objective was to develop a system on-site to carry out such testing, which includes sourcing, handling and feeding fish, setting up a test pool, training with cameras and a sound projector, and adjusting conditions so that fish responses could be readily observed.

4. Methods

4.1 Pool setup

The trial was carried out in a disused swimming pool at Phapheng Resort (about 3 km upstream of Phapheng Falls in southern Laos) during March 2015. The pool is irregularly shaped and is about 20 m long by 7 m wide and about 1.9 m maximum depth when fully filled.

Setting up the pool and fish for the trial was to be the responsibility of a contractor who was unavailable for most of the period of the trial, so DSPC staff had to carry out or supervise all of the work.

On 26 Feb 2015 DSPC staff pumped all water out of the pool, which was then scrubbed and cleaned (Figure 1). Water from the Mekong River (~ 30 m away) was pumped into the pool to fill it to about 1.4 m maximum depth and a filter was set up to clean the water. Catfish were stocked in the pool (20 fish in each of 3 species – see Table 1) and the fish were fed each day with commercial fish pellets. By 4 March (i.e. after 6 days) there was a heavy green algal bloom in the pool. The algae originate from the river and are not likely to be harmful to fish, but they had become dense enough to prevent observation or photography of the fish.

Figure 1. **Cleaning the pool at Phapheng Resort**

On 5 March the catfish were removed and stocked in floating cages in the river (Figure 2); then the pool was drained, cleaned again, and refilled by pumping river water through an improved gravel filter which was effective in removing sediment[1]. In the filter water passes through 3 layers of gravel - coarse, medium and fine - which collect sediment and provide biological substrata, and then the water passes through a fine cloth towel which strains algal cells. The main gravel filter should be cleaned at least once per week and the algal filter needs to be cleaned twice each day, or more often if it is clogging. The pool was refilled to about 1.2 m maximum depth (i.e. not as deep as initially) and a 'fish house' was placed in the deepest point of the pool. The fish house was a wooden tetrahedral frame with edges about 0.9 m long. As well as shelter offered by the house, a small bag of fish feed was tied in the house to attract fish; food was changed daily. By attracting the fish to stay in or near the house they could be exposed to sounds and their responses observed and filmed.

[1] Algae extract dissolved nutrients from water, but sediment also acts as a sink for adsorbed nutrients (NPK and micronutrients), which are desorbed when algae extract nutrients from the water column; hence adding riverine sediment to a test pool is very undesirable as it is a 'sink' for nutrients.

Figure 2. **Floating cages holding fish in the river near the pool**

Tests were carried out over the period 7-13 March 2015 during the dry season, when air temperatures reached 33-36^{o}C each day. To prevent over-heating, the pool was partly shaded and the filter pump was run to circulate the water. To inhibit the growth of algae, after the first trial, polystyrene foam was used to partly cover water in the shallow end of the pool. Nevertheless, and despite the improved filter and shading, algae again grew rapidly so that within 4 days visibility was significantly affected. The pool was drained and refilled on 11 March to a shallower depth of about 0.7 m, and a 2 cm mesh seine net was used to confine the fish to about half of the pool area to make observation and later removal of fish easier (Figure 3).

Figure 3. **The final pool setup, 0.7 m deep, shaded and with a fine mesh net to confine fish**

Some measurements of water quality parameters in the pool were made as shown in Appendix 1. Although warm, the water was well-oxygenated during the morning and fish appeared to be in good condition while within the pool.

4.2 Fish used in trials

More than 200 fish species are known from the Khone Falls area (Baird et al., 1999). The most important in catches are catfish (several families) and carps (Cyprinidae). The trials used eight species of fish from aquaculture, supplied from Ban Hat Xai Khun hatchery which is about 20 km upstream of the test site. The hatchery is run by the government agency LARReC (Living Aquatic Resources Research Centre) and the fish were transported to the site by Somphanh Philavong, the hatchery manager. As shown in Table 1, the test species included three common Mekong catfishes and three common Mekong carps. Two of these (striped catfish and Siamese mud carp) are among the most abundant fish in catches in the Mekong. Two exotic species were also tested, one of which (mrigal) is a cyprinid which is similar to several Mekong species.

As shown in Figures 4 to 6, the catfishes and carps which were tested have well-developed swim bladders, with the variation in swim bladder sizes and shapes likely to reflect differences in hearing ability and vocalisation patterns. It is well-known that catfish produce sounds using their swim bladders or by stridulation using their pectoral fins (e.g. Kaatz et al., 2010). Many Mekong catfish and cyprinids are known to vocalise loudly and distinctively (e.g. Baird and Phylaivanh, 1999), so it would be expected that such fish would also be able to hear and discriminate sounds well.

As well as these catfish and cyprinids, tilapia were tested, as they are non-Otophysan fish, one of a diverse group of fish (Perciformes) which differs from the other species tested in having a closed-off swim bladder (physoclistous fish) and no Weberian apparatus.

