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Final report

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Contents

Glossary of terms

Fish lock A fish lock, in principle, has the same function as a lock for a ship. It has a gate at its entrance, a holding chamber and a gate at its exit. It attracts fish into the holding chamber and when the exit gate opens the fish move from the chamber upstream of the barrier. At the XHPP, there are two fish locks located at the upstream end of the fish pass (i.e. fish pass exit), which facilitate the final part of the upstream journey for fish wishing to move past the dam.

Fish pass A specially-designed sloping concrete channel, with a defined entrance and exit, that allows fish to swim around barriers such as dams and weirs. At the XHPP, the fish pass facilitates the first part of the upstream journey for fish wishing to move past the dam (and the locks facilitate the second part of the journey).

Fish pass facility Refers to the combination of the fish pass and fish locks – given that they work together in facilitating the complete journey for fish passing the XHPP.

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2 Executive summary

The site of the world's most productive inland fishery — the Lower Mekong Basin (LMB) — is currently being progressively developed for hydropower generation. There are plans to build eleven hydropower plants on the mainstem of the Mekong River, and many more on its tributaries. Unless appropriate fish passage measures are incorporated into these facilities, many migratory fish species will be obstructed from accessing vital feeding, spawning and nursery habitat, and their populations will be greatly diminished or may even become locally extinct.

The first mainstem Mekong hydropower facility — at Xayaburi in Lao PDR — has already been built and began operating in October 2019. Significant investment was put towards mitigating fish passage at the Xayaburi Hydroelectric Power Plant (XHPP) via the installation of a vertical slot fish pass and two locks. These fish pass facilities were designed to set the best-practice standard for future mainstem hydropower developments.

The current research project was established between Australia, Thailand and Lao PDR to optimise the effectiveness of the Xayaburi fish pass facilities. The specific objectives of this project were to: (1) develop a suite of monitoring techniques for assessing the performance of mainstem fish pass facilities in the LMB; (2) optimise the Xayaburi fish pass facilities; and (3) provide a standard for monitoring and constructing other fish pass facilities in the LMB.

This project has greatly enhanced monitoring capabilities for assessing the effectiveness of mainstem fish pass facilities in the LMB; and provided a standard for designing, constructing and monitoring other fish pass facilities in the LMB. The monitoring techniques developed during this study have been empirically validated on the XHPP's fish pass facilities. They have also generated baseline knowledge on the effectiveness of the XHPP's fish pass facilities. Specifically, FIS/2017/017 showed that *Sikukia gudgeri*, *Hypsibarbus lagleri*, *Hemibagrus filamentus*, *Puntioplites falcifer*, *Barbonymus schwanenfeldii*, and *Scaphognathops bandanensis* can all be safely PIT tagged for long-term assessments of fish pass effectiveness. As of April 2024, a total of 4861 wild Mekong fish have been PIT tagged so far for monitoring the effectiveness of the Xayaburi fish pass, and the Xayaburi fish pass has found to be capable of achieving a passage efficiency of 87%. These findings will be critical for optimising the operation of the fish pass facilities during a recently approved follow-up project (FIS/2023/133) to the current one. Consequently, the benefits of FIS/2017/017 are expected to be realised in terms of fish pass optimisation and improved guidance for future LMB hydropower developments over the coming 5–10 years.

The data generated by FIS/2017/017 represent the first and only empirical source of knowledge on the effectiveness of hydropower fisheries mitigation measures for the LMB, and are consequently generating high levels of interest from public and private stakeholders – especially the MRC and other hydropower developers in the region. Other highlights from the project include the generation (to date) of 7 international conference presentations, 3 international journal papers, 7 reports, 3 sets of instructional videos, 2 training manuals, and one pending PhD thesis.

The high level of interest in the learnings from FIS/2017/017 throughout Southeast Asia is a strong testament to a cohesive team and what can be achieved when due consideration is awarded to researching and developing monitoring techniques for assessing fisheries mitigation efforts. The next phase of the work (FIS/2023/133) will apply the newly developed techniques to optimise the Xayaburi fish pass facilities, and inform the design and construction of the fish pass facilities at the next proposed mainstem hydropower plant – to be located upstream at Luang Prabang.

3 Background

3.1 Impacts of dams on fisheries and the role of fish passage technologies

The development of mainstem dams has long been a highly contentious issue (Ziv *et al.*, 2012; Winemiller *et al.*, 2016). Such structures improve livelihoods by sustaining agricultural production and hydropower generation, and creating employment opportunities — especially while they are being constructed. However, they can have unfavourable consequences for riverine biota, by modifying river flows, generating cold-water pollution and disrupting connectivity (Pringle *et al.*, 2000). In particular, they prevent migratory fishes from accessing critical feeding, spawning and nursery habitat to complete their life cycles (Orr *et al.*, 2012). Consequently, dams are thought to have contributed to the declines of many inland fisheries around the globe, and these declines are likely to be exacerbated as the growth in dam construction continues over the coming decades (Ziv *et al.*, 2012; Winemiller *et al.*, 2016).

Fish passage technologies are being increasingly used in rivers around the globe to mitigate the barrier impacts of dams and other infrastructure on fisheries (Clay, 1995; Baumgartner *et al.*, 2020). The most common form, fish passes (or fishways), consist of channels that go around or through a physical barrier and enable fish to pass without suffering unnecessary stress (Baumgartner *et al.*, 2016). These technologies have been effective in circumstances where they have been suitably designed and operated for the target species and local hydrological conditions (Baumgartner *et al.*, 2020; Stuart and Marsden, 2021). By contrast, they have yielded sub-optimal fish passage outcomes where unsuitable designs have been applied, and/or there facilitation of fish movements has not been properly assessed and monitored (Petts, 1984; Welcomme, 1985). Consequently, the monitoring and evaluation phase of any fish pass installation is at least equally as important as the design and construction phase.

3.2 Monitoring approaches for assessing fish movements through fish pass facilities

Fish movement patterns can be assessed using a wide range of mark-recapture techniques (Lucas and Baras, 2000). These mark-recapture techniques are generally characterised as either natural marks (e.g. morphological features), synthetic passive marks and tags (e.g. tattoos, brands), or electronic tags (e.g. passive integrated transponder (PIT) tags, acoustic tags, radio tags) (Lucas and Baras, 2000). Of the range of techniques currently available, PIT tagging has been found to be particularly useful for investigating the movements of temperate freshwater species through fish pass facilities (Castro-Santos *et al.*, 1996), principally due to the fact that the tags (1) are powered electromagnetically and don’t need a battery, (2) are relatively inexpensive, and (3) can be used on both large and small-bodied species to provide comprehensive information on their movements (Castro-Santos *et al.*, 1996). The tags function by sending out a unique signal that can be detected by a low frequency antenna (Axel *et al.*, 2005). Consequently, the effectiveness of any PIT tagging system in a fish pass is reliant on there being an appropriately configured PIT antenna system within the fish pass. It is also crucial that the target species can retain the PIT tags for long periods of time without being negatively affected, and that there is an efficient procedure available for regularly tagging large populations of the target species.

3.3 The Xayaburi fish pass research project

The issue of hydropower construction is currently particularly topical in the Lower Mekong Basin (LMB) in South East Asia (Ziv *et al.*, 2012). The LMB fish community is extremely diverse, with approximately 850 freshwater species, or as many as 1100 species if coastal and marine species are additionally considered (Hortle, 2009; Orr *et al.*, 2012). Many of these species are endemic to the LMB, including a giant catfish – *Pangasianodon gigas* – which can reach up to 350 kg, a giant freshwater stingray – *Himantura chaophraya* – which can grow up to 600 kg, and a critically endangered species of freshwater dolphin – *Orcaella brevirostris*. The LMB fish community is also highly productive, and supports a value chain with an estimated annual first-sale worth of about $US17 billion (Nam *et al.*, 2015). These fish supply 50–80% of the animal protein consumed by the 60 million people occupying the LMB (Hortle, 2007; Baumgartner *et al.*, 2016). Nonetheless, the LMB fish community has recently been imperilled by extensive river development. There are plans to construct eleven hydropower plants on the main channel of the Mekong River, and many more on its tributaries. The first of these, at Xayaburi, in northern Lao PDR, has already been built and recently became operational in October 2019.

The Xayaburi Hydropower Project is a run-of-river facility, which is about 810 m long by 32 m high and has an installed capacity of 1,260 MW. A significant amount of investment has been allocated towards mitigating the impacts on fish passage, through the installation of a vertical slot fish pass and two locks. The Xayaburi fish pass facilities were designed to pass large biomasses of more than 100 species of fishes, ranging in size from several centimetres to more than one metre. However, the performance of the Xayaburi fish pass facilities remain untested, and prior to the current research no monitoring techniques had been developed for maximising their performance.

In 2017, the Lao and Australian governments facilitated a partnership between Xayaburi Power Company Limited (XPCL), Charles Sturt University (CSU), National University of Laos (NUoL) and the National Agriculture and Forestry Research Institute (NAFRI) to initiate a research program at the Xayaburi fish pass site. The research program sought to develop a set of monitoring approaches for evaluating the effectiveness of mainstem fish pass facilities in the LMB; and to use these approaches to optimise the operation of the Xayaburi fish pass itself. It was anticipated that the knowledge and tools developed from the Xayaburi fish pass research project would also serve as a benchmark for building and monitoring other future fish pass facilities in the LMB.

4 Objectives

This project had three specific objectives:

4.1 Objective 1: To develop a suite of monitoring techniques for assessing the performance of mainstem fish pass facilities in the LMB

Given that the Xayaburi Hydropower Plant and fish pass facilities were firsts of their kind on the mainstem of the Mekong River, an initial goal was to establish a set of monitoring techniques that could be used to evaluate the effectiveness of the Xayaburi fish pass facilities and other future mainstem fish pass facilities in the LMB.

4.2 Objective 2: To optimise the Xayaburi fish pass facilities

Objective 2 was to apply the monitoring techniques developed under Objective 1 to the Xayaburi fish pass facilities, to maximise their effectiveness in facilitating fish passage. This was achieved by using the monitoring techniques to assess a suite of fish movement indicators (see Appendix 2), and then applying the obtained knowledge to adaptively manage fish movements through the fish pass facilities.

4.3 Objective 3: To provide a standard for monitoring and constructing other fish pass facilities in the LMB

Once the monitoring techniques and protocols were developed (Objective 1) and validated on the Xayaburi fish pass facilities (Objective 2), the third objective was to make them the standard techniques and protocols for monitoring other fish pass facilities planned for the LMB. Objective 3 also involved feeding the monitoring and evaluation results from the Xayaburi fish pass facilities back into informing the design and construction of future mainstem fish pass facilities.

Figure 1. Aerial view of the Xayaburi Hydropower project looking upstream during the construction phase. The fish pass is located on the right-hand side of the HPP in this picture (source: unknown).

5 Methodology

5.1 Overall approach

The key research activities for this project were all undertaken onsite at the Xayaburi Hydropower Plant, which is situated in the province of Xayaburi, about 103 km south of Luang Prabang in Lao PDR (Figure 2).

The overall project approach involved conducting eight interdependent studies, essentially in chronological order (Figure 3) (see Appendix 2 for more detail on the approaches for each study).

The eight studies resulted in a suite of scientific manuscripts, grey literature technical reports and a policy brief, which have been summarised in Section 7.

The key findings from the eight studies have been summarised in Section 7 and the specific results have been reported in Appendix 2.

Figure 2. Map of South East Asia, with the Xayaburi HPP site in northern Lao PDR represented by a yellow star.

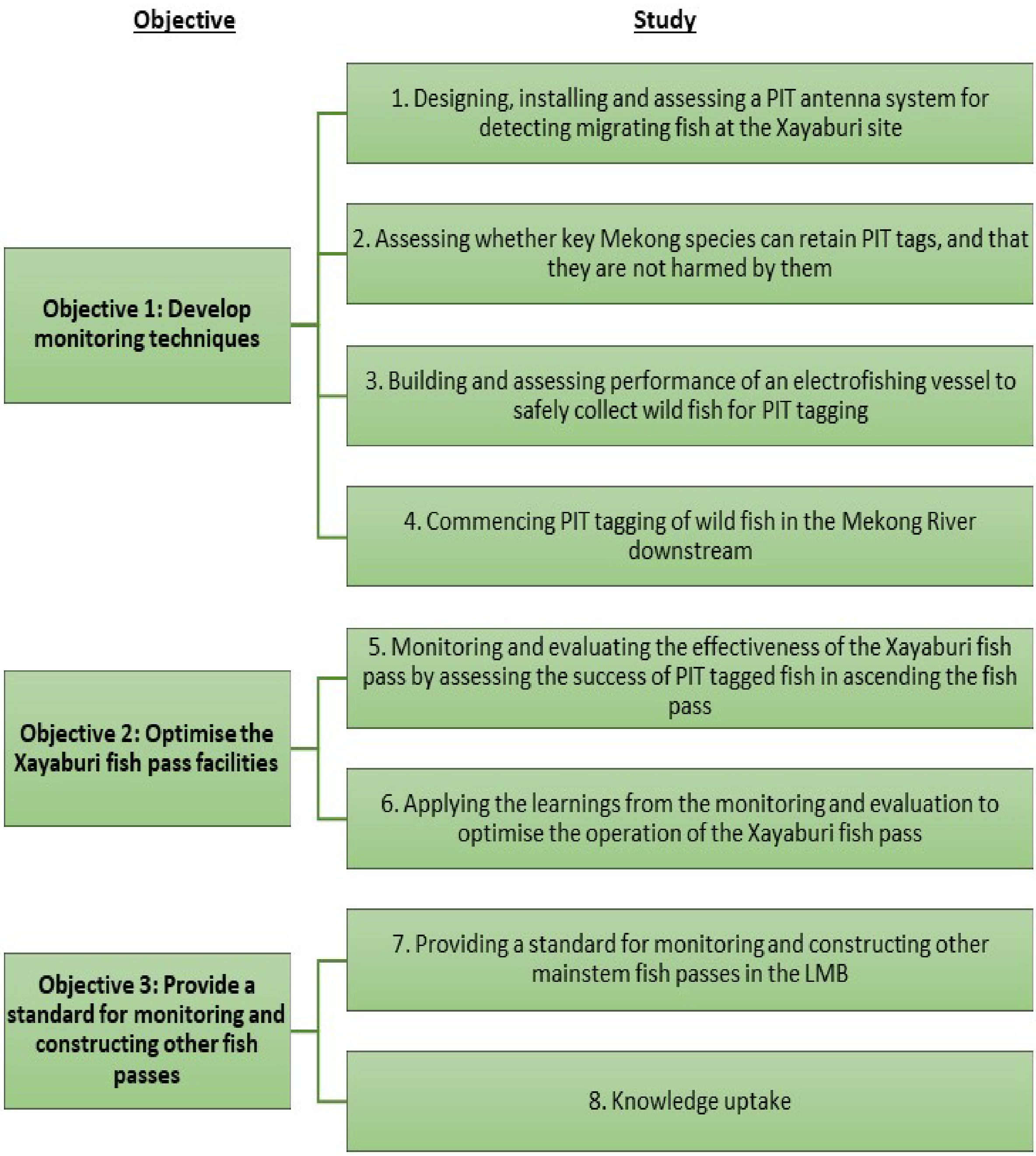

Figure 3. Organisational chart, showing the relationship between the three objectives and their studies.

5.2 Objective 1: To develop a suite of monitoring techniques for assessing the performance of mainstem fish pass facilities in the LMB

Objective 1 was addressed by undertaking Study's 1–4:

1. Designing, installing and assessing a PIT antenna system for detecting migrating fish at the Xayaburi site
2. Assessing whether key Mekong species can retain PIT tags, and that they are not harmed by them
3. Building and assessing performance of an electrofishing vessel to safely collect wild fish for PIT tagging
4. Commencing PIT tagging of wild fish in the Mekong River downstream.

5.3 Objective 2: To optimise the Xayaburi fish pass facilities

Two studies (Study's 5 and 6) were undertaken to address Objective 2:

5. Monitoring and evaluating the effectiveness of the Xayaburi fish pass by assessing the success of PIT tagged fish in ascending the fish pass
6. Applying the learnings from the monitoring and evaluation to optimise the operation of the Xayaburi fish pass.