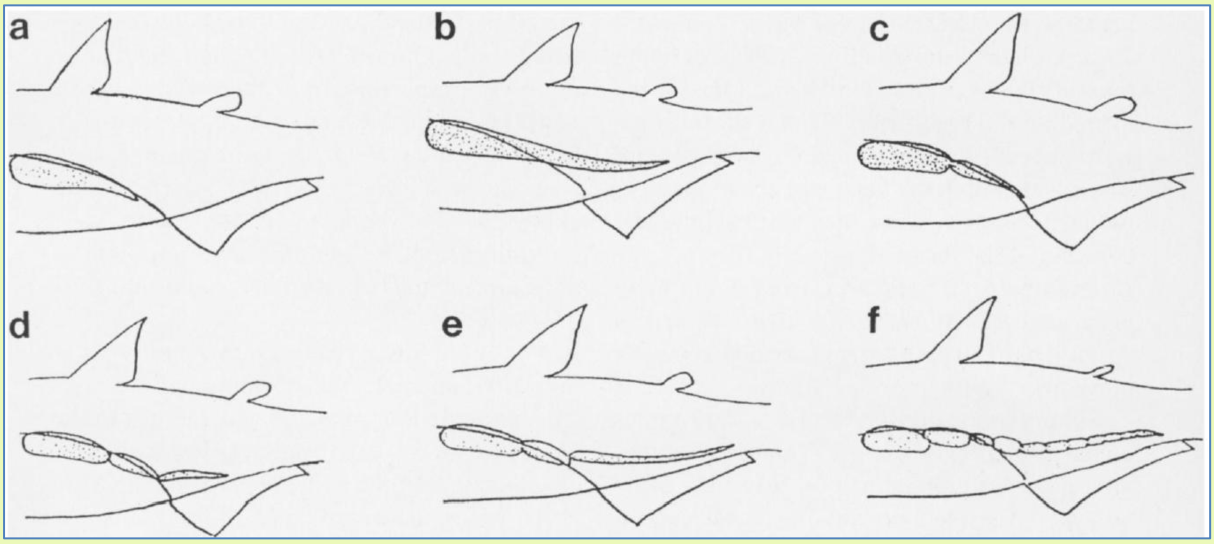
Rather than using wild fish, the trials used fish bred in captivity from locally caught parents. All fish were in good condition and were of a size that was easily observed and filmed. As the trial had limited aims, it was only intended that these fish would be indicative of results for some common Mekong fish.

Table 1. **Fish species used in the trials**

Family	Species	English name	Lao name	Origin	Feeding habit	Maximum Length recorded (cm)	Length of test fish (cm)
CATFISH							
Pangasiidae	*Pangasianodon hypophthalmus*	Striped catfish	Pa suai kiao	Mekong	Omnivorous	150	18
Bagridae	*Hemibagrus wyckioides*	Red-tailed catfish	Pa keung hang deng	Mekong	Omnivorous	130	21
Bagridae	*Hemibagrus spilopterus*	Yellow catfish	Pa kot leuang	Mekong	Omnivorous	36	14
CARPS							
Cyprinidae	*Henicorhynchus siamensis*	Siamese mud carp	Pa soi hua po	Mekong	Herbivorous	23	14
Cyprinidae	*Amblyrhynchichthys micracanthus*	Snub-nosed barb	Pa ta po	Mekong	Omnivorous	46	21
Cyprinidae	*Barbonymus gonionotus*	Silver barb	Pa pak	Mekong	Omnivorous	33	12
Cyprinidae	*Cirrhinus cirrhosus*	Mrigal	Pa mrigal	India	Omnivorous	115	16
PERCH-LIKE FISHES							
Cichlidae	*Oreochromis niloticus*	Nile tilapia	Pa nin	Africa	Herbivorous	46	24

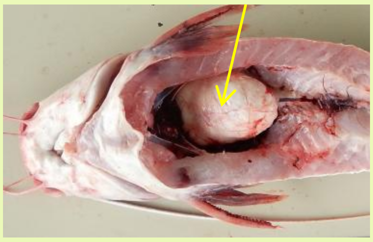
Note: lengths of test fish are ± 1 cm.

Pangasianodon hypophthalmus



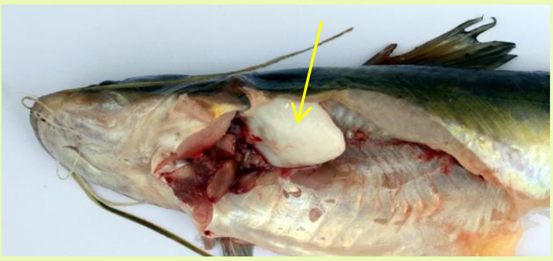
The six types of swim bladders in Pangasiidae (Roberts and Vidthayanon, 1991)
Pangasiidae have swim bladders with 1, 2 or 3 chambers. ***P. hypophthalmus* has a simple single-chambered swim bladder (Type b).** Hence the sensitivity to sounds is likely to vary by species.

Hemibagrus wyckioides



Single-chambered swim bladder

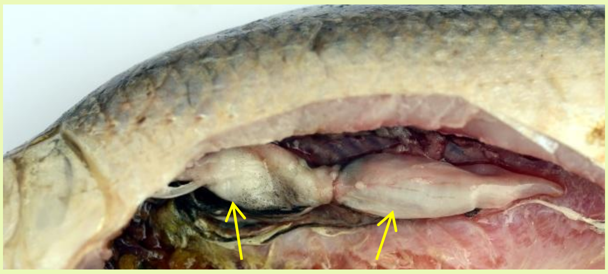
Hemibagrus spilopterus



Single-chambered swim bladder

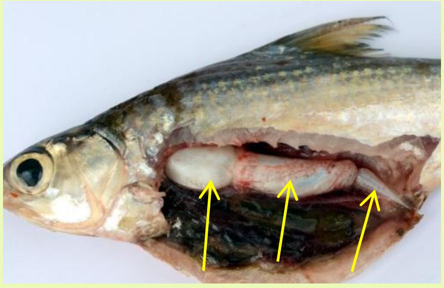
Figure 4. **Catfishes used in the trials, showing morphology of their swim bladders**