5.4 Objective 3: To provide a standard for monitoring and constructing other fish pass facilities in the LMB

Objective 3 was addressed by performing Study's 7 and 8:

7. Providing a standard for monitoring and constructing other mainstem fish pass facilities in the LMB
8. The uptake of project outputs.

To foster the adoption of project-generated knowledge and other outputs (i.e. Study 8), numerous extension activities were undertaken over the project's lifespan, including:

- Site visits by officials (e.g. the Australian ambassador visited Xayaburi in October 2020)
- Communication and extension activities targeted towards end users (e.g. the team developed and shared PIT tagging training videos during the lockdown period of COVID-19, and then gave follow-up face-to-face training once travel resumed)
- Hands-on training of fisheries scientists, managers and students in Asia and Australia (e.g. boat handling and electrofishing training was provided to XPCL, LARReC and NUOL staff)
- Presentations – conference and other (e.g. hosting one international conference (Fish Passage 2018) and one conference session (at the 3rd World Irrigation Forum in 2019) on fish passage).

The learnings and scale-out arising from FIS/2017/017 have been reported in the Impacts section (Section 8) for the sake of brevity and to minimise repetition. Nevertheless, these broadly translated to:

- Dissemination of learnings to high level government officials (e.g. the Australian ambassador)
- Design advice and construction supervision (e.g. for constructing the PIT antennas)
- Provision of technical assistance (e.g. for the PIT tagging program)
- Mentoring and staff development (e.g. for the boat handling and electrofishing training)
- Policy advice and guidance documents (e.g. via a policy brief developed for DFAT and ACIAR).

A summary of the approaches taken for each of the eight studies has been presented in Table 1. Detailed versions of these study approaches are provided in Appendix 2.

Table 1. Summary of the approaches used for each study (and study objective).

Objective	Study	Study approach
Objective 1: Develop monitoring techniques	1: Design, install and assess a PIT system	Assessed a range of potentially suitable antenna arrangements for the fish pass, after considering the dimensions of the vertical slot fish pass, site environmental conditions, and available budget. Initially constructed prototypes of the antenna configurations and tested them 'in the dry' at CSU – Albury campus. An optimal antenna design was selected for the Xayaburi fish pass and this design was then implemented. The reader systems were installed and linked to a cloud-based database (FishNet) to continuously record fish movements at the site.
	2: Assess PIT tag retention	Assessed the ability of Mekong species to be able to retain PIT tags indefinitely without the tags affecting their condition or causing death. Undertook experiments on key species in replicated outdoor tanks at the Xayaburi Aquatic Laboratory, with PIT tagged and control (untagged) individuals. Checked for tag retention and assessed body condition and mortality at the end of each trial.
	3: Build and assess electrofishing boat for capturing fish to tag	Designed and commissioned the construction of an electrofishing boat. Assessed the function of the boat and trained in-country partners in how to use it safely.

Objective	**Study**	**Study approach**
	4: Commence PIT tagging wild fish	Used the e-fishing boat to capture fish, and tagged and released these fish using the technique validated in Study 2. In addition, captured fish from the exit of the fish pass for tagging.
Objective 2: Optimise the Xayaburi fish pass facilities	5: Monitor and evaluate effectiveness of fish pass	Assessed a range of 'success measures' using the PIT tag detection data in FishNet, including number of fish tagged annually, percentage of tagged fish detected, and percentage of fish successfully ascending the fish pass. Also assessed the physical conditions that fish may be exposed to when passing through the hydropower turbines, by passing data loggers, known as Sensor Fish, through the hydropower structure.
	6: Optimise the Xayaburi fish pass	Results from the monitoring and evaluation study used to inform the Xayaburi fish pass's operational settings.
Objective 3: Provide a standard for monitoring and constructing other fish pass facilities	7: Develop a standard for monitoring and evaluating other fish pass facilities for mainstem hydropower plants	The monitoring protocols developed (Study's 1–4) and fish pass M&E knowledge gained (Study's 5 and 6) used to formally develop recommendations for optimising the effectiveness of fish pass facilities for other mainstem hydropower plants in the LMB.
	8: Knowledge uptake	Hosted numerous stakeholder engagement meetings, one international conference and one conference session on fish passage.

6 Achievements against activities and outputs/milestones

FIS/2017/017's project activities had to be strictly performed in chronological order, because they possessed sequential timeframes and were inter-dependent on one another.

This sequence entailed designing, building and optimising the PIT detection system; then conducting PIT tag retention trials to evaluate the success of PIT tagging local species; then developing a safe and efficient approach for collecting fish from the Mekong River; then PIT tagging the fish and releasing them back into the river; and then monitoring and assessing the PIT tagged fish ascending the fish pass to maximise the operational effectiveness of the fish pass. The project activities and associated milestones have been displayed here in a chronological sequence (i.e. by year, rather than by objective) to reflect their timing. Nonetheless, the strategic relationships to project objectives have still been included in the table.

The novel methodological approaches developed during this study have piqued the interest of government agencies, developers, and the MRC (through the Joint Environmental Monitoring program) and scientists. This has been evidenced by a significant increase in requests from these stakeholders to access the data and for the data to be presented at various regional forums. The team is working to publish the data in reputable international journals, to ensure the data are defensible and have passed peer review.

Table 2. Achievements against activities and outputs/milestones. For each activity, O1 = Objective 1; O2 = Objective 2, O3 = Objective 3. Also, S1 = Study 1; S2 = Study 2 and so on up to Study 8. G = General (i.e. not specific to any particular objective or study).

Year 1 (Sep 2019 – Aug 2020)

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Approvals to commence **(G)**	MOU's and agreements exchanged Panel membership confirmed with Communication and Publication Plan discussed Terms of Reference endorsed	Commencement	Completed.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.2	Antenna systems installed (commenced during SRA) **(O1-S1)**	Meeting minutes and agreed workplan Site selection finalised Monitoring systems conceptualised	Within three months	Completed. Antenna specifications from SRA have been successfully applied to the Xayaburi site. Functional and effective system has been installed. Linked to cloud-based database to maximise user efficiency.
1.3	Conclude antenna design experiments (commenced during SRA) **(O1-S1)**	Ensure that all antennas on site are operating optimally	Within six months	Completed. Antennas have been operating effectively and efficiently since being commissioned.
1.4	Continue tag retention trials (commenced during SRA) **(O1-S2)**	Design document completed and species selected	Within nine months	Completed. Fourteen PIT tag retention trials have been undertaken so far.
1.5	Update other groups **(G)**	Liaise with MRC and other interested groups where work overlaps	Opportunistically	Completed. CSU has finalised its involvement in the JEM project. This project tested the effectiveness and efficiency of acoustic tagging and PIT tagging around the Don Sahong hydropower plant near Khone Falls.
1.6	Project steering committee meeting **(G)**	Hold team meeting on site	Nov 2019	DEVIATION FROM PLANNED ACTIVITY: Cancelled due to site closure associated with a regal visit by the Thai Princess. Meeting deferred to 2021. Not COVID-related.
1.7	Construct electrofishing boat **(O1-S3)**	XPCL purchase and build boat under guidance of CSU staff and receive electrofishing training from CSU staff.	Within first year	Completed. XPCL/Lao staff have been successfully trained in electrofishing and can operate the boat independently now.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.8	Training in PIT tagging and safe fish husbandry **(O1-S2)**	Perform training of XPCL, NUOL and LARReC staff in fish tagging	Aug 2020 (but ongoing in each year)	Completed. Variation funding by ACIAR provided an opportunity to develop a series of instructional videos with an expert videographer. The variation funding also enabled a CSU scientist to work on the project full time in Lao PDR. He visited the site four times during the COVID lockdown, and enabled this work to progress efficiently.

Year 2 (Sep 2020 – Aug 2021)

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Annual reporting **(G)**	Annual reporting to DFAT	March 2021	Completed. Annual report was shifted to December 2020 to enable reporting on any COVID-delays. Successfully accepted as per ACIAR contracting conditions.
2.2	Organise a reference panel discussion about technical aspects (this may be virtual depending on COVID-restrictions) **(G)**	Meeting on site	Nov 2020	DEVIATION FROM PLANNED ACTIVITY: Was shifted into a virtual mode and deferred to early 2021 during the Pandemic, and used to progress a Pandemic plan. The meeting was effective in gaining strong participation and engagement (as evidenced by the meeting participant list and minutes).
2.3	Refine cloud-based database **(O1-S4)**	New queries specific to Xayaburi added	Oct 2020 (ongoing)	Completed successfully; but also continually being refined as the project advanced. Not impacted by COVID.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.4	Monitoring and evaluation program initiated **(O2-S5/S6)**	Large-scale tagging activity	All year based on seasonal fish movement Field trips led by NUOL and LARReC during COVID travel restrictions	NUOL, LARReC and CSU staff visited the site regularly during the period of COVID-related border closures to maintain continuity of field activities. The rest of the team resumed face-to-face visits once the borders re-opened.
2.5	Update other groups **(O3-S8)**	Liaise with MRC and other interested groups where work overlaps	Opportunistically	The team has successfully run demonstrations of PIT and acoustic tag use at Don Sahong. The team also participated in a virtual meeting with Ministry of Energy and Mines and DFAT. The meeting was effective in gaining strong participation and engagement (as evidenced by the meeting participant list and minutes).
2.7	Project steering committee meeting (May need to be delayed depending on COVID-19) **(G)**	Hold team meeting on site	Pushed into early 2021	DEVIATION FROM PLANNED ACTIVITY: Switched to virtual mode while travel restrictions were in place. First meeting held and written up. Commitment to discuss disseminating key messages in 2022 and beyond. The meeting was effective in gaining strong participation and engagement (as evidenced by the meeting participant list and minutes).

Year 3 (Sep 2021 – Dec 2022)

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Monitoring and evaluation continues **(O2-S5/S6)**	Regularly reporting project outcomes	Jul–Dec 2021	The electrofishing vessel was operational again. At this point we had tagged 4861 individual fish, from 40 species. These fish have been effectively providing robust data on species movement patterns at the site.
3.2	Scientific papers produced **(O1-S8)**	International Fish team produce scientific papers	Jul–Dec 2021	DEVIATION FROM PLANNED ACTIVITY: COVID ended up delaying these papers, so a project extension was granted until June 2024 to complete them.
3.3	Hold annual meeting Annual reporting **(G)**	Fish scientist team meet on site Steering committee meet on site	May 2022	The annual report was completed on time and accepted. Also, a face-to-face meeting was held with the reference panel in Oct 2022. The meeting was effective in gaining strong engagement (as evidenced by the meeting participant list and minutes).
3.4	Hold stakeholder workshop and final project review **(G)**	Fish scientist team meet in Vientiane with other interested parties as agreed by the project team	May 2022	DEVIATION FROM PLANNED ACTIVITY: Travel restrictions were lifted in 2022 and travel was resumed. The final workshop and project review were delayed because a project extension was granted until Jun 2024 (see 1.2 for an explanation).

No.	Activity	Outputs/ milestones	Completion date	Comments
3.5	Regular reporting **(G)**	The team assist XPCL with preparation of formal reporting	Aug 2022	Reporting requirements were successfully met as per the contracting requirements. An additional annual report was provided in Apr 2023 in accordance with the project being granted an extension until Jun 2024. The report was structured and formatted to effectively address both ACIAR and DFAT's reporting requirements. This became the approach for all subsequent reports, as it avoided duplication and was more efficient for the project reporting.
3.6	Final reporting and project review meeting **(O3-S7/S8)**	Project final review meeting Final report to DFAT/ACIAR completed	Dec 2022	DEVIATION FROM PLANNED ACTIVITY: The final reporting and project review were delayed because a project extension was granted until Jun 2024 (see 1.2 for an explanation).

Final 18 months (Jan 2023 – Jun 2024) (Variation 3)

No.	Activity	Outputs/ milestones	Completion date	Comments
4.1	Plan the next 5-year stage of the Xayaburi project **(G)**	Face-to-face workshop at XPCL headquarters in Bangkok to co-design the next stage of the Xayaburi project, with XPCL, ACIAR and DFAT. Follow-up online workshops to continue co-designing the project extension.	Feb 2023 Mar 2024	Co-design workshop was successfully run in Bangkok, with strong participation and engagement (as evidenced by the meeting participant lists and minutes). It has set the framework for the project's activities over the next five years.

No.	Activity	Outputs/ milestones	Completion date	Comments
4.2	Publications on key results from first stage of project **(O3-S8)**	Publish the initial key findings from the first stage of the project (there will be at least four papers – (1) antenna design trials, (2) assessing PIT tag retention in Mekong species, (3) modelling the PIT tagging requirements, and 4) assessing the fishway's effectiveness).	Mar 2024	Three papers have been published so far (one on the PIT tag retention results, one on Sensor Fish trial results and one on the effectiveness of PIT tag systems for Mekong fishes). The paper on PIT antenna design trials is 95% complete and will be submitted in 2024. The papers on modelling the PIT tagging requirements, and assessing the fishway's effectiveness are still both being drafted and will be submitted within Year 1 of FIS/2023/133. Key results and messages from Xayaburi will be disseminated to the international scientific community. Learnings can be applied to future Mekong (and beyond) hydropower projects.
4.3	Refine the PIT tagging requirements models **(O1-S4)**	Refine the PIT tagging requirements models, and in particular — the ages of the PIT tagged fish, by undertaking an otolith (fish earbone) aging study.	Mar 2024	TBC. A non-species-specific pilot model has been developed for estimating the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild. This model will be further refined and submitted for publishing for during FIS/2023/133.

No.	Activity	Outputs/ milestones	Completion date	Comments
4.4	Continue PIT tagging more fish in the wild **(O1-S4)**	Build up the wild PIT-tagged populations of key species to statistically robust numbers (as determined by our PIT tagging requirements models).	Mar 2024	This is an ongoing activity that will be continued into FIS/2023/133. Maintenance of high numbers of key species with PIT tags in the wild — is necessary to facilitate statistically robust assessments of fishway effectiveness and efficiency. The team has also built a pilot mathematical model to guide XPCL in terms of how many fish need to be tagged each year to offset natural, fishing and tag shedding losses (see 4.3).
4.5	Continue engaging KarlTek Pty. Ltd. to manage the PIT tag database (FishNet) **(O1-S1/S4)**	FishNet maintained so that the fish pass's effectiveness can be assessed using the recently installed upstream PIT antenna system (i.e. third antenna system that was installed upstream of the lock in September 2022).	Mar 2024	This is an ongoing activity that will be continued into FIS/2023/133. Allows for continued statistically robust assessments of fish pass effectiveness and efficiency.
4.6.	Support ongoing activities of project advisory reference group **(G)**	Meetings to discuss and agree upon long term direction of project	Mar 2024	Agreement of the reference group on the way forward.
4.7	Final reporting and project review meeting **(O3-S7/S8)**	Project final review meeting Final report to DFAT/ACIAR completed	Dec 2022	TBC (this report). Conclusion of project requirements, dissemination of outputs.

7 Key results and discussion

7.1 Pushing the limits of telemetry systems: The effectiveness of a passive integrated transponder antenna system at the world's largest fish pass

Thanasak Poomchaivej[ab, *], Wayne Robinson[c], Lee J. Baumgartner[c], Nathan Ning[c], Xiaodi Huangc[e], Karl Pomorin[f]. (2024). Currently under review with *Ecological Engineering.*

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[f]Karltek Pty Ltd, Sanctuary Lakes, Melbourne, Victoria, Australia

ACIAR objective(s) addressed: Objective 1 (Study 1)

Source of data/knowledge: ACIAR FIS/2017/017

Overview: Passive Integrated Transponder (PIT) systems are being increasingly used for monitoring fish movements and assessing the effectiveness of fish pass mitigation measures. However, PIT tag detectability has been limited primarily by size constraints of the antenna required, confining their use to smaller fish pass structures. This study introduces innovative approaches for constructing and installing PIT antenna systems capable of detecting 12 mm full-duplex and 23 mm half-duplex PIT tags on the world's largest fish pass.

Contribution to knowledge: The study demonstrated the successful performance of an 8-PIT antenna array in the environment of steel-reinforced concrete, with the largest PIT antenna in the array measuring 6.6 m by 1.5 m

Application to management: The empirical findings from the Xayaburi Hydroelectric Power Plant's fish pass underscore the potential to apply such technologies on other sizable fish pass facilities on large rivers like the Mekong. The need for innovative fish pass monitoring technologies like these will only grow over the coming decades as fish pass facilities are increasingly incorporated into large river infrastructure developments around the globe.

Figure 4. PIT antenna pre-installation testing at Charles Sturt University, Albury, NSW (source: Karl Pomorin)

7.2 Suitability of tropical river fishes for PIT tagging: Results for four Lower Mekong species

Thanasak Poomchaivej[ab, *], Wayne Robinson[c], Lee J. Baumgartner[c], Nathan Ning[c], Xiaodi Huangc[ce]. (2024). *Fisheries Research* 272: 106930.

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ACIAR objective(s) addressed: Objective 1 (Study 2)

Source of data/knowledge: ACIAR FIS/2017/017

Overview: Tropical river systems support some of the most productive inland fisheries around the world, but their fisheries are being placed under growing pressure from disruptions to connectivity caused by river developments. Fish passage measures and complementary monitoring techniques are needed to mitigate the barrier impacts of river developments and validate the effectiveness of such measures, respectively. Passive integrated transponder (PIT) systems have been shown to be effective for monitoring the effectiveness of fish passage measures in temperate river systems, but remain largely untested in tropical systems. This study investigated the suitability of four wild-caught tropical species from the Mekong River (*Hypsibarbus lagleri, Hemibagrus filamentus*, *Barbonymus schwanenfeldii*, and *Scaphognathops bandanensis*) to PIT tagging.

Contribution to knowledge: There was no significant impact of PIT tagging on mortality; no fish lost condition from tagging; and the overall tag rejection rate was very low (4.5%) in all four species.

Application to management: The study findings indicate that *H. lagleri, H. filamentus, B. schwanenfeldii,* and *S. bandanensis* are all suitable for being PIT tagged in tropical river systems, and therefore could potentially be used to assess various fish passage metrics such as approach, attraction and passage efficiency.

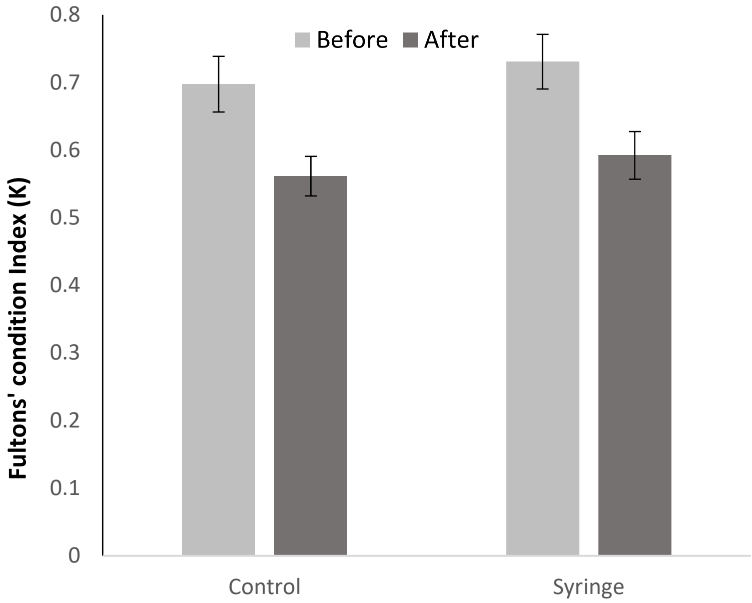

Figure 5. Average (+/- 1 SE) Fulton Condition Index for *Hemibagrus filamentous* at the beginning and end of the PIT tag trial for that species. 'Syringe' represents fish that were PIT tagged, and 'Control' represents fish that were not.

7.3 Mekong River Electrofishing Sampling Project: February 26 – March 3, 2020

Alan J. Temple[a], Lee J. Baumgartner[b], Jarrod McPherson[b], Garry Thorncraft[c]. (2020). Report.

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ACIAR objective(s) addressed: Objective 1 (Study 3)

Source of data/knowledge: ACIAR FIS/2017/017

Overview: Electrofishing is well accepted as a fish collection technique for tagging programs (Sigourney *et al.*, 2005). It entails putting a DC current into the water to temporarily stun the fish, and netting them as they float to the surface. The technique is efficient and safe, since large numbers of fish can potentially be collected in a short period of time, and the fish recover quickly from being stunned (Bohlin *et al.*, 1989; Burkhardt and Gutreuter, 1995). Nevertheless, it has not been used before in the Lower Mekong Basin; and is currently a banned technology under government legislation. The FIS/2017/017 team negotiated a 'research exemption' from the Lao government to use electrofishing exclusively at the Xayaburi site for PIT tagging large numbers of fish. XPCL funded the purchase of an electrofishing boat on the proviso that the project team could set the boat up and train Lao government, University and XPCL staff in its safe and efficient use.

Contribution to knowledge: The FIS/2017/017 team successfully set up the electrofishing boat and trained the Lao government, University and XPCL staff in its proper operation and safety practices; as well as in efficient and standardised sampling, approaches to minimise fish mortality, and electrofishing boat evaluation.

Application to management: The Lao government, University and XPCL staff are now proficient in using boat electrofishing to safely collect fish for an ongoing PIT tagging program onsite. The XPCL electrofishing boat will additionally be used to collect and monitor fish at the new hydropower site at Luang Prabang.

Figure 6. XPCL staff being trained in using the electrofishing boat by the FIS/2017/017 team (source: Rohit Pothula).

7.4 PIT tagging systems are suitable for assessing cumulative impacts of Mekong River hydropower plants on (upstream) fish migrations in Lao PDR

Wayne Robinson[a], Lee J. Baumgartner[a], Khampheng Homsombath[b], Nathan Ning[a], Khamla Phommachanh[b], Thonglom Phommavong[c], Thanasak Poomchaivej[d], Karl Pomorin[e], Dulce Simmanivong[f], Douangkham Singhanouvong[b], Phousone Vorasane[c] (2024). *Fisheries Research* 274: 106995.

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[d]CK Power Public Company Limited, Dindaeng, Bangkok, Thailand

[e]KarlTek P/L, Point Cook, Victoria, Australia

[f]Australian Centre for International Agricultural Research, Phnom Penh, Cambodia

ACIAR objective(s) addressed: Objective 1 (Study 4)

Source of data/knowledge: ACIAR FIS/2017/017

Overview: The Mekong fishery is currently being threatened by plans for extensive hydropower development. This study presents empirical evidence of long-distance migrations along the Mekong mainstem by *Hypsibarbus malcomi* – one of the most important species in the Mekong River fishery. The species was observed to migrate 354 km upstream through one current and three proposed hydropower developments. We used Passive Integrated Transponder (PIT) tags to assess the movements of 233 wild fish, including 77 *H. malcomi*, starting from Vientiane in April 2022. Five of the PIT tagged *H. malcolmi* were detected at the top of the Xayaburi hydropower plant fish pass within 15 months of being tagged and released at Vientiane.

Contribution to knowledge: The results directly show that *H. malcolmi* performs long distance migrations in the mainstem of the Mekong River. They also underscore the importance of using a fishery independent and efficient monitoring technology, such as PIT tagging, to assess the migration patterns of fish in river basins that are undergoing extensive development.

Application to management: Appropriately designed fish pass facilities will need to be incorporated in mainstem hydropower developments within the Lower Mekong Basin, to meet the migratory requirements of *H. malcolmi*.

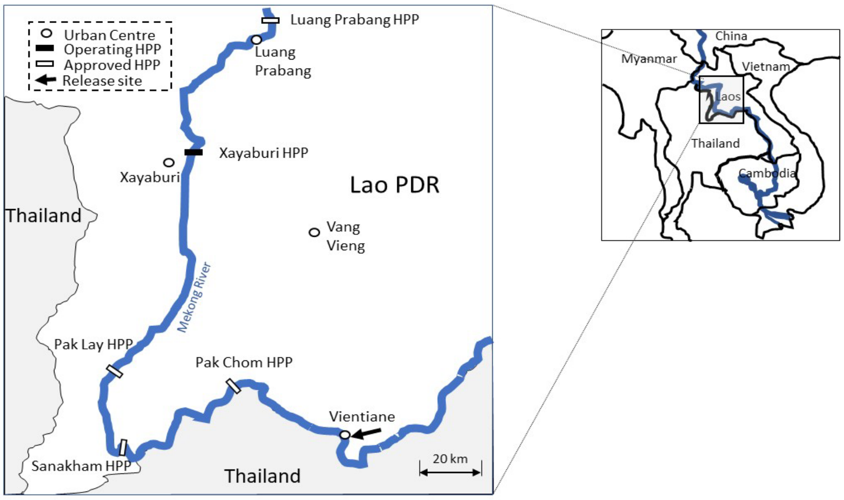

Figure 7. Mainstem hydropower plants (HPP) proposed for northern Lao PDR in the Lower Mekong Basin.

7.5 Sensor Fish deployments at the Xayaburi Hydropower Plant: Measurements and simulations

Pedro Romero-Gomez[a], Thanasak Poomchaivej[b], Rajesh Razdan[b], Wayne Robinson[c], Rudolf Peyreder[a], Michael Raeder[b], Lee J. Baumgartner[c] (2024). *Water* 16, 775
https://doi.org/10.3390/w16050775

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ACIAR objective(s) addressed: Objective 2 (Study 5)

Source of data/knowledge: ANDRITZ and ACIAR FIS/2017/017

Overview: Hydropower production can adversely impact fish passage by impeding upstream fish migrations and causing hydraulic stresses during downstream turbine passage. Sensor Fish are specialised data loggers, which can be used to assess the hydraulic conditions that fish may be subjected to as they undertake turbine passage. This study investigated low pressures and collision rates through the Kaplan-type turbine runners of the Xayaburi hydropower facility, using Sensor Fish and a numerical approach based on flow and passage simulations.

Contribution to knowledge: The results show that pressure drops through the turbine runner were very sensitive to the elevation of Sensor Fish release, but collision rates on the runner were not. The frequency of occurrence of collision rates was 8.2–9.3%. Empirically measured magnitudes (by the Sensor Fish) validated the corresponding simulation outcomes with respect to the averaged magnitudes and their variability. The simulations used in this study were performed based on current industry practices for designing turbines.

Application to management: The agreement between the measured and simulated outcomes provides turbine engineers with certainty about the predictive power of flow simulations for fish passage investigations. This can enhance the development of 'fish-friendly' hydropower technologies.

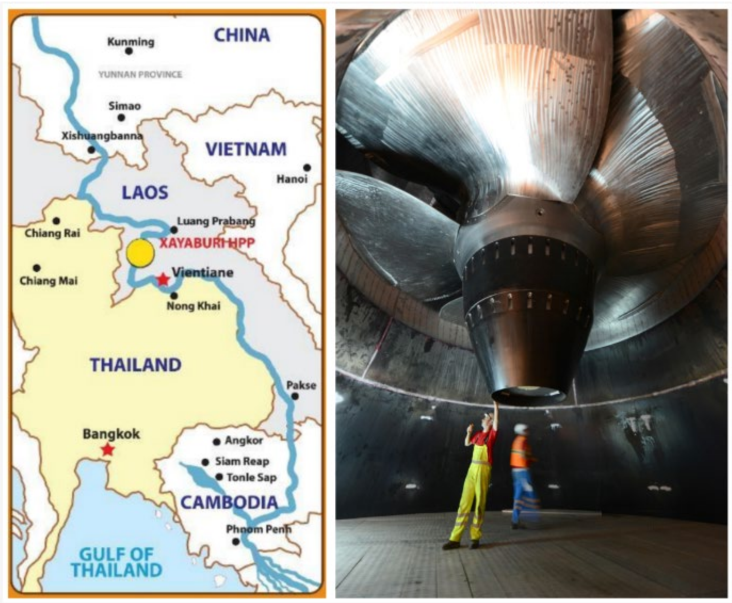

Figure 8. The location of the Xayaburi Hydroelectric Power Plant on the Mekong River in the northern Lao PDR (left), and the Kaplan-type runner tested (not to scale) (right) (source: Romero-Gomez *et al.* (2024)).

8 Impacts

8.1 Scientific impacts – now and in 5 years

Scientific advances

The global impacts of river infrastructure on fisheries are well-established and largely accepted. However, there is less empirical evidence around the effectiveness of technical solutions, and knowledge for the Mekong context is currently completely lacking. Given that the Xayaburi hydropower facility is the first of a series of hydropower developments planned for the mainstem Mekong over the coming decades, it warranted rigorous assessment as a model for the other hydropower developments. So, the team has worked hard to establish a scientific knowledge base around the methods for assessing and optimising fish passage at Mekong hydropower facilities. In doing so, the FIS/2017/017 project has resulted in a number of 'world firsts', including:

- ***A highly functioning PIT tag system on the world's largest fish pass.*** It had previously been assumed that PIT tagging technologies could only work on fish pass facilities with relatively small openings because of the physical limitations of PIT system read ranges. We have greatly advanced the limits of these tracking technologies by successfully installing and validating the effectiveness of a PIT system on the largest fish pass in the world (Poomchaivej *et al.* 2024b under review and Appendix 2, Study 1).
- ***Empirical validation of the suitability of Mekong species for PIT tagging.*** The suitability of Mekong fishes for PIT tagging was completely unknown (apart from two species being tested by Grieve *et al.* 2018). Tested PIT tag retention in multiple key Mekong species and determined their suitability for long-term assessments of fish pass effectiveness (Poomchaivej *et al.* 2024a and Appendix 2, Study 3).
- ***A fully certified electrofishing boat and electrofishing protocols for the Mekong River.*** Electrofishing is not currently permitted in the LMB, but is widely regarded as a safe and effective fish collection technique for PIT tagging elsewhere around the world. We successfully commissioned the construction of an electrofishing boat for XPCL and obtained all necessary approvals to use this approach for the Xayaburi PIT tagging program. We also established appropriate electrofishing protocols for the Mekong context and trained XPCL and government fisheries research staff in these protocols so that they are now able to proficiently capture fish for PIT tagging, independently (Appendix 2, Study 3).
- ***Empirical evidence of Mekong fishes undertaking long-distance migrations, through reaches where hydropower plants will be constructed.*** We successfully used PIT tagging technologies to empirically demonstrate that Mekong fish perform long-distance migrations along the mainstem – in reaches where large hydropower developments are planned (Robinson *et al.* 2024 and Appendix 2, Study 4).
- ***Evidence that appropriately designed and operated fish pass facilities can offer high passage efficiencies (>85%) at run-of-river hydropower facilities on the Mekong River.*** Our initial assessments provide world-first evidence that there is genuine potential to alleviate the barrier impacts of the planned hydropower plants for the Mekong if suitably designed and operated mitigation measures are incorporated in these developments (Appendix 2, Study 5).
- ***PIT tag detections defining seasonal migration patterns in the mainstem Mekong River.*** We now have 5 years of data showing that many Mekong fishes have defined migration seasons, so we will be able to use the findings to optimise the operations of fish passage mitigation measures for these Mekong fishes (Appendix 2, Study 6).

- ***Developing a standard for monitoring and constructing other mainstem fish pass facilities in the LMB.*** The monitoring protocols developed during the PIT antenna design and testing, PIT tag retention testing, boat electrofishing, PIT tagging, Sensor Fish trials, and use of the sustainable PIT tagging model – along with the learnings from the Xayaburi fish pass M&E study – are now available for designing and assessing the fish pass measures at the other planned hydropower facilities on the Mekong River (Appendix 2, Study 7).