Henicorhynchus siamensis



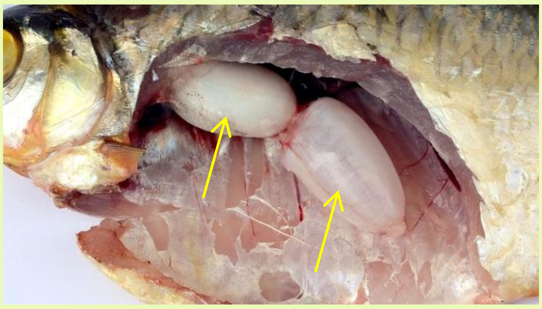
Two-chambered swim bladder

Amblyrhynchichthys micracanthus



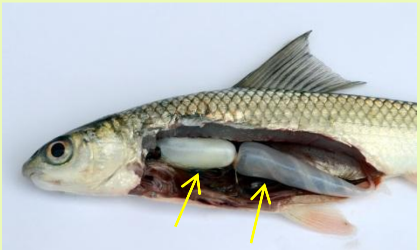
Three-chambered swim bladder

Barbonymus gonionotus



Two-chambered swim bladder

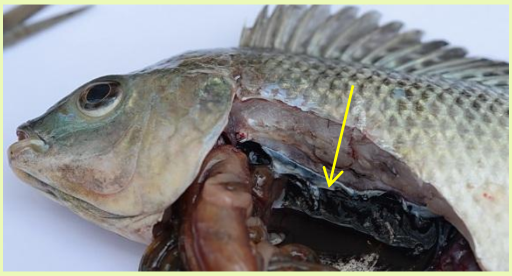
Cirrhinus cirrhosus



Two-chambered swim bladder

Figure 5. **Carps (Cyprinidae) as used in the trials, showing morphology of their swim bladders**

Oreochromis niloticus



Simple small swim bladder, above abdominal cavity

Figure 6. **Nile tilapia as used in the trials, showing morphology of its swim bladder**

4.3 Sound projector and test settings

The sound projector comprised two heavy-duty 140 Watt Underwater Speakers (Clarke Synthesis AQ339) mounted to an aluminium frame (Figure 7). Volume is adjustable and the speakers provide up to 160 dB sound pressure[2] at 400 Hz. Power was provided by a 12-volt battery. The speakers are connected to a control unit which produces an output signal via an amplifier as either a sine wave (which was used throughout) or a triangular wave. The control unit was connected to a laptop computer through which the user selected (1) a desired frequency range within 20 Hz to 800 kHz, (2) a step size in Hz, (3) duration of each frequency in Hz, (4) a profile; either a steep rise with sudden drop, or a saw (regular rise and fall, like a siren), which was used in most of the trials. A randomised series of pulses of selected frequencies can also be output, but was only used once.

It should be noted that a sound level of 160 dB in air[2] would be well above the pain threshold for humans, but in water a sound pressure of 160 dB is approximately equivalent in power to sound pressure of 100 dB in air – quite noisy, but well below the pain threshold for humans and not likely to cause any permanent effects on fish in its vicinity; people can swim near the speakers at full volume with little or no discomfort.

Figure 7. **Somphone installing the underwater speakers in the pool**

Tests were carried out using a series of different frequency ranges, starting within the expected range of maximum sensitivity for most fish (100-1000 Hz) and then using other ranges depending upon observed responses. The tests' sound (i.e. like a siren) can be heard on GoPro recordings at the times indicated in the tables. The tests were generally run for about 20-30 seconds at intervals of a few minutes, or longer intervals if a response was being retested.

4.4 Cameras and recording

Fish movements were recorded on video underwater using a GoPro Hero4 Black camera and from the surface using a Nikon D800 camera with a wide angle lens. Sony underwater cameras were initially used to observe fish directly via a laptop computer, but the footage was relatively poor in quality so was not retained.

[2] Underwater sound levels here are expressed (as is conventional) relative to 1 μPa, whereas sounds in air are expressed relative to 20 μPa

4.5 Test procedure

Because of the time taken to improve filters and shading and to clean and re-fill the pool (as mentioned above) there was relatively limited time to test individual species in detail. Fish were stocked in the pool on the day before each test to allow them to adjust to the pool and fish house.

There was insufficient time to carry out detailed tests of sensitivity to different sound pressure or to test individual fish within a species, partly because the equipment used is quite basic, but also because a lot of time was taken up with pool cleaning and setup. In any case, the tests were adequate for the main purposes for which they were carried out.

Fish were tested as follows.

7 Mar 15	Test 3 species of catfish
8 Mar 15	Test to recheck responses of *Hemibagrus*
11 Mar 15	Test 4 species of cyprinids
13 Mar 15	Test tilapia and retest *P. hypophthalmus*, the most sensitive species of catfish

Fish were held in cages in the river nearby and introduced to the test pool on the day before each test.

The responses of fish were recorded and observed from the surface of the pool and also later checked on the GoPro camera (for catfish). Responses can be graded from little or no effect to a strong effect based on observations of fish behaviour.

5. Results

5.1 Catfish

Behaviour of catfish prior to sound testing

The first batch of fish (3 catfish species; 10 fish of each species) was introduced to the pool on 6 March and their behaviour observed (Figure 8). Most of the fish stayed within the fish house for most of the time during the day, but some fish would leave the house and cruise around the pool at irregular intervals. The 3 species showed a varying degree of mobility and activity as discussed below.