Scientific outputs

To date, the FIS/2017/017 project has resulted (see the Publications (Excel) list) in:

- **Three papers** being published in international scientific journals (also see Section 10.2).
    - One of these papers was on the suitability of Mekong fish species for PIT tagging; the second empirically demonstrated long-distance migrations up the Mekong River and Xayaburi fish pass; and the third was on Sensor Fish trials at Xayaburi.
    - Many other papers are being prepared and/or have been submitted for publication. The key papers include the sustainable PIT tagging population model and the fish pass effectiveness paper. These will be published over the next 5 years during FIS/2023/133.
- **Seven reports**
    - Highlights include a project progress report for the Lao government in 2019.
- **Two training manuals**
- **Three sets of instructional videos**
    - Highlights include the instructional video on the PIT tagging process, which has so far been viewed more than 3600 times on YouTube.
- **Seven conference presentations**
    - Highlights include hosting the Fish Passage 2018 conference and a conference session on fish passage at the 3rd World Irrigation Forum in 2019.
- **One PhD thesis** (still in progress). Thanasak Poomchaivej has finalised two of his three PhD data chapters – the first has recently been published and the second has been submitted for review. The third chapter is underway. He is aiming to complete his PhD by mid-2025, even though he is enrolled part-time until 2026.

Figure 9. Professor Lee Baumgartner shooting one of the instructional PIT tagging films to guide the in-country team members (source: Nathan Ning).

8.2 Capacity impacts – now and in 5 years

The FIS/2017/017 project has developed capacity within the XPCL staff, educational institutions, government departments in Lao PDR, hydropower developers and the MRC – as well as in the project team itself and other research staff.

XPCL

Our project team worked with XPCL to focus building capacity in two key areas:

1. **PIT tagging:** To ensure that the Xayaburi PIT tagging program is effective over the long term, it was crucial that the PIT antennas are able to detect fish, fish do not shed tags, and tagging does not influence mortality. Any weaknesses in these areas will otherwise result in poor data quality.
2. **Electrofishing:** This was the first time that a commercial electrofishing research vessel has been used in the Lower Mekong Basin – so it was critical that the in-country staff be fully trained in boat electrofishing practices for the Mekong conditions.

Educational institutions

There is presently limited technical capacity to implement tertiary courses in Lao PDR focused on hydropower mitigation and monitoring techniques, due to most lecturing staff not being specifically trained in the subjects they are allocated to teach. This often results in reduced learning outcomes for graduates.

The FIS/2017/017 project team has been building capacity in educational institutions by supporting the design of curriculums; and through the delivery of a new CSU Graduate Certificate in Fisheries Ecology and Aquatic Engineering (as part of FIS/2018/153). There are plans to develop a fish passage masterclass specific to hydropower infrastructure impacts as part of FIS/2023/133. The team has already had great success running masterclasses throughout South East Asia and Indonesia for fish passage measures specific to irrigation infrastructure impacts, as part of FIS/2018/153. So the successful elements of those masterclasses will be adapted to form the basis of the hydropower masterclasses for FIS/2023/133. NUoL has also been given conditional approval to host Masters' students on site at Xayaburi for FIS/2023/133, so such students will be considered on a case by case basis by XPCL. These students would form important components of our project team while gaining crucial practical experience. We will seek out the most promising graduates in educational facilities and offer them international educational opportunities (e.g. by assisting them in applying for international PhD scholarships).

The capacity impacts from each of these arrangements (curriculum design, the Graduate Certificate, masterclasses and Masters programs) are critical to alleviating the impacts of the Xayaburi Hydropower Project beyond the life of the ACIAR activity, as well as the impacts of all of the other planned hydropower projects throughout the LMB and elsewhere around the world. In particular, they will enable future employees in the hydropower industry, and government line agencies, to better-understand how to gain sustainable outcomes for power generation and healthy rivers. We expect that the larger spatial scale capacity impacts will occur within a 10-year timeframe (Category 2), although impacts at this scale will be influenced by donor body acceptance and investment.

Government departments

The current reduced educational institution capacity in Lao PDR subsequently leads to all learning occurring in an employment context – and graduates ultimately being incapable of effectively managing fish passage issues. It can even result in a self-defeating cycle if there is a weak educational foundation, little historical institutional capacity and no mentoring opportunities for graduates. The Lao Ministry of Energy and Mines signalled at a co-design meeting for FIS/2023/133, that they would like their employees to have the opportunity to learn about sustainable hydropower via a 'sustainable hydropower' masterclass. Consequently, this masterclass will be key deliverable for FIS/2023/133.

Developers and the MRC

Hydropower developers are financing and constructing a series of new projects as part of infrastructure development plans in the Lower Mekong Basin. Consequently, the FIS/2017/017 team has started engaging with, and building the capacity, of these hydropower developers and the MRC to ensure that fish passage technologies are broadly incorporated into regional hydropower plans.

Specific examples of capacity-building activities leading directly to long-term impacts

- ACIAR and XPCL team members and one PhD student obtained exposure and experience presenting their results from the FIS/2017/017 project at the 2022 Australian Society for Fish Biology Conference on the Gold Coast in 2022 (see the Publications (Excel) list).
- PhD student (and head environmental engineer for XPCL), Thanasak Poomchaivej is on track to complete his PhD by mid-2025.
- The team has mentored XPCL staff in setting up aquaria, general fish husbandry, and conducting PIT tag retention trials. This was done face-to-face in 2020 prior to the COVID-19 pandemic; via online meetings while the international borders were closed during the COVID-19 pandemic; and then face-to-face again once the borders re-opened in 2022. Nearly 5000 fish have been tagged and released so far.
- The in-country staff (from XPCL, NUoL and LARReC) were trained in the use of Sensor Fish (the robotic data logging fish that can assess the hydraulic conditions fish may potentially be exposed to while passing through hydropower turbines) during a field trip in October 2022. The training was provided Dr Daniel Deng (a Pacific Northwest National Laboratory (PNNL) engineer who developed the Sensor Fish) and the CSU team. The in-country staff then assisted in undertaking actual trials to apply learnings.
- The in-country staff were also given applied training in PIT antenna design and construction while they assisted with the installation of the third antenna system upstream of the locks, in September 2022.

Figure 10. Dr Wayne Robinson using a scalpel insertion technique to PIT tag a *Hypsibarbus* spp. individual during a field visit in June 2020 (left image) (source: Thavonne Phommavong); and XPCL team members measuring a fish during the August 2020 field trip (right image) (source: Wayne Robinson).

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The LMB fishery is currently regarded as the most productive inland fishery in the world, and is critical for sustaining the livelihoods of many southeast Asians – especially those living in rural areas. If the fish passage mitigation measures at Xayaburi are found to work successfully, they will reduce fishery declines and potentially harmful impacts on the livelihoods of many LMB people. Alternatively, if the fish passage mitigation measures are found to perform sub-optimally, then the FIS/2023/133 team will refocus its research towards enhancing fish passage by (1) adjusting the fish pass's design features, and (2) refining and optimising its operational processes. Those improvements should then be incorporated into engineering designs at future mainstem hydropower projects to achieve best-practice.

So far 1100+ PIT tagged fish (comprised of 18 species) have been detected ascending the Xayaburi fish pass since the fish pass antenna systems were installed in late 2019, and 404 PIT tagged fish (comprised of 17 species) have been detected upstream of the locks at least once (and some multiple times) since the IO PIT system was installed on 25 September 2022 (see Appendix 2, Section 11.2.5). These fish will economically benefit upstream fishers, both directly themselves, and by facilitating population growth and therefore additional productivity upstream. For example, at least one tagged migratory fish was captured by a fisher 80 km upstream from the study site.

8.3.2 Social impacts

Fish and other aquatic animals from the LMB fishery constitute around 50% of the animal protein intake of Lao PDR citizens. Assuming the Xayaburi fish pass performs as planned, it will contribute to maintaining fisheries production, and food security and incomes for fishing families. Additional likely benefits will include improved community co-management frameworks. Most rural people consider floodplain capture fisheries to be shared resources. There are many villages in the Xayaburi region, located at varying distances away from the fish pass site. Despite these villages being located at differing distances from the fish pass site, there is a general view within the community that any anticipated benefits from the fish pass should be distributed equally among all of the villages. Consequently, fish moving upstream via the fish pass will become more accessible to the other villages; resulting in equitable access to the fishery resource.

In addition, FIS/2017/017 has led to the following specific examples of community engagement:

(1) Community members (PAFO office) were involved in the February 2020 boat electrofishing and PIT tagging training exercises. Members from the local provincial and district fisheries offices participated in training activities and learned about the project and its objectives.

(2) XPCL have run an ongoing education program with local villages to alert them that some fish may possess a PIT tag and what to do if this occurs. These consultations have been greatly appreciated by local people.

8.3.3 Environmental impacts

Research outcomes within this project have only positive environmental benefits, although realising those benefits is dependent on the Xayaburi fish pass continuing to perform as evidenced thus far.

FIS/2017/017 has shown that the Xayaburi fish pass is capable of achieving very high (>85%) upstream passage efficiencies for fish already in the fish pass entrance. To put this result into context, Noonan et al. (2012) reviewed 65 papers on fish passage studies undertaken around the globe from 1960 to 2011, and reported an average upstream fish passage efficiency of 41.7%. The XHPP has a multi-entrance complex for guiding fish towards the fish pass entrance, so a key research priority for FIS/2023/133 will be to assess how effective this multi-entrance complex is for ensuring that fish can reach the fish pass entrance. More recent PIT detection results from the recently installed third PIT antenna system suggest that the locks can also perform highly efficiently if they are operated according to their intended specifications (Appendix 2, Study 4).

Findings from our other fish passage studies in South East Asia (FIS/2014/041, FIS/2018/153), albeit at low head barriers (<6 m), indicate that fish pass facilities can generate detectable recovery outcomes within 12 months of construction. Quantifiable benefits for short-lived species are expected within 12 months (Category 1), and within 5 years (Category 2) for longer-lived species.

8.4 Communication and dissemination activities

Numerous meetings, site visits by officials, extension activities, training events, conference presentations and other communication activities were undertaken as part of FIS/2017/017. Some of the highlight examples include:

Meetings:

- Two online reference panel meetings held during covid.
- A face-to-face Reference Panel meeting held on site on 17/10/22, and a co-design meeting was held at XPCL headquarters in Bangkok in February 2023.
- The CSU team held monthly online meetings with the key stakeholders (XPCL, NUoL, LARREC) over the life of the project to progress tasks and resolve issues.

Site visits by officials:

- The Australian ambassador visited Xayaburi on 5 October 2020. Presentations were given to him about the operations (by the XPCL site manager), the ACIAR Xayaburi fish passage project (by Dr Wayne Robinson from CSU), and PIT tagging trials (by one of the XPCL fish technicians). He was then taken on a tour of the facilities (including the fish research centre and fish monitoring station) and participated in releasing some PIT-tagged fish.

Communication and extension activities targeted towards end users:

- CK Power released an online video outlining how the Xayaburi hydropower plant, and the fish pass, operates: https://youtu.be/IslaT7L15x0
- The PIT tagging training videos were translated into three languages (Lao, Vietnamese and Bahasa) and uploaded onto the Crawford Fund You Tube site: https://www.youtube.com/watch?v=adz7tNNoTd8&list=PLvLMhkEc96QGDV0wKNV7hu632x2ZRu5ok
- The Sensor Fish instructional videos have also been shared with the in-country project members.
- CSU, XPCL and the Australian embassy coordinated a series of twitter posts on the Australian Ambassador’s visit to the fish pass site in October 2020.
    - https://twitter.com/CSUMedia/status/1318703302092218370
    - https://www.facebook.com/1615859382008899/posts/2666592953602198/
    - https://fb.watch/2k1SV8CqdX/

Figure 11. The Australian ambassador, Mr Jean-Bernard Carrasco (fourth from the left) being given a tour of the Xayaburi Fish Montioring Station during a visit to the site on 5 October 2020 (source: Thonglom Phommavong).

Hands-on training of fisheries scientists, managers and students in Asia and Australia:

- The boat handling and electrofishing training provided to XPCL, LARReC and NUoL staff during the February and June 2020 field trips.
- The hands-on training provided by CSU/NUoL staff to XPCL staff in conducting PIT tag retention trials during field trips in February, June, August, October, and December 2020.
- The hands-on training provided by CSU staff to XPCL and NUoL staff in constructing and operating PIT antenna systems during the September 2022 field trip for installing the third antenna system.
- The hands-on training provided by CSU and PNNL staff to XPCL and NUoL staff on using Sensor Fish in October 2022.

Presentations – conference and other:

- Hosting the Fish Passage 2018 conference, and the conference session on fish passage at the 3rd World Irrigation Forum in 2019.
- The 7 presentations delivered so far at the three different conferences: 2018 Fish Passage conference in Albury, the 2019 World Irrigation Forum in Indonesia, and the 2022 Australian Society for Fish Biology conference on the Gold Coast (Appendix I).
- Presentations of the 2018 fish passage conference have been loaded online by University of Massachusetts (https://scholarworks.umass.edu/cgi/viewcontent.cgi?article=2287&context=fishpassage_conference).

9 Conclusions and recommendations

9.1 Conclusions

FIS/2017/017 has successfully developed a suite of monitoring techniques for assessing the performance of mainstem fish pass facilities in the LMB. The project team and XPCL have been empirically validating the effectiveness of these monitoring techniques while assessing the effectiveness of the Xayaburi fish pass facilities and optimising their operations, and these aspects will be progressed further during FIS/2023/133. The techniques developed during FIS/2017/017 also provide an effective standard for monitoring and constructing other fish pass facilities in the LMB, such as those at the next proposed mainstem Mekong hydropower site at Luang Prabang.

Three of the monitoring techniques have already been peer-reviewed and published in international journals (the suitability of Mekong species for PIT tagging, the PIT tagging program itself, and the Sensor Fish trials). The other key techniques are still under review (the PIT antenna system development) or are close to journal submission stage (the sustainable PIT tagging population model). These techniques will be published during FIS/2023/133.

The FIS/2017/017 project leverages a strong knowledge base from another ACIAR-supported fish passage program of work in South East Asia, that originally began as a proof-of-concept study (FIS/2006/183), before progressing to a research and implementation phase (FIS/2009/041), then to a monitoring/evaluation phase to validate impact (FIS/2018/153) and eventually to a scale out and scale up phase (FIS/2018/153). FIS/2017/017 has built upon the work done for these other ACIAR projects by (1) modifying the fish pass assessment techniques to effectively work for mainstem fish pass facilities on large hydropower facilities, and (2) using the knowledge to inform the design and operation of other fish pass facilities on hydropower facilities throughout the broader South East Asian region.

The techniques and other knowledge generated by this project have stimulated interest from public and private stakeholders like the MRC; and have led to a request for the research to be continued and extended to the next proposed mainstem Mekong hydropower site at Luang Prabang (for FIS/2023/133). FIS/2017/017 has also led to numerous other outputs, including 7 international conference presentations, 3 international journal papers, 7 reports, 3 sets of instructional videos, 2 training manuals, and one pending PhD thesis (see Appendix I).

9.2 Recommendations

Project management and capacity building strategies need to be flexible and applicable in varying settings.

The international border closures during the COVID-19 pandemic prevented the team from being able to conduct any face-to-face training events at the XHPP. So in the absence of being able to hold face-to-face training events, we used some of the travel budget to develop instructional training videos for the XPCL staff, and increased the frequency of our online meetings with them to elaborate on the instructions in the training videos. We then reinforced the learnings of XPCL staff members by resuming face-to-face training sessions as soon the COVID-19 pandemic ended, and international travel was permitted again. This hybrid capacity building approach – although not optimal – ensured that the PIT tag trials and PIT tagging program could both be continued during the COVID-19 pandemic at the XHPP aquatic laboratory in the absence of FIS/2017/017 team members being onsite for that period.

Not all Mekong species are suitable for PIT tagging and/or being kept in aquaria in general.

One species (*Mekongina erythrospila*) appeared to be susceptible to mortality after tagging, and another (*Pangasianodon hypophthalmus*) was difficult to hold in captivity, presumably because of its dietary and/or behavioural preferences. In comparison, the other key Mekong species (*Sikukia gudgeri*, *Hypsibarbus lagleri*, *Hemibagrus filamentus*, *Puntioplites falcifer*, *Barbonymus schwanenfeldii,* and *Scaphognathops* bandanensis) could be safely PIT tagged for long-term monitoring studies. The variability in species suitability highlights the value of tag retention trials before performing large-scale tagging in the wild.