Pangasianodon hypophthalmus: most or all of the fish left the house 1-2 times per hour and cruised around the pool; this species was relatively highly mobile and active, even when within the house. This is a pelagic and highly migratory species, consistent with its shape and elongate well-developed swim bladder.

Hemibagrus spilopterus: some of the fish (usually 3-5) left the house occasionally, perhaps 1-2 times per hour, but they generally swam within a few metres of the house then returned to it within a minute or two; these fish are intermediate in terms of mobility and within this species it seems that some individuals are more sedentary. This species is also of intermediate activity; when in the house they often remained still or attempted to penetrate within the tight group of *H. wyckioides.* This is a very common and widespread Mekong species which is primarily benthic, as can be seen from its shape and relatively small swim bladder.

Hemibagrus wyckioides: these catfish never left the house during the day; they were highly sedentary and tended to clump together in a tight group, moving mainly to try to get further within the shelter of the group. Similarly to *H. spilopterus*, they are a benthic species with a relatively small swim bladder.

These observations were made during daylight hours, and it is possible that some *Hemibagrus* species are nocturnal, which would explain the relative immobility of *H. wyckioides* during the day.

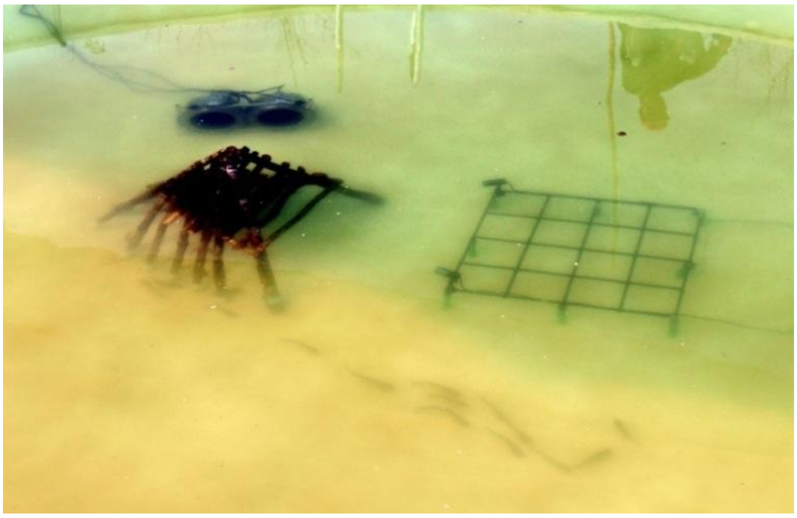


Figure 8. **View from the surface of the pool, just after the catfish were introduced**
The fish house is centre left, speakers are about 1 m to the rear, and a frame to hold two video cameras is right centre. The GroPro camera was placed on the left of the frame facing the fish house. Ten *P. hypopthalmus* are in the foreground while the other two species are within or near the fish house

Vocalisation by catfish

Pangasianodon hypophthalmus is quite vocal; emitting sounds like clicks or rasps frequently, which can be heard clearly on the GoPro videos. The two *Hemibagrus* species appear to be relatively quiet, with only occasional clicks and deeper grunts audible on the GoPro recordings when only they were in the fish house.

Tests with catfish

Fish were exposed to sounds as summarised in Table 2. In the first test the sound level was gradually increased to maximum; in all later tests the sound was set at maximum for the duration.

Pangasianodon hypophthalmus showed the most pronounced response to sound; within the expected range of 100-1000 Hz they left the fish house immediately and stayed well away for several minutes after the first two tests finished (Figure 9 shows some GoPro Clips). They also reacted strongly to low frequency sound (20-100 Hz), moving and staying well away from the speakers. They responded to higher frequency sound (4000-10,000 Hz), but swam about rapidly rather than moving unidirectionally away from the speakers. *Hemibagrus spilopterus* showed a relatively moderate or weak response, some fish moving away in response to sound and swimming in a school with the *P. hypophthalmus*, while some fish stayed in the house, whereas *H. wyckioides* showed little or no response to sound and none of the 10 *H. wyckioides* moved out of the fish house at any time. Hence the three catfish species appear to vary from very responsive to relatively non-responsive to sounds over the ranges tested.

After the first day of testing, the ten *P. hypophthalmus* were removed from the pool leaving the two *Hemibagrus* species. The next day these two species were re-tested (Table 3). While both these catfishes showed some level of response at several sound ranges, generally in most trials the fish stayed within the house (about 0.5 from the speakers); and *H. spilopterus* generally showed a stronger response to sound than *H. wyckioides*. Interestingly there was a very definite response by *H. spilopterus* to very high frequency sound (2000-20,000 Hz).