The presence of Australian scientists in-country would significantly aid in maintaining project momentum and efficiently resolving problems.

In-country scientists would be able to provide crucial assistance to staff at XPCL, NUoL and LARReC, and ensure knowledge is efficiently shared, as necessary. For instance, we fortuitously had a team member remain in-country for the period of international border closures during the COVID-19 pandemic. That staff member was able to ensure that our project workplan at the XHPP continued, largely uninterrupted, throughout the pandemic even though Australian-based staff were prohibited from travelling.

Robust empirical data enable appropriately designed fishways to be incorporated into Mekong hydropower plants can be fish-friendly; now is the time to impart the learnings before these facilities are constructed.

The level of investment in fish passage mitigation measures required for these large hydropower plants, is unprecedented anywhere in the tropical world. Yet, with the exception of FIS/2017/017, there are presently no research efforts under way globally to inform the likely success, or otherwise, of such investments in a river system with a highly diverse fish community such as the Mekong. Furthermore, the need for empirical data is highly urgent because plans to construct eight other mainstem HPPs on the Lower Mekong are already at various stages of development, and the next site at Luang Prabang is underway.

Fish passage at hydropower plants needs to be optimised for both upstream and downstream migrations.

FIS/2017/017 has generated knowledge to facilitate effective upstream migration at the Xayaburi fish pass. Equivalent or stronger knowledge is now needed to facilitate effective downstream migration, by considering aspects such the ‘fish-friendliness’ of the XHPP’s turbine design and the suitability of the facilities for supporting the downstream movements of juvenile life-stages. These aspects will be investigated in FIS/2023/133.

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10.2 List of publications produced by project

1. Poomchaivej, T., Robinson, W., Ning, N., Baumgartner, L. J. & Huang, X. (2024). Suitability of tropical river fishes for PIT tagging: Results for four Lower Mekong species. *Fisheries Research* **272**, 106930.

2. Robinson, W., Baumgartner, L. J., Homsombath, K., Ning, N., Phommachanh, K., Phommavong, T., Poomchaivej, T., Pomorin, K., Simmanivong, D. & Singhanouvong, D. (2024). PIT tagging systems are suitable for assessing cumulative impacts of Mekong River hydropower plants on (upstream) fish migrations in Lao PDR. *Fisheries Research* **274**, 106995.

3. Romero-Gomez, P., Poomchaivej, T., Razdan, R., Robinson, W., Peyreder, R., Raeder, M. & Baumgartner, L. J. (2024). Sensor Fish Deployments at the Xayaburi Hydropower Plant: Measurements and Simulations. *Water* **16**, 775.

****Please see the FIS/201/017 publications Excel sheet for the full list of all outputs from this project.**

11 Appendixes

11.1 Appendix 1: Key results from the eight FIS/2017/017 studies

For Objective 1, we: (1) successfully designed, installed and assessed PIT antennas at the entrance and exit of the Xayaburi fish pass in late 2019, and then installed and assessed a third antenna system upstream of the two locks in September 2022 (Study 1); (2) empirically validated the suitability of key Mekong species for PIT tagging (Study 2); (3) commissioned an electrofishing boat and established protocols for efficiently and safely collecting fish for the PIT tagging program at the Xayaburi site (Study 3); and (4) commenced a large-scale PIT tagging program of wild populations of the key Mekong fish species for monitoring the effectiveness of the Xayaburi fish pass facilities (Study 4).

For Objective 2, we assessed the passage efficiency of the fish pass and found that it was capable of achieving a high (>85%) passage efficiency (Study 5). In addition, it was found that 404 individual PIT tagged fish, comprised of 17 species, have been detected at least once (and some multiple times) upstream of the locks since the third antenna system was installed on 25 September 2022.

We also obtained baseline information on upstream migration as a precursor to optimising fish pass operations at a later stage (Study 6). This involved investigating the seasonal timing of upstream migrations to determine key times of fish passage.

The reliability of flow simulation assessments through the turbines was additionally investigated by concurrently assessing the hydraulic conditions that fish would be subjected to during downstream turbine passage, using specialised data loggers known as Sensor Fish. The hydraulic conditions measured by the Sensor Fish validated the outcomes from the flow simulation assessments, providing confidence in the predictive power of using flow simulations for fish passage investigations. Therefore, these empirically validated flow simulation approaches can be applied to enhance the development of ‘fish-friendly’ hydropower technologies going forward.

For Objective 3, all of the monitoring protocols developed during Study's 1–4, and fish pass M&E knowledge gained from Study's 5 and 6, were collated and applied to develop key recommendations for sustainable hydropower development in the LMB (Study 7). The monitoring approaches for PIT antenna design and testing, PIT tag retention testing, boat electrofishing, PIT tagging, using Sensor Fish, and applying the sustainable PIT tagging model, were all included, along with the learnings from the Xayaburi fish pass M&E study.

We also fostered the adoption of project-generated knowledge and other outputs by conducting various extension activities (Study 8), including site visits by officials; communication and extension activities targeted towards end users; hands-on training of fisheries scientists, managers and students; and presentations (conference and other). The learnings and scale-out arising from FIS/2017/017 has broadly translated to dissemination of learnings to high level government officials; design advice and construction supervision; provision of technical assistance; mentoring and staff development; and policy advice and guidance documents.

Table A1.1. Key results for each of the three objectives and their associated studies.

Objective	Study	Key results
Objective 1: Develop monitoring techniques	1: Design and install PIT system	We successfully designed, installed and assessed PIT antennas for the entrance and exit of the fish pass, and I/O structure upstream of the locks
	2: Assess PIT tag retention	We assessed the potential to PIT tag key Mekong fishes and found that *Sikukia gudgeri, Hypsibarbus lagleri, Hemibagrus filamentus, Puntioplites falcifer, Barbonymus schwanenfeldii*, and *Scaphognathops bandanensis* can all be safely PIT tagged for long-term assessments of fish pass effectiveness.
	3: Build and assess electrofishing boat for capturing fish to tag	An electrofishing boat was commissioned and protocols were established for efficiently and safely collecting fish for the PIT tagging program
	4: Commence PIT tagging wild fish	A total of 4861 wild Mekong fish have been PIT tagged so far for monitoring the effectiveness of the Xayaburi fish pass. We have also developed a non-species-specific pilot model for estimating the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild.
Objective 2: Optimise the Xayaburi fish pass facilities	5: Monitor and evaluate effectiveness of fish pass	The Xayaburi fish pass was found to be capable of achieving a passage efficiency of 87%. Furthermore, 404 individual PIT tagged fish, comprised of 17 species, have been detected (at least once) upstream of the locks since the third antenna system was installed on 25/9/22.
	6: Optimise the Xayaburi fish pass	Baseline information was obtained on upstream migration as a precursor to optimising fish pass operations at a later stage. A flow simulation approach for enhancing the development of ‘fish-friendly’ hydropower technologies, was also validated using Sensor Fish.
Objective 3: Provide a standard for monitoring and constructing other fish pass facilities in the LMB	7: Develop a standard for monitoring and evaluating other fish pass facilities for mainstem HPPs	The monitoring protocols developed during Study's 1–4, and fish pass M&E knowledge gained from Study's 5 and 6, were collated and applied to develop key recommendations for sustainable hydropower development in the LMB.
	8: Knowledge uptake	Knowledge dissemination occurred via various extension activities, including site visits by officials; communication and extension activities targeted towards end users; hands-on training of fisheries scientists, managers and students; and presentations (conference and other).

11.2 Appendix 2: FIS/2017/017 detailed study results

11.2.1 Study 1 – Designing, installing and assessing a PIT antenna system for detecting migrating fish at the Xayaburi site (Objective 1)

Study aim

The aim of Study 1 was to set up a PIT antenna system within the Xayaburi fish pass and configure it to support the monitoring of fish movements through the fish pass, and to install the antenna system and test its effectiveness *in situ*.

The slots in the Xayaburi fish pass are up to 1.5 m wide in order to pass large fish and biomasses on the Mekong River at this site. Some of the slots are also up to 16 m tall, to account for large fluctuations in river level. The unprecedented size of the fish pass slots presents a number of challenges for achieving a PIT antenna system detection range that effectively monitors the movements of fish through the fish pass.

Study approach

Developing the antenna configurations for testing

The team assessed a range of potentially suitable antenna arrangements for the fish pass in late 2018, after considering the design and dimensions of the vertical slot fish pass baffles, site environmental conditions (particularly the hydrology), and available budget.

Figure A2.1. Slots where antennas were installed in the Xayaburi fish pass (source: unknown).

To accommodate the unprecedented size of the Xayaburi fish pass vertical slots, six antenna configurations with various dimensions were initially tested to determine whether their dimensions would theoretically allow sufficient PIT tag detection capabilities. These six antenna configurations comprised of:

1. One antenna, 12 m long by 0.6 m wide (this is near the full height of the exit baffle but with the smallest slot width)

2. One antenna, 1.1 m long by 0.9 m wide (this is a standard small antenna which has worked at other installations)
3. One antenna, 8 m long by 1.5 m wide (this is half the height of the tallest entrance baffle but with the largest slot width)
4. One antenna, 6 m long by 1 m wide (this is half the height of the exit baffle but with the medium slot width)
5. One antenna, 6 m long by 0.6 m wide (this is half the height of the exit baffle but with the small slot width)
6. Four antennas, 1 x 6m by 1.5m; 1 x 6m by 1.0m; 1 x 6m by 0.6m; 1 x 6m by 0.6m) (this configuration sought to test all four antennas connected in a synchronised arrangement as a test of a full installation) (Figure 4).

The broad goal of this initial assessment was to determine whether it might be notionally possible to use a single large antenna on each 12–15 m fish pass slot, or whether it would be necessary to use a bank of smaller antennas to cover these larger slots. Although a single large antenna would yield the fastest read speed, it was unknown whether it would perform optimally because of its large dimensions and the current physical limitations of PIT technology.

In the event that a single large design did provide sub-optimal results, it would be necessary to assess configurations involving multiple antennas to cover the larger slots. This would require assessing the antennas forming the multiple-antenna configurations firstly, individually — to determine whether the antennas could perform successfully in principle, and secondly, simultaneously— to determine whether the antennas were influenced by interference from one another.

<u>Testing of prototype antenna designs ‘in the dry’</u>

Prototypes of the antenna configurations were constructed and set up ‘in the dry’ on the grounds of the Charles Sturt University – Albury campus. Testing prototype antenna configurations ‘in the dry’ is an effective way of determining antenna performance in the absence of excessive interference. Should antennas not work in a low interference environment, then it is unlikely that they will perform in the field.

Efficiency tests were then performed on each antenna configuration, using two standard PIT tag sizes: 23 mm and 12 mm. The 12 mm tag is preferable over the 23 mm tag, as it is much smaller and produces a lower tag burden on fish (i.e. results in a lower proportion of tag weight to fish weight). However, the 12 mm tag has a smaller read-range than the 23 mm tag, and therefore it was essential to determine whether the 12 mm tag could perform efficiently with large antennas.

Five tag readings were taken for each antenna configuration tested using the 12 mm tags, and one tag reading was taken for each of the tag configurations tested using the 23 mm tags. The maximum and solid read distances were recorded (in cm) for each of the antenna configurations. The maximum read distance was defined as the furthest distance at which a PIT tag first became detectable by an antenna, whereas the solid read distance was defined as the distance at which a PIT tag became continuously detectable by a PIT antenna.

We also assessed the capacity of each antenna configuration to detect fish passing when swimming at their maximum (i.e. burst) velocities. To do this, we estimated the swimming velocities (in ms^{-1}) required by fish to avoid detection by each antenna configuration, by:

(a) multiplying the maximum read distance by two to give a total antenna detection zone (accounting for PIT tag detection in two opposing directions from an antenna), and

(b) multiplying the antenna detection distance (in m) by the antenna read speed (in reads/sec) (Table A2.1).

These antenna avoidance swimming velocities were then compared with the burst swimming velocities of several Mekong fish species collected from the region (Table A2.2) to determine whether each antenna configuration would be at risk of not detecting fish that swam through the detection loop at speed.

Figure A2.2. FIS/2017/017 team members conducting the antenna design experiments at CSU (Albury) in November 2018. This was the test of the four antennas, 1 x 6 m by 1.5 m; 1 x 6 m by 1.0 m; 1 x 6 m by 0.6 m; 1 x 6 m by 0.6 m) (source: Karl Pomorin). The white vertical supports for the antennas are not part of the actual antennas.

<u>*In situ* testing of the chosen antenna design at Xayaburi Hydropower project and finalising the installation</u>

Once an optimal antenna design was chosen for the Xayaburi Hydropower project fish pass, it was then implemented on site. Based on earlier discussions, it was proposed to proceed with a proof-of-concept demonstration of a PIT system which could monitor movements through the fish pass. A minimum of two sets of antennas were required in order to determine directionality. To try and measure movement through the fish pass itself, one 'bank' of antennas was fitted to the entrance slots, and a second 'bank' was fitted to the exit slots. The reader systems were installed and linked to a cloud-based database (FishNet).

<u>Assessing fish detection rate *in situ*</u>

We assessed the detection rate of *Hypsibarbus* species by the PIT system using data collected from the fish during the first two years of operation.

All PIT tagged fish had been released below the fish pass during that two-year period, so it was assumed that any PIT tagged fish detected by the fish pass exit antenna array had passed through the PIT tag entrance antenna array. Consequently, the detection rate of the entrance antenna array was calculated as:

Detection Rate = No. tags detected at exit ÷ no. tags detected at entrance

Including only fish detected at the fish pass exit in calculations excluded fish that hesitated from ascending beyond the fish pass entrance, or unsuccessfully tried to navigate the fish pass. All *Hypsibarbus* species had been tagged with 23 mm half duplex tags during this period.

<u>Installation of third PIT antenna system upstream of the fish locks</u>

A third antenna system (comprised of seven antennas) was installed and activated upstream of the fish locks on 25 September 2022, to assess passage through the locks as well as the fish pass entrance and exit.

Results

<u>Testing of prototype antenna configurations 'in the dry'</u>

<u>*Initial test of antenna configurations*</u>

Tests initially focused on the largest antenna configuration, with the logic for this being that if this configuration worked effectively, then it could be reasonably assumed that all smaller antenna configurations would also work. The results of the initial test showed that it would not be possible to use a single antenna configuration to cover the large vertical slots in the fish pass, since this configuration recorded very low maximum (8.2 cm) and solid (4.8 cm) read distances (for the 12 mm PIT tags). The antenna also had a very large non-reading zone where no tags were detected at all (Table A2.1; Figure 2.3).

Burst swimming velocities for Mekong fish species collected from the site were found to be generally <u>**well under 9 ms^{-1} for all species**</u> (apart from *Hemibagrus nemurus*, which recorded a burst swimming speed of more than 50 ms^{-1}) (Table XX). In comparison to these burst swimming velocities, the swimming velocities required to avoid detection by each antenna configuration were all more than 17 ms^{-1} for the 12 mm PIT tags (apart from that produced by the single 12 m antenna configuration) (Table XX), suggesting that these antenna configurations would theoretically provide acceptable performance.

<u>*Individual test of antennas in the four-antenna configuration*</u>

Given the unacceptable results provided by the single large 12 m antenna configuration, a four-antenna configuration was developed for further assessment (Table A2.1). Each of the antennas in the four-antenna configuration were individually tested using 12 mm and 23 mm PIT tags. Results from the individual tests suggested that this antenna configuration had the potential to provide an acceptable alternative to the single 12 m antenna configuration, since the avoidance swimming velocities yielded by each antenna were greater than the 9 ms^{-1} burst swimming speed threshold reported during the initial testing — for both the 12 mm and 23 mm PIT tags (Table XX)). Solid read distances ranged from 22.5–52.5 cm for 12 mm tags, and 30–80 cm for 23 mm tags (Table). As these individual test results were deemed to be acceptable for both the 12 mm and 23 mm tags, it was decided to focus only on the 12 mm tag size for all remaining assessments for the sake of efficiency.