Table 2. **Summary of tests of responses of 3 catfish species to sound, 7 March 2015**

No.	Time	Duration (s)	Freq. (Herz)		Step	Cycles of each Freq	Response			Notes on response	Time on Nikon (hh:mm)	Time on Go Pro (mm:ss)
			Min	Max			Ph	Hs	Hw			
1	15:00	34	100	500	20	20	Strong	Moderate	Nil or weak	All Ph left and stayed away from the house; none returned for the duration of the tests. Seven Hs left and stayed with Ph school. Hw appeared agitated, but all stayed together in house.	2:47:26 PM	6:31
2	15:00	25	500	1000	20	20	Strong	Weak	Nil or weak	Ph were 2 m from speakers; when sound turned on then swam to the far end of pool, did not come back. Hw moved about in the house, but stayed there in a bunch with 3 Hs. Hs in the house became more active and tried to burrow beneath Hw.	NV	10:01
										All Ph returned to house at 11:15 on GoPro, clicking can be heard, speakers were moved closer to house at 11:45 on GoPro when Ph and 7 Hs left the house. Sign for 1000-2000 Hz was placed in front of house and kept there to see whether clear on the video.		11:15
										All Ph and seven Hs came back into house at 15:40		15:40
3	15:20	29	1000	2000	20	20	Nil or very weak	Nil or very weak	Nil or very weak	Ph swam about 1 m from speakers, no clear response. Hw and Hs moved about in their house but stayed together.	2:57:46 PM	16:45
5	15:30	30	2000	4000	40	40	Nil or very weak	Nil or very weak	Nil or very weak	Ph swam about 1 m from speakers, no clear response. Hw and Hs moved about in their house but stay together	NV	NV
6	15:40	28	20	100	20	20	Strong	Moderate	Nil or weak	Ph were near speakers, when sound turned on they startled then swam directly away and stayed > 5 m away. Five Hs came out of house and stayed with the Ph school.	2:59:38 PM	NV
7	15:50	18	4000	10000	50	50	Strong?	Moderate	Nil or weak	At the start, Ph & five Hs were about 3 m from speakers, quiet. They startled and swam away rapidly then swam about quickly, non- directional relative to the speakers. Hs initially separated from Ph then re-joined them. 5 Hs stayed in the house	3:02:08 PM	NV
8*	16:00	00:00:00	500	10000	50	50	Not clear	Not clear	Not clear	Ph and 5 Hs were outside, about 5 m from the house, stayed still in a tight group, unclear effect.	3:04:34 PM	NV

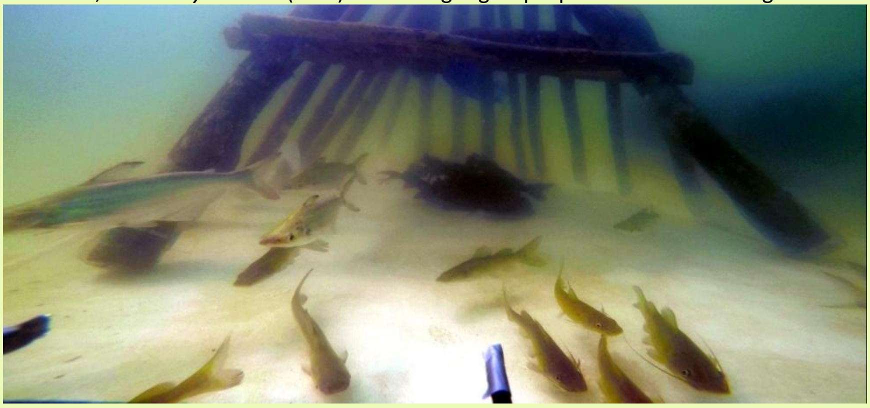
Notes: Test fish: 10 each of *Pangasianodon hypophthalmus* (Ph), *Hemibagrus spilopterus* (Hs), *Hemibagrus wyckioides* (Hw). Output was a sine wave with saw pattern. * - random pattern of sounds. NV-no useable video.

***Table 3.* Summary of tests of responses of 2 *Hemibagrus* species to sound, 8 March 2015**

No.	Time	Duration (s)	Freq. (Herz)		Step	Cycles of each Freq	Response		Notes	Time on Go Pro (mm:ss)
			Min	Max			Hs	Hw		
1	8:12	22	2000	8000	50	50	Weak	Weak	Fish moved together and faced the speaker and became less active.	7:00
2	8:14	25	20	100	10	20	Weak-moderate	Weak-moderate	Fish initially moved away from the speakers but then moved back together.	9:01
3	8:15	25	200	800	20	20	Moderate	Moderate	Initially all fish startled and moved away from speakers, one Hs left the house but returned after 23 sec.	10:47
4	8:17	16	500	700	20	20	Nil or weak	Nil or weak	Slightly increased activity but no exit.	12:54
5	8:18	11	500	700	20	20	Nil or weak	Nil or weak	Little or no response and no exit.	13:16
6	8:21	21	2000	20000	50	50	Moderate	Weak	Very agitated, 5 Hs left the house and stayed out.	16:06

Notes: Test fish: 10 *Hemibagrus spilopterus* (Hs), 10 *Hemibagrus wyckioides* (Hw).
Output was a sine wave with saw pattern. Nikon surface video was not useable.


Prior to turning on sound. *P. hypopthalmus* (silver) cruise at the outside of the fish group, *H. spilopterus* (yellow) further in, and *H. wyckioides* (dark) are in a tight group. Speakers are centre-right in the background.


When sound is turned on, all *P. hypopthalmus* (silver) and seven of ten *H. spilopterus* (yellow) exit rapidly. Note: part of the camera mount can be seen in the foreground.


All of the ten *H. wyckioides* (dark) and 3 *H. spilopterus* (yellow, but obscured) remained in the fish house during the first trial.

Figure 9. **Examples of GoPro clips from the first test of catfish**
See also cover of this report.

After the second test all catfish were removed from the pool.

To recheck the reaction of *P. hypophthalmus* and in the absence of other fish species, five untested *P. hypophthalmus* were introduced to the pool on 12 March and then tested on 13 March using a frequency range of 100-1000 Hz. The five fish reacted strongly and swam away from the fish house and stayed at least 5 m away for the speakers, confirming the earlier observation of a strong response over this range (Table 2).

5.2 Carps

Five individual fish of each of the four cyprinid (carp) species as well as five tilapia were introduced to the pool on 10 March (Figure 10). The tilapia were territorial, with four of them occupying the fish house and chasing the other fish that entered it. One tilapia was sick and later died as it was infected with ectoparasites. The five tilapia were removed from the pond in mid-morning, leaving the four cyprinid species (20 fish in total), which were relatively active; in contrast to the catfish they formed a single school and swam around the full extent of the pool; they were feeding on insects on the surface within hours of introduction. The cyprinids only entered the fish house occasionally and generally left it within a few seconds. Hence, to check their responses it was necessary to watch the school and turn on the sound projector when the fish swam close to the speakers. Because the cyprinids were rarely within the fish house, the GoPro footage was not useful, so only Video taken from the surface was retained.

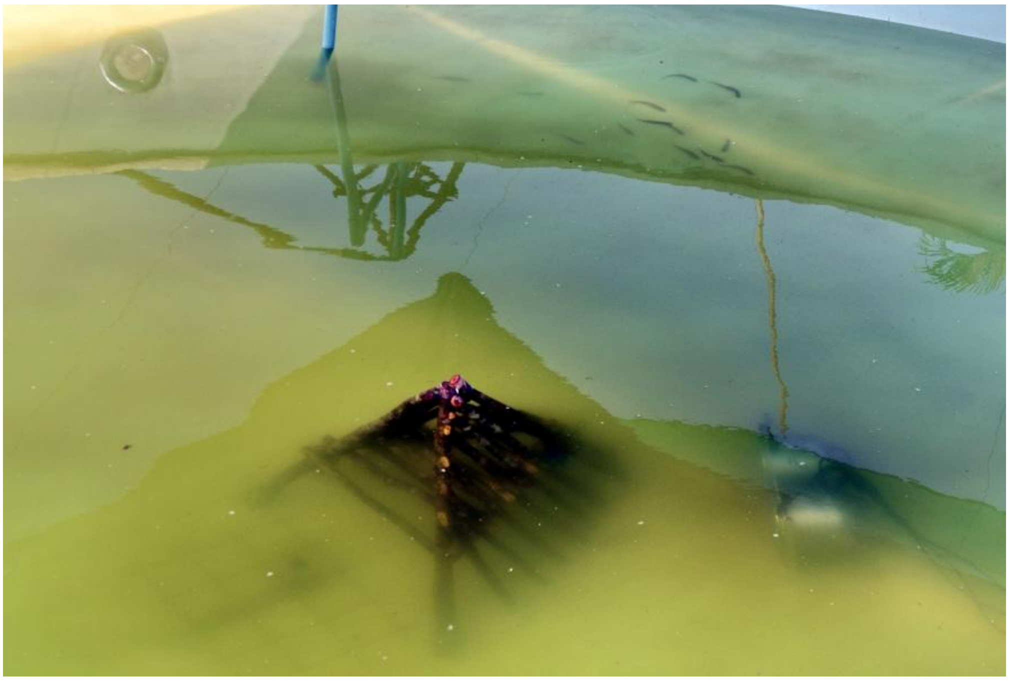


Figure 10. **The test setup as filmed from above, Cyprinids are cruising at upper right**

In general (and in contrast to the catfish), each of the cyprinid species appeared to respond to sounds similarly, with the school of four species staying together throughout most of the tests (Figure 10). However, with the setup used it was not possible to discriminate individual fish's behaviour within the school. In one test, the five *Barbonymus* separated from the other three species for some time, suggesting some minor species-specific difference in responses, as would be expected.

As summarised in Table 4, the cyprinids responded most strongly to sounds between 20 and 120 Hz and also responded well to 100-500 Hz, with little or no response to higher frequencies. The general pattern was that fish were cruising before the sound started, then when the sound was turned on the fish startled (i.e. they rapidly increased speed and changed direction), then they swam away from the speakers.

After completing the tests the cyprinids were removed from the pool and the pool was drained and refilled.

***Table 4.* Summary of tests of responses of 4 carp species to sound, 11 March 2015**

No.	Time	Duration (sec)	Frequency (Herz)		Step	Cycles of each Freq	Response	Notes
			Min	Max				
1	9:38	27	100	500	20	20	Moderate-strong	Fish darted away from speakers as soon as low tone started and they stayed away.
2	9:42	17	500	1000	20	20	Weak	Delayed response - fish milled around for a few seconds before swimming away.
3	9:46	15	20	120	20	20	Strong	Fish darted away from speakers as soon as low tone started and they stayed away.
4	10:40	7+7+11	20	120	20	20	Strong	Recheck - one hour after previous test, fish still responded strongly by swimming away,
5	10:45	26	100	300	20	20	Weak	Delayed response; fish milled around for a few seconds before swimming away.
6	10:48	18	300	700	20	20	Weak or negligible	Fish swam straight towards speakers before recouping and swimming away, minor
7	10:54	20	1000	4000	50	20	Weak or negligible	Little or no response evident.
8	10:59	36	100	1000	20	20	Weak or negligible	Initial effect, but fish stayed near speakers for > 10 sec, may have habituated.
9	11:03	20	2000	20000	50	50	Weak or negligible	Little or no response evident.

Notes: Test fish: 5 each of *Henicorhynchus siamensis, Amblyrhynchichthys micracanthus, Barbonymus gonionotus, and Cirrhinus cirrhosus.* Output was a sine wave with saw pattern. GoPro video was not useable as fish rarely entered the fish house. Times refer to Nikon video.