<u>*Simultaneous test of antennas in the four-antenna configuration*</u>

Testing antennas in the four-antenna configuration was performed simultaneously to determine whether they were influenced by interference from each other. Solid read distances ranged from 30–40 cm for the 12 mm tags (Table XX). The avoidance swimming velocities yielded by each antenna were again greater than (or equal to) the 9 ms^{-1} burst swimming speed threshold reported during the initial testing, for the 12 mm PIT tags (Table A2.1).

Single read test of a double-antenna configuration

A ‘double antenna’ configuration was required to test whether two antennas, stacked on top of one another, would perform adequately without interference. This was important because the optimal antenna design would require two antennas within each slot, one on top of another (Table A2.1). The solid read distance for one antenna (6 m long by 0.6 m wide) was 27 cm, while the solid read distance for both antennas was 37 cm. The antenna avoidance swimming velocity for the one antenna was 2.2 ms^{-1}, whereas it was 3.7 ms^{-1} for both antennas.

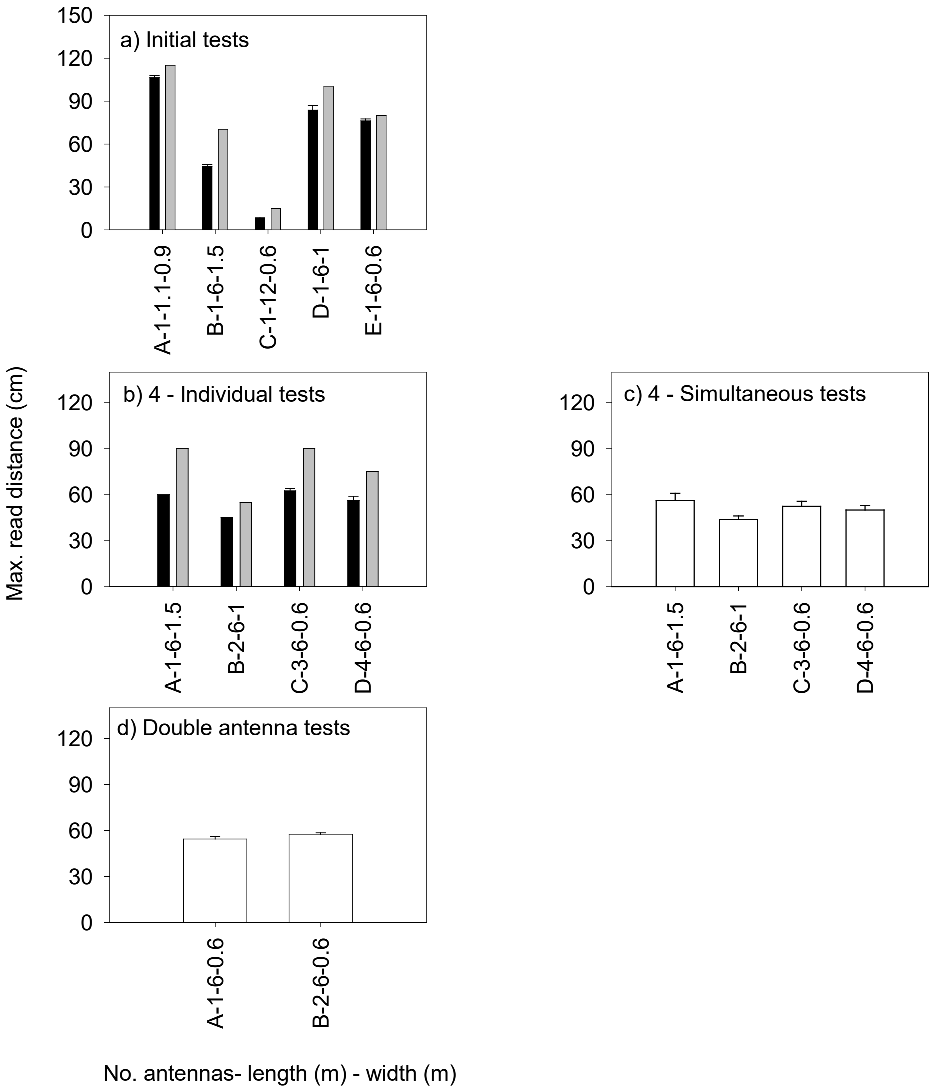


Figure A2.3. Average (+1 SE) maximum read distances for each antenna configuration. Antenna configurations were tested iteratively, with five configurations being initially assessed (a), followed by the antennas in a four-antenna configuration being assessed individually (b) and simultaneously (c), and then a double-antenna configuration being assessed (d). The initial (a) and four-antenna individual (b) tests were conducted for both 12 mm (black bars) and 23 mm (grey bars) PIT tags, whereas the four-antenna simultaneous (c) and double antenna (d) tests were conducted for 12 mm PIT tags only. Note, five readings were taken for each 12 mm PIT tag-antenna configuration trial, and one reading was taken for each 23 mm PIT tag-antenna configuration trial (hence why no standard errors were calculated for the 23 mm trials).

Table A2.1. The swimming velocities needed by fish to avoid detection by each antenna configuration. Antenna configurations were assessed iteratively, with initial, 4 antenna - individual, 4 antenna - simultaneous and double antenna tests conducted in sequence. The 12 mm tags yielded sufficient results in the first two testing scenarios, and thus the 23 mm tags were not used in the last two testing scenarios (NA = non-assessable because multiple antennas were reading simultaneously). Solid read distance refers to the distance where tags were reading consistently, detection distance is where tags were pinging intermittently, reads per second is the number of pings per second for the tag, avoidance velocity is the extrapolation of the detection distance multiplied by the pings per second to determine how fast a fish would need to be swimming to avoid detection on the antenna.

					12 mm tag						23 mm tag					
Testing scenario	Configuration	Number	Length (m)	Width (m)	Solid read dist. (cm)	SE	Detection dist. (m)	Reads per/sec	SE	Avoidance vel. (m/s)	Solid read dist. (cm)	SE	Detection dist. (m)	Reads per/sec	SE	Avoidance vel. (m/s)
Initial	A-1-1.1-0.9	1	1.1	0.9	74.0	1.9	1.5	22.6	3.7	33.4	90	0	1.8	23	0	41.4
Initial	B-1-6-1.5	1	6	1.5	30.5	0.5	0.6	29.0	2.0	17.7	50	0	1	33	0	33
Initial	C-1-12-0.6	1	12	0.6	4.8	0.2	0.1	0.0	0.0	NA	8	0	0.16	0	0	NA
Initial	D-1-6-1	1	6	1.0	55.0	2.0	1.1	19.3	0.9	21.2	75	0	1.5	22	0	33
Initial	E-1-6-0.6	1	6	0.6	53.8	1.3	1.1	22.8	1.3	24.5	65	0	1.3	30	0	39
4 - Individual	A-1-6-1.5	1	6	1.5	52.5	1.4	1.1	17.8	2.1	18.6	80	0	1.6	24	0	38.4
4 - Individual	B-2-6-1	2	6	1.0	22.5	1.4	0.5	20.0	0.4	9.0	30	0	0.6	24	0	14.4
4 - Individual	C-3-6-0.6	3	6	0.6	47.8	2.4	1.0	16.8	0.9	16.0	75	0	1.5	28	0	42
4 - Individual	D-4-6-0.6	4	6	0.6	37.5	1.4	0.8	17.5	1.6	13.1	50	0	1	18	0	18
4 - Simultaneous	A-1-6-1.5	1	6	1.5	40.0	5.4	0.8	17.5	1.6	13.1	*23 mm tags not tested.					
4 - Simultaneous	B-2-6-1	2	6	1.0	30.0	4.6	0.6	20.0	0.4	9.0	(12 mm tags yielded sufficient results)					
4 - Simultaneous	C-3-6-0.6	3	6	0.6	33.8	2.4	0.7	20.0	0.4	9.0						
4 - Simultaneous	D-4-6-0.6	4	6	0.6	32.5	4.3	0.7	20.0	0.4	9.0						
Double	A-1-6-0.6	1	6	0.6	26.9	3.0	0.5	4.0	0.6	2.2						
Double	B-2-6-0.6	2	6	0.6	36.9	2.5	0.7	5.0	0.2	3.7						

Table A2.2. Burst swimming velocities of Mekong fish species collected from the Mekong River at the proposed hydropower project site region (adapted from FishTek 2015). Body lengths were taken from FishBase (www.fishbase.org).

Species	Max. body length (cm)	Burst speed (bodylengths/s)	Burst speed (m/s)	Number of fish tested
Hypsibarbus sp.	39.7	13.9	5.5	144
Puntioplites falcifer	40.0	11.2	4.5	103
Pangasius elongatus	28.2	11.2	3.2	120
Henicorhynchus sp.	14.9	58.05	8.6	106
Hemibagrus nemurus	65.0	>100	>65	137

In situ testing of the chosen antenna design at Xayaburi Hydropower project and finalising the installation

The chosen PIT antenna system was successfully installed at the entrance and exit points of the Xayaburi Hydropower project fish pass in October 2019. The reader systems were installed and linked to a cloud-based database.

Assessing fish detection probability *in situ*

A total of 313 *Hypsibarbus* were detected at the exit antenna of the fish pass between August 8, 2020, and December 31, 2022, and each of these fish had been previously detected at the entrance antenna. This indicates that none of the 313 fish had passed the entrance antenna undetected, and that therefore, the overall detection rate for 23 mm half-duplex tags was 100%.

Results for the third antenna system upstream of the fish locks

The third antenna system was tested upon commissioning and was found to successfully support maximum read distances of more than 40 cm for both 12 mm and 23 mm PIT tags (Figure A2.4).

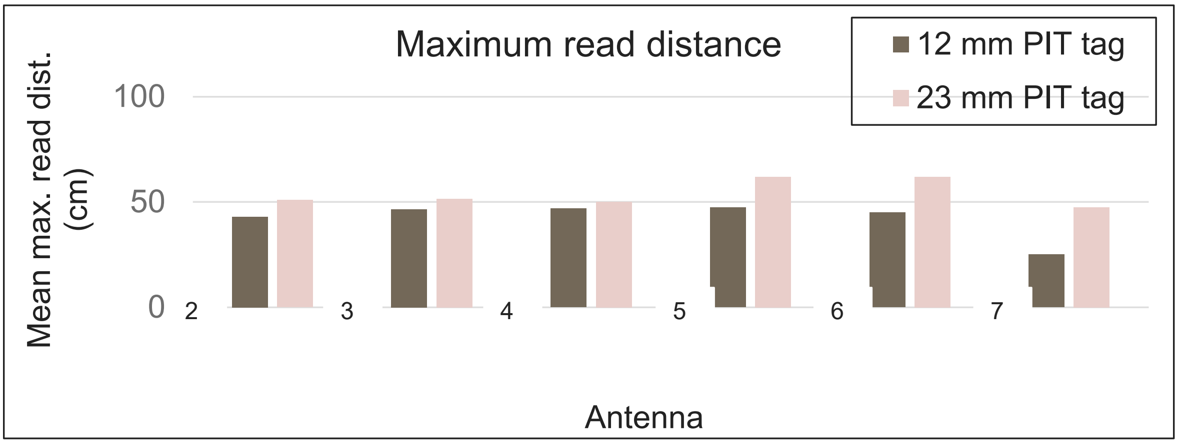


Figure A2.4. Maximum read distance of the third antenna system for 12 mm and 23 mm PIT tags.

Discussion

A PIT detection system was successfully scoped, designed, installed and assessed at the Xayaburi Hydropower project fish pass. The system is now operational and scanning for the presence of tagged fish. The process of assessing antenna designs, prior to installation, proved an essential requirement to ensure functional systems were installed in the field. The realisation was that *in situ* testing is significantly beneficial for practical applications.

The testing of the double-antenna configuration was because the only practical solution was to 'stack' antennas on top of one another. To test the potential for each antenna to interfere with the other, both were powered simultaneously and read performance was assessed. When applied in a multiplexing setup (i.e. with the two antennas being set to rapidly turn on and off in an alternating sequence), the double-antenna configuration worked effectively. A limitation of multiplexing is that it reduces the reads per sec of the antennas because there is some degree of 'off' time while the other antenna is activated. Nevertheless, the influence of this limitation is likely to be greatly lessened at the Xayaburi site because the upper antennas can be completely switched off during the dry season when river levels are low, and therefore only the lower antennas are submerged. During high flows, the multiplexing is controlled by the operating software, but should not impact the read distance.

There were several other lessons-learned that could be practically applied. Firstly, it was determined that 12 m long antennas were completely inappropriate and did not even work for a small slot size. Secondly, while 8 m x 1.5 m antennas were determined to function well, the optimal point at which these antennas became non-functional was not explored. So the extension of that finding is that there are significant limitations on the sizes of antennas that could be tested at future sites (MacLeod and Gagen, 2018) (unless antenna sizes are within ranges which have been demonstrated to work in similar situations).

A further extension was that the team focused on detection efficiencies of 12 mm tags, with limited testing of 23 mm tags. It should be noted that these tags were tested in a low interference environment. Electromagnetic radiation from hydropower plants, concrete reinforcement or the presence of conductive materials near antennas can greatly reduce performance (De Cos and Las-Heras, 2011). Consequently, it was unknown whether 12 mm tags would perform equally well in an *in situ* test. Due to intermittent, radiated noise at the site, the performance of 12 mm tags fluctuated and was sometimes lower than it was during the *ex situ* tests. However, the performance of 23 mm tags was satisfactory.

In terms of the next stage of the project, there is considerable confidence that the system is adequately detecting 23 mm tags and that antenna performance will be suitable. The PIT antenna system has provided a platform to collect reliable fish passage data going forward. Should the antenna reliability be matched by acceptable rates of tag retention and mortality, then this system will be an excellent vehicle to provide reliable long-term fish migration information.

<u>Results for the third antenna system upstream of the fish locks</u>

The third antenna system was found to effectively facilitate maximum read distances of more than 40 cm for both 12 mm and 23 mm PIT tags. Numerous fish and species have since been detected by this antenna system (see more details in Study 3).

Key messages

- PIT antenna systems were successfully designed, installed and assessed at the entrance and exit of the Xayaburi fish pass.
- A third antenna system was successfully installed in September 2022 upstream of the two locks, to quantify passage through the locks as well as the fish pass entrance and exit.

11.2.2 Study 2 – Assessing whether key Mekong species can retain PIT tags, and that they are not harmed by them (Objective 1)

Study aim

Along with establishing a functioning PIT antenna system, it is imperative that the target fish species retain the PIT tags for long periods of time without the tags negatively impacting their condition or causing mortality. This study investigated whether PIT tags can be retained within key Mekong fishes, without affecting their mortality, or body condition.

Study approach

To assess this, we undertook PIT tag retention trials on the fishes in 12,000 L (5 m x 2 m x 1.2 m) outdoor tanks at the Xayaburi Aquatic Laboratory – a purpose-built fish research facility built by XPCL on site. We considered nine different species/size class combinations as representative Mekong River species for testing, because of their (1) migratory behaviour, (2) economic importance, and (3) ecological significance (Table A2.3).

Table A2.3. Species and size classes assessed for PIT tag retention.

Species/size class
Mekongina erythrospila
Sikukia gudgeri
Hypsibarbus lagleri >210 mm
Hypsibarbus lagleri 150 to 210 mm
Hypsibarbus lagleri all sizes
Pangasianodon hypophthalmus
Hemibagrus filamentus
Puntioplites falcifer
Barbonymus schwanenfeldii
Scaphognathops bandanensis
Hemibagrus nemurus
Pangassius elongates
Henicorhynchus lobatus, H. siamensis)

For each species (and therefore experiment), 5 tanks (i.e. replicates) were set up each with 40 individuals (i.e. 200 individuals in total). Of the 40 individuals in each tank, 20 were randomly chosen for PIT tagging and the other 20 have been left as control fish (i.e. not PIT tagged). Tagged fish had a 23 mm Biomark PIT tag inserted into the peritoneal cavity. This tagging location was selected because it has the lowest rate of shedding and mortality in other Mekong species (Grieve *et al.*, 2018a; Grieve *et al.*, 2018b) and presents the lowest risk to fish consumers (as surviving fish were to be released at the end of the experiment). Control fish were handled in the same manner as tagged fish, but without the tag insertion.