5.3 Nile tilapia

Five tilapia were introduced to the pool on 12 March. This species was mobile, but relatively slow-swimming, and as for the cyprinids, the tilapia moved around the pool slowly, apparently feeding on algae and only entering the fish house only occasionally (Figure 11). Their response to sound was tested in the same way as cyprinids – by turning on the sound when the fish had swum close to the speakers and observing their response.

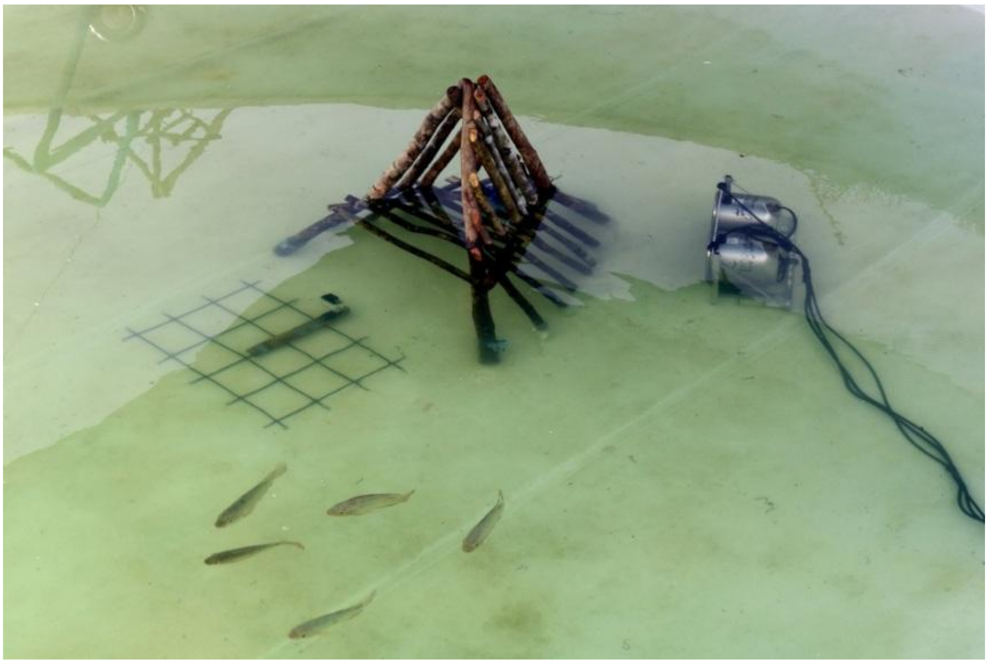


Figure 11. Five tilapia swimming in front of the fish house and speakers

In this test the conditions for observation had been improved; water is clear and shallow, and only one underwater camera was being used, a GoPro on the frame facing the fish house.

As summarised in Table 5, tilapia were unresponsive to virtually all sounds. The only noticeable reaction was when a single fish startled when it was close to the speakers at a high frequency output.

To further check the sensitivity of tilapia, the upper edge of the pool was tapped with a wooden stick, but the tilapia did not respond. Then the side of the pool was tapped and the fish swam towards the source. This response is likely a result of training by growers who tap the side of a pond when feeding fish, although non-responsive to a range of sounds, perhaps tilapia can detect the vibrations via their lateral line.

Table 5. **Summary of tests of responses of Nile tilapia to sound, 13 March 2015**

No.	Time	Duration (s)	Frequency (Herz)		Step	Cycles of each Freq	Response	Notes
			Min	Max				
1	8:29	41	100	1000	20	20	No response	No response
2	8:32	20	0	100	20	20	No response	No response
3	8:33	24	1000	5000	50	50	No response	No response
4	8:54	19	5000	15000	50	50	Weak response	One fish about 0.5 m from speakers startled then swam quickly away, the other 4 fish were at

Notes: Test fish: five *Oreochromis niloticus*, commercial monosex strain. Output was a sine wave with saw pattern. GoPro video was not useable as fish rarely entered the fish house. Times refer to Nikon video.

A single goby was incidentally introduced into the pond with the river water (i.e. through the pump) and it can be clearly seen in the first video swimming rapidly away from the sound source at 100-1000 Hz.

6. Discussion and Conclusions

6.1 Overview

The results show that fish which are representative of the most important groups of Mekong fish (catfishes and cyprinids) detect sound within expected ranges, and that these fish avoid loud noises within a range of 20-1000 Hz (catfish) and 20-500 Hz (Cyprinids), initially startling then swimming away from the sound source. Therefore, loud noises with frequencies in the range of 20-1000 Hz can be expected to deter many species of Mekong fish and development of an acoustic fish deterrence (AFD) system should be further investigated

The three catfish species showed a range of responses (high, moderate and low) which are consistent with their ecology and morphology:

- *Pangasianodon hypophthalmus*: highly responsive pelagic catfish with well-developed elongate swim bladder and an active vocaliser; can be expected to use and detect sound well, as was observed.

- *Hemibagrus spilopterus*: moderately responsive benthic catfish, medium sized and moderately active, small swim bladder, showed some response to sound, but much less than *P. hypophthalmus*.

- *Hemibagrus wyckioides*: low level of response, large benthic catfish, relatively sedentary species (during daylight) and perhaps relies less on sound and more on use of other systems, e.g. scent and touch via its very long barbels.

The four cyprinid species all showed a similar and high level of response to sound; all are active and migratory fish which have well-developed swim bladders, so they are all likely to be able to detect and utilise sound to orient and navigate within their environment, to communicate and to avoid predators and detect prey, hence the results are much as expected.