The experiments each ran for 50 days, as per the protocols used by Grieve *et al.* (2018a, b). Tag-related mortality and shedding (i.e. tag loss) have both been found to be highest during this period (Dare, 2003), and an earlier unpublished pilot study on Mekong species by our team revealed that delayed mortality impacts extended up to 40 days (L. Baumgartner unpublished data). We checked for shedding daily in the tagged fish, and compared fish condition and mortality rates between tagged and control fish at the end of each experiment.

A complete description of these methods is provided in Poomchaivej *et al.* (2024).

Figure A2.5. Dr Wayne Robinson using a scalpel insertion technique to PIT tag a *Hypsibarbus* spp. individual during a field visit in June 2020 (source: Thavonne Phommavong).

Results

Some species are either sensitive to tagging or have been difficult to care for in the fish research centre. For instance, one of the migratory species commonly captured at the site, *Mekongina erythrospila*, experiences high mortality from handling and significantly reduced growth rates after tags are inserted (Figure A2.6). Consequently, it appears that this species in not suitable for longer term migration trials.

Table A2.4. PIT tag retention findings for species and size classes assessed.

Species	Key findings
Mekongina erythrospila	Susceptible to increased mortality after tagging
Sikukia gudgeri	Very low mortality rate suitable for tag and release in the field
*Hypsibarbus lagleri*** >210 mm	Very low mortality rate suitable for tag & release in the field
*Hypsibarbus lagleri*** 150 to 210 mm	Very low mortality rate suitable for tag & release in the field
*Hypsibarbus lagleri*** all sizes	Very low mortality rate suitable for tag & release in the field
Pangasianodon hypophthalmus	Difficult to maintain in captivity. Requires better understanding of diet/habits
Hemibagrus filamentus	Low mortality rate suitable for tag & release in the field
*Puntioplites falcifer***	Low mortality rate suitable for tag & release in the field
Barbonymus schwanenfeldii	Very low mortality rate suitable for tag & release in the field
Scaphognathops bandanensis	Low mortality rate suitable for tag & release in the field
*Hemibagrus nemurus***	Pending
*Pangassius elongates***	Pending
Henicorhynchus lobatus, H. siamensis)**	Pending

** = one of the five high priority target species for investigation in this project (FishTek performed swimming speed trials on these 'target' species & used the data to help initially design the Xayaburi fish pass).

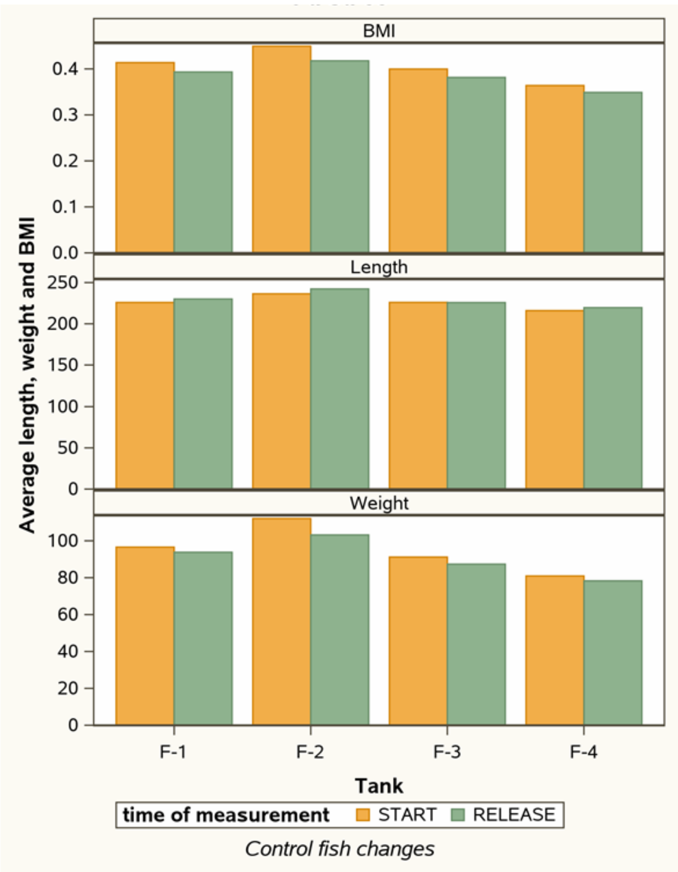


Figure A2.6. Changes in the condition (as assessed by body mass index — BMI), length (mm) and weight (g) of untagged (i.e. control) *Mekongina erythrospila* in each tank (F1–F4), between the start and end (release point) of PIT tag retention trial 3. The declines in weight and body mass index during the trial indicate that even non-tagged fish of this species were not easy to husband in 2020.

Discussion

Our experiments empirically demonstrated that *Sikukia gudgeri*, *Hypsibarbus lagleri*, *Hemibagrus filamentus*, *Puntioplites falcifer*, *Barbonymus schwanenfeldii,* and *Scaphognathops bandanensis* can all be safely PIT tagged for long-term assessments of fish pass effectiveness. By contrast, *Mekongina erythrospila* appeared to be susceptible to mortality after tagging. It was difficult to maintain *Pangasianodon hypophthalmus* in captivity, presumably because of it diet/habits. This finding reinforces the value of tag retention trials prior to large-scale tagging in the field. In addition, appropriate consideration should be given to husbandry and operator experience to reduce the likelihood of mortalities in PIT tagging studies.

Key messages

- *Sikukia gudgeri, Hypsibarbus lagleri, Hemibagrus filamentus, Puntioplites falcifer, Barbonymus schwanenfeldii*, and *Scaphognathops bandanensis* are all suitable for PIT tagging in tropical river systems.

11.2.3 Study 3 – Building and assessing performance of an electrofishing vessel to safely collect wild fish for PIT tagging (Objective 1)

Study aim

Following the establishment of an effective PIT antenna system and the refinement of the PIT tagging technique, the final stage of developing a PIT tagging program is to establish a fish collection technique that efficiently captures fish for tagging, without harming them. The aim of this study was to develop boat electrofishing as an efficient and relatively safe technique to collect fish for the PIT tagging program at the Xayaburi site.

Study approach

Electrofishing is a safe and effective fish collection technique, which is commonly used for tagging programs in both Australia and the USA (Sigourney *et al.*, 2005). However, it is not permitted in the LMB, and so the team has negotiated a 'research exemption' from the Lao government to use the equipment exclusively at the Xayaburi site.

In 2019–20, XPCL and the FIS/2017/017 team co-designed and commissioned the construction of an electrofishing boat to capture wild fish for PIT tagging. XPCL funded the purchase of the boat. We (the team) then organised for an international electrofishing expert (Dr Alan Temple, U.S. Fish and Wildlife Service) to assist with evaluating the performance of the electrofishing boat and to optimise its operation for the local Mekong conditions.

During the training week, the project team aided in managing training sessions on the theoretical and practical aspects of safe boat electrofishing. The team also reviewed the appropriateness of the electrofishing guidelines and training resources that the project team had drafted for the XPCL staff; performed a safety assessment of the XPCL electrofishing boat; and determined safe electrofishing settings for the Mekong River at the Xayaburi site.

Results

The electrofishing boat hull was custom built and purchased from Abelly International Limited (Yantai city, Shandong, China). Charles Sturt University staff advised XPCL and Abelly International on the specific design requirements prior to construction. The hull and boat trailer were constructed first, followed by the electrode fitting and control box installation. The electrofishing apparatus was purchased from Midwest Lake Electrofishing Systems in the USA. A marine mechanic then installed the outboard motors and hydraulic steering.

On-water, weight distribution testing was conducted to ensure that the boat would be stable during operations. Following fit-out, a safety inspection and test of the electrical outputs was performed, which covered:

- Boat electrode dimensions
- Electrode condition and boat control box functioning
- Efforts to derive electrical settings for effective and standardised sampling
- A plan for future work aimed at increasing efficiency and standardization
- Additional information on testing equipment and water quality metres.

See Temple (2020) for the detailed results of the evaluation of the electrofishing boat.

Discussion

An electrofishing boat was successfully built and protocols were established for efficiently and safely collecting fish for the PIT tagging program at the Xayaburi site. XPCL and government fisheries research staff have been trained in these protocols, and are now able to proficiently capture fish for PIT tagging, independently.

Key messages

- XPCL and government fisheries research staff can now proficiently use boat electrofishing methods to capture fish for PIT tagging at the Xayaburi site, without any instruction from the FIS/2017/017 team.

11.2.4 Study 4 – Commencing PIT tagging of wild fish in the Mekong River downstream (Objective 1)

Study aim

After validating the success of the PIT tagging technique on several target species, sufficient populations of PIT-tagged fish should be maintained in the wild to generate usable tag data. The aim of this study was to commence PIT tagging wild populations of the target species in the Mekong, downstream of the Xayaburi site.

Study approach

We used the electrofishing boat to capture the fish, and then tagged and released the fish using the technique validated in Study 3. Fish were additionally captured from the exit of the fish pass and tagged and released.

We also developed a generic (non-species-specific) pilot model for estimating the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild. It was based on a combination of anecdotal information, expert opinion and/or literature for related fish species (where such literature is available).

Results

PIT tagging outcomes

As of 15/4/24, 4,861 individual fish, from 40 species, have been tagged and released into the Mekong (at Xayaburi and Vientiane).

The most released fish have been *Hypsibarbus* spp. and *Puntioplites falcifer* (Table A2.5). The team have attempted to tag a wide range of fish sizes. The biggest fish so far (*Hemibagrus wyckioides*) was 1150 mm.

Table A2.5. Total number and maximum length (TL, mm) of fish tagged and released into the Mekong as of 15/4/24, since training commenced in February 2020.

Species	Number	Max length
Cyprinus carpio	3	377
Hypsibarbus sp.	2	450
Laotian shad	4	217
Henicorhynchus siamensis	30	212
Channa striata	1	366
Probarbus jullieni	3	800
Neolissochilus stracheyi	2	340
Cosmochilus harmandi	44	690
Pa Kae	154	465
Cirrhinus molitorella	103	790
Cirrhinus mrigala	4	880
Pa Ka-ho India	1	501
Hampala macrolepidota	13	374
Pa Khae-kwai	33	780
Hemibagrus wyckioides	15	1150
Labiobarbus leptocheilus	72	260
Mystacoleucus obtusirostris	77	163
Pa Kob	4	595
Hemibagrus filamentus	109	484
Gyrinocheilus pennocki	3	191
Sikukia gudgeri	556	225
Hemisilurus mekongensis	3	460
Oreochromis niloticus	1	185
Hypsibarbus spp.	1478	700
Hypsibarbus malcolmi	34	530
Scaphognathops bandanensis	351	364
Labeo chrysophekadion	102	780
Pa Ro-ho	1	538
Mekongina erythrospila	89	393
Puntioplites falcifer	1269	406
Raiamas guttatus	7	365
Hampala dispar	8	315
Pangasianodon hypophthalmus	13	730
Chitala ornata	2	700
Pa Ven	7	420
Pa Ven (Yellow)	1	212
Barbonymus schwanenfeldii	220	310
Barbonymus altus	38	242
Pa Wa	3	700
Pa Yorn	1	246
Grand Total	**4861**	**1150**

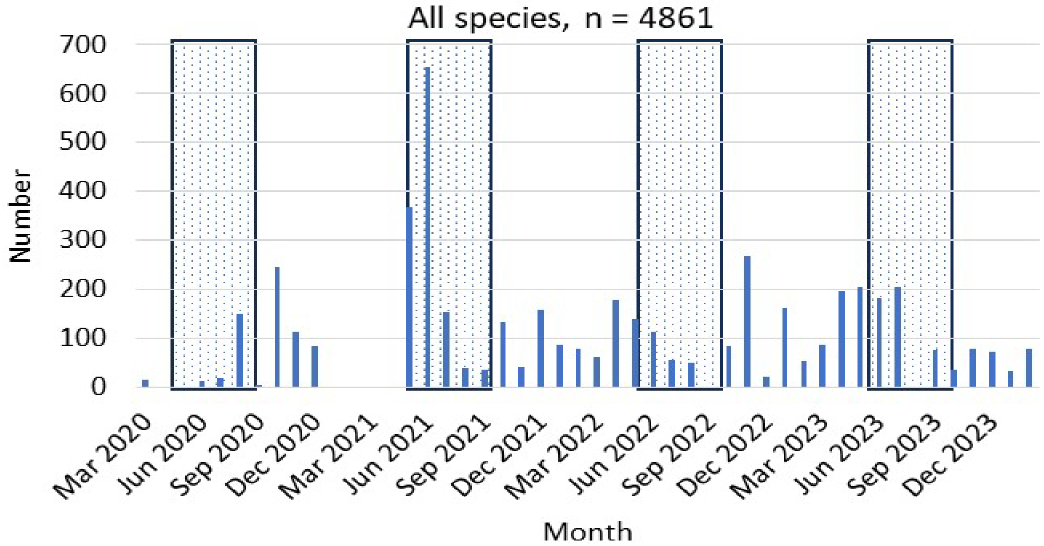


Figure A2.7. Total number of fish PIT tagged and released into the Mekong River since PIT tagging commenced in February 2020 (up until15/4/24). Shaded areas represent the wet season (May–September).

<u>Maintaining PIT tagged fish populations in the Mekong River</u>

To calculate the number of fish that need to be tagged each year to maintain the tagged fish populations, three main sources of tag loss need to be considered:

1. Shedding of tags and mortality for the tagging process
    a. PIT tag trials
2. Harvest by anglers
    a. Literature/empirical data
3. Natural mortality (age-related)
    a. Age/length relationship data (literature/empirical) used along with the Von Bertalanffy growth function

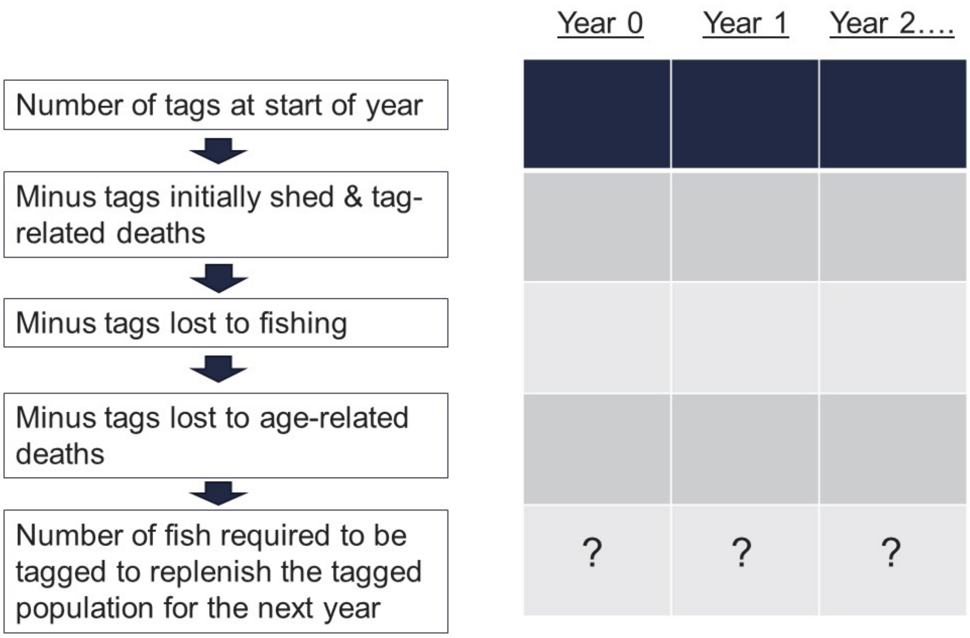


Figure A2.8. Modelling approach for estimating the number of fish that need to be tagged each year to maintain the tagged fish populations.

EXAMPLE: Depletion of the tagged fish population without any new tagging

If we started with 137 tagged *Barbonymus schwanenfeldii* at the end of 2024 (Year 0) and did not tag any new fish, the tagged population would rapidly be depleted.

	2024	2025	2026	2027	2028	2029	2030	2031
				??	??	??	??	??

EXAMPLE: Recommended numbers of Barbonymus schwanenfeldii *to be tagged over the next 10 years to maintain the tagged population*

Three target number scenarios

Targets	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Barbonymus schwanenfeldii											
Case 1: 137	76	75	75	75	75	75	75	75	75	75	75
Case 2: 500	439	277	274	274	274	274	274	274	274	274	274
Case 3: 1000	939	554	547	547	547	547	547	547	547	547	547

Discussion

4861 fish, from 40 species, have been tagged and released into the Mekong River so far, as part of the Xayaburi PIT tagging program.

Large-scale tagging has commenced, but many tag/releases have still been via the release of surviving fish at the completion of each tag retention trials, and/or by actively tagging and releasing fish into the Mekong on an opportunistic basis. The intention is to continue this PIT tagging program at the Xayaburi site into FIS/2023/133, and to start an equivalent program at the next site at Luang Prabang.

We will use the PIT tagging maintenance model for estimating the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild. This model will continue to be refined as more species-specific data are collected.

Key messages

- A wide-scale PIT tagging program has been successfully established at the Xayaburi site.
- We also developed a generic (non-species-specific) pilot model for estimating the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild.

11.2.5 Study 5 – Monitoring and evaluating the effectiveness of the Xayaburi fish pass by assessing the success of PIT tagged fish in ascending the fish pass (Objective 2)

Study aim

The aim of this study was to assess the passage effectiveness of the Xayaburi fish pass and locks by quantifying the success of PIT tagged fish in negotiating these structures.

Study approach

A monitoring and evaluation (M&E) project activity was initiated in combination with the PIT tagging of wild fish in the Mekong River.

Fish pass effectiveness

The M&E activity involved assessing the percentage of fish successfully ascending the Xayaburi fish pass, using the PIT detection system that had been initially installed and activated to monitor both the entrance and exit fish-pass baffles in November 2019.

Fish passage effectiveness was assessed for the period from November 2019 (i.e. the commissioning date of the PIT antenna system) up until 21 February 2023 – which was around the time when the PIT antenna system started experiencing major outages for maintenance and updates.

Lock passage effectiveness

The third antenna system was then installed and activated upstream of the two fish locks in the IO structure, on 25 September 2022, to assess passage through the locks as well.

It was challenging to calculate an unbiased estimate of the passage efficiency of these locks, because of the more recent timing of the installation of the third antenna system, and due to there being a number of maintenance outages and other interruptions to the fish pass antenna systems since this third antenna system had been installed. These have since been rectified and there is now uninterrupted operation.

Therefore, to estimate the passage effectiveness of the two locks, we assessed the number of unique PIT tagged fish detected upstream of the locks as a percentage of the number of unique fish PIT tagged at sites immediately downstream of the fish pass (i.e. sites where XPCL tagged fish, but not sites further downstream where LARREC tagged fish). This percentage was calculated for the period subsequent to the installation of the IO antenna system (i.e. from 25 September 2022 onwards).

Additional Sensor Fish component

We also assessed the physical conditions (pressure changes, shear stress and physical strikes) that fish may potentially be subjected to when passing through the hydropower turbines, by sending data loggers, known as Sensor Fish, through the hydropower structure. Sensor Fish are passed through the turbines and then recaptured downstream so that their data can be downloaded.

For this study, we investigated low pressures and collision rates through the Kaplan-type turbine runners of the Xayaburi hydropower facility, using Sensor Fish and a corresponding numerical approach based on flow and passage simulations.

Results

Fish pass effectiveness

A total of 1290 tagged fish (comprised of 20 species) were detected in the fish pass up until 21 February 2023.

Of the unique fish that were detected, 1123 (87.1%) (comprised of 18 species) ultimately ascended the fish pass successfully.

Some species were more successful at ascending the fish pass than others.

For *Henicorhynchus siamensis, Hampala macrolepidota,* Pa Khae-kwai, *Labiobarbus leptocheilus, Mystacoleucus obtusirostris, Gyrinocheilus pennocki* and *Hampala dispar* – there was 100% passage success.

Other species, such as *Labeo chrysophekadion* (79%), *Scaphognathops bandanensis* (78%) and *Cosmochilus harmandi* (78%) were not quite as successful at ascending the fish pass. Two fish species, *Probarbus jullieni* and Pa Wa, had a zero-passage success rate.

Of the 1290 unique fish that ascended, 576 were 'simple' ascents where they were detected at the entrance, then the exit, then not again. By contrast, 546 were 'complex' ascents, which were detected at multiple antennas over extended periods of time, before they ultimately ascended.

Barbonymus altus individuals provided examples of a simple ascent behaviour.

Hemibagrus filamentus was an exemplar species with a complex ascent behaviour. These fish regularly moved up and down within the fish pass over multiple-days and months.

Table A2.6. Passage efficiency of species observed at the Xayaburi fish pass. Passage efficiency was calculated from the number of individuals of a species observed at both the entrance and exit of the fish pass, expressed as a percentage of the total number of individuals of that species observed in the fish pass (either at the entrance or exit or both).

Species	Total detected (unique individual fish)	Ascended	Did not ascend	% passing
Henicorhynchus siamensis	1	1	0	100
Hampala macrolepidota	1	1	0	100
Pa Khae-kwai	1	1	0	100
Labiobarbus leptocheilus	19	19	0	100
Mystacoleucus obtusirostris	5	5	0	100
Gyrinocheilus pennocki	2	2	0	100
Hampala dispar	2	2	0	100
Mekongina erythrospila	25	24	1	96
Hemibagrus filamentus	32	30	2	94
Barbonymus schwanenfeldii	59	55	4	93
Puntioplites falcifer	472	426	46	90
Cirrhinus molitorella	18	16	2	89
Sikukia gudgeri	173	149	24	86
Barbonymus altus	13	11	2	85
Hypsibarbus spp.	382	316	66	83
Labeo chrysophekadion	19	15	4	79
Scaphognathops bandanensis	55	43	12	78
Cosmochilus harmandi	9	7	2	78
Probarbus jullieni	1	0	1	0
Pa Wa	1	0	1	0
Total	**1290**	**1123**	**167**	

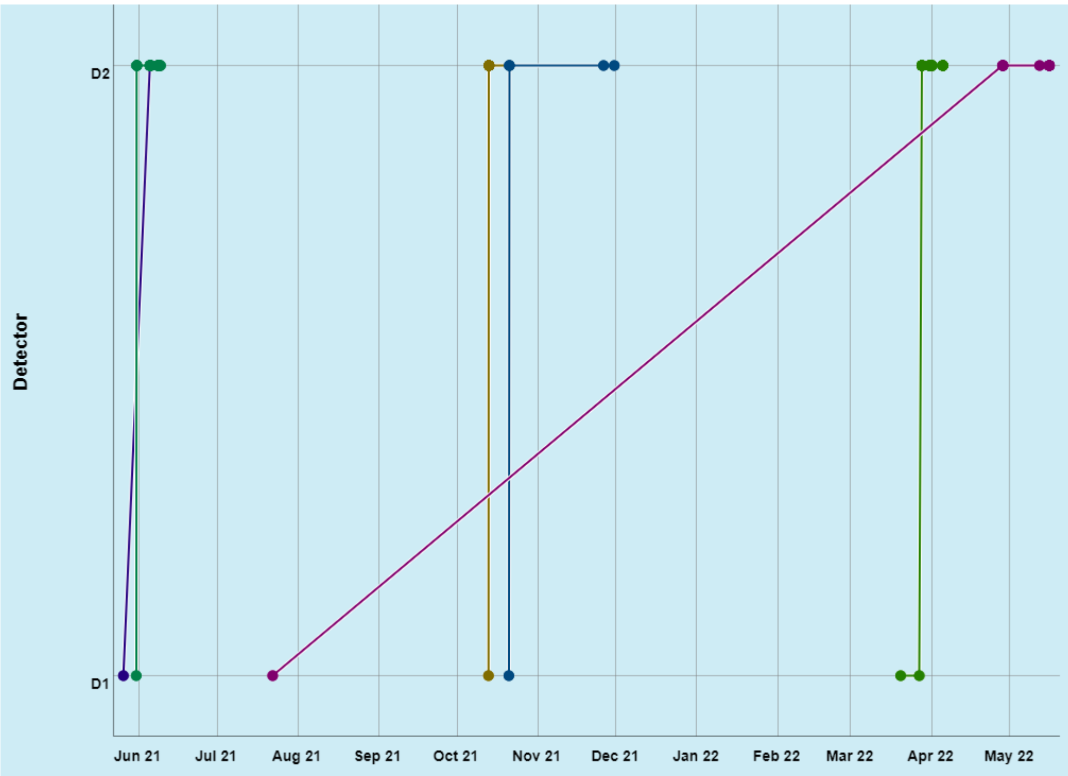


Figure A2.9. Example of a ‘simple’ ascent for six *Barbonymus altus* individuals (the different colours represent each individual). On the y-axis is the antennas (D1 – entrance and D2 – fish pass exit). X-axis is the time scale.

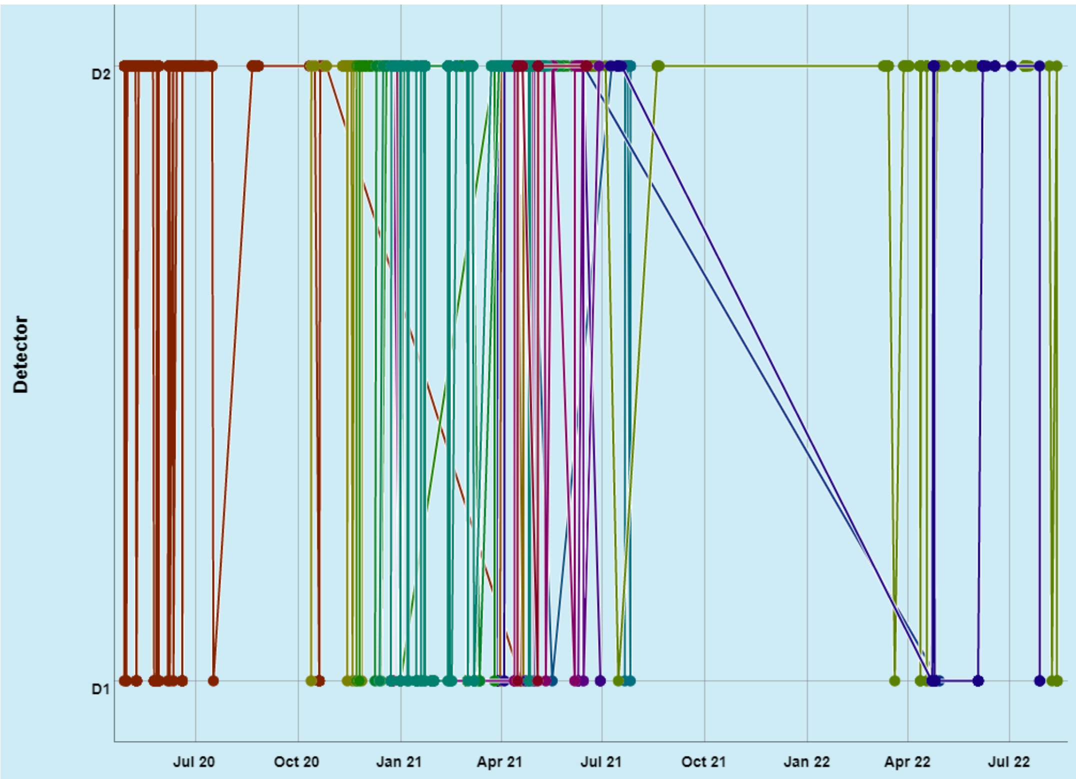


Figure A2.10. Example of ‘complex’ ascents for 22 *Hemibagrus filamentus* individuals (the different colours represent each individual). On the y-axis is the antennas (D1 – entrance and D2 – fish pass exit). X-axis is the time scale.

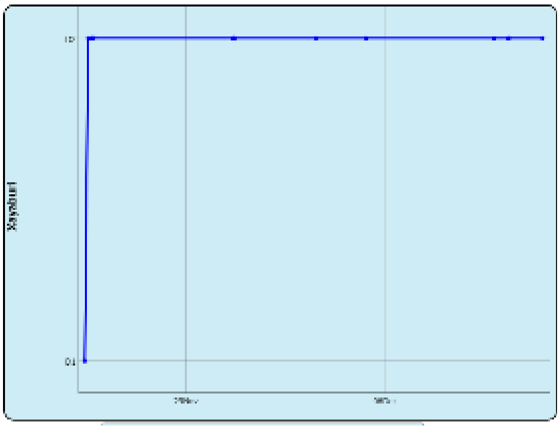
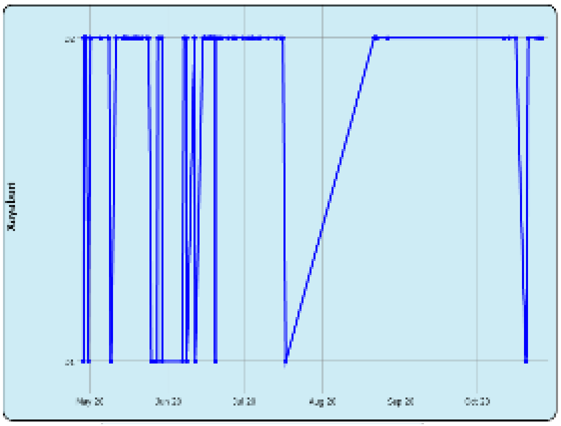
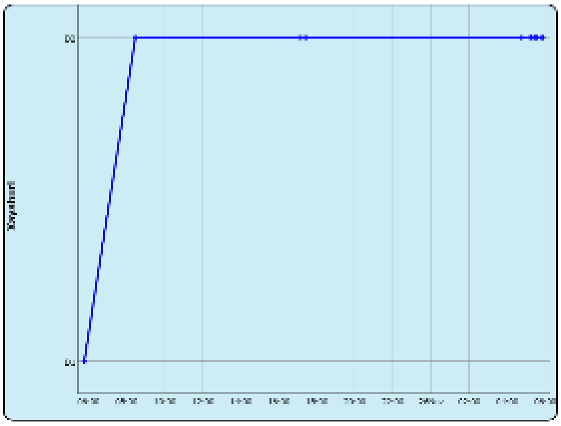
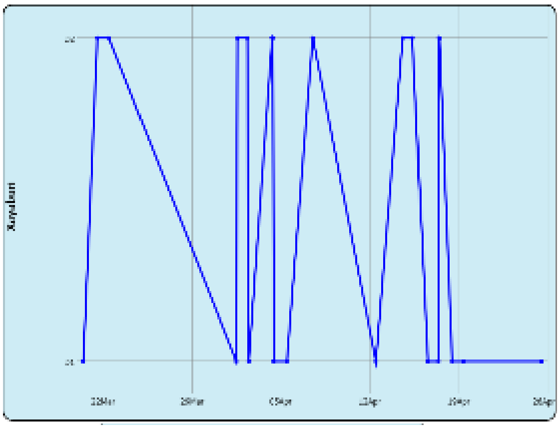
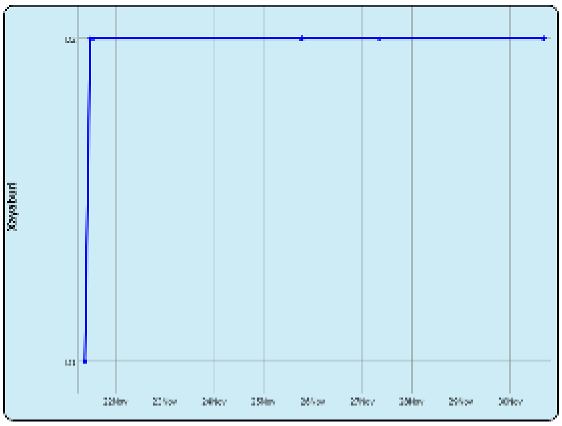