Mekong fish evolved within an environment that is turbid for much of the year, where a good sense of hearing would generally be an advantage for survival. By contrast, Nile tilapia were almost non-responsive to sound, as might be expected given that they originate from relatively clear waters in Africa, where they feed on macrophytes and phytoplankton and likely utilise other senses (sight and smell) to a greater degree than hearing. While the Nile tilapia's hearing may be relatively poor, the strain of fish which was used is the result of an intensive breeding program which may have altered its natural hearing abilities.

6.2 Further studies of captive fish

It would be useful to perform more detailed pool studies of the responses of individual species, which should correlate with and support results from fieldwork. Additionally, the response of some large and high-profile species such as the giant catfish (*Pangasianodon gigas*), giant barb (*Catlocarpio siamensis*) and Jullien's barb (*Probarbus jullieni*) should be recorded. These large fish might not be present during field testing, but all can be purchased from aquaculture farms in Thailand.

Based on the observations of rapid algal growth, for any future trials the pool should only be filled to a shallow depth (0.7 m max.) which is adequate for most fish, makes observation easier, and allows easier water management and recapture of fish. Rather than attempting to filter algae efficiently from the water, it would be generally preferable to hold fish in cages in the river, transferring them to the pool within a day of filling it, and then carrying out any tests within a day or two of stocking. In this way, tests with a single species or group of species could be completed in less than 2 days, and the pool could be drained and refilled after one or two tests.

During testing, the pool management and system setup and approach were improved greatly, so that any future work could be carried out more expeditiously. During the tests there were problems with staff availability (absence of a contractor) and lack of experience of DSPC staff, so adequate planning and training should be allowed for prior to the tests, with cameras to be set up and tested and times and dates carefully cross-checked.

6.3 Field testing and improving deterrence

Based on the test results and existing literature, for deterring most species of Mekong fish the effective frequency range is likely to be 20-1000 Herz, so field testing of deterrence of wild fish could be implemented with the unit in its current configuration, outputting a saw pattern (i.e. siren) over that range. However, prior to field testing, it would also be desirable to add functions to the sound projector as follows.

1) A function is needed to allow breaks to be specified in the output (e.g. the unit could emit for 5 seconds on, 5 seconds off) to enhance the startling effect and to reduce habituation, and to save power on any long deployment in the field.

2) A function is needed to allow duration of each frequency to be specified by time (rather than cycles) so that the shape of any output pattern can be specified exactly.

Field testing is needed because the pool system tested the response of fish which were within a confined area where a speaker was turned on nearby, whereas in the field, wild fish would be swimming towards a sound-emitting device, so their response may be different. Furthermore, the tested fish were captive-bred and included only six of the many species found in the Khone Falls area. Background noise and other features of the natural environment also affect whether fish can detect a sound, avoid a sound source, and then continue to stay away from it. The experimental approach in the field would be a comparison of fishing gears which are set in pairs, with the sound projector operating near one of the gears each day and switched between the gears in a random pattern (i.e. a paired comparison). The effectiveness of sound in repelling fish would be judged by the differences in catches between the gears with and without the adjacent sound source.

In addition to field-testing the sound projector, and thinking ahead to developing a workable system, it is recommended to investigate the feasibility of a mechanical device which would create random clanging or banging noises. It seems probable that a mechanical device which rattled or banged would repel many fish, which have been naturally selected to avoid injury caused by collision with moving rocks; or to avoid predators which signal their presence by vibration through the substrate. Fishers in Cambodia use marble-filled cans which rattle underwater to divert fish into traps (Deap et al., 2003); and in northeast Thailand metal rings rattled underwater are used to scare fish into nets in reservoirs (Figure 12). In the Khone Falls area, similar rattling devices are used to scare fish into nets, and these are generally banned under community fishery regulations (Baird, 2001). In shallow streams in northern Laos, fishers drag cans over rocks to scare fish into traps (Kongher Herjalearn, 2015 pers. comm.). A suitable device for deterring fish could be a rotating drum or wheel with attached paddles and internal steel balls, which would be positioned underwater and which could be driven hydraulically. Such a system would likely be much cheaper, more robust and require less maintenance than the high-tech speaker-based systems which have been used elsewhere to do what is essentially a simple job – generate loud noises to scare fish away from a place which may be dangerous for them. If possible, a prototype could be field-tested at the same time as the sound projector.

Figure 12. **Metal rings arrayed on a pole are rattled underwater to scare fish into nets**
Photo at Huai Luang Reservoir, northeast Thailand.

6.4 Planning for further work on AFD

It is recommended that further pool-based observations and field work be planned for October to November for several reasons.

1) Fish are migrating downstream at that time.
2) The river will be carrying less sediment, detritus and algae.
3) There is an overload of work at present that requires full commitment from the staff.

Planning should take account of the suggestions above in 5.2 and 5.3, and also include measures to ensure that staff members are allocated and available for the job, and that fish which are disease-free are sourced well ahead of any planned experiments.

Field work would be based on the established monitoring system, in which trained fishers set gears and process and document catches, so is unlikely to present any special difficulties.

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Appendix 1. **Water quality measurements during the trial**

Date	pH	DO (%)	Conductivity (µS/cm)	Temperature (^{o}C)	Time
10/03/2015	7.4	98.7	221	28.7	9:30
11/03/2015	7.0	91.6	251	27.4	8:56
12/03/2015	7.0	90.4	216	29.3	10:30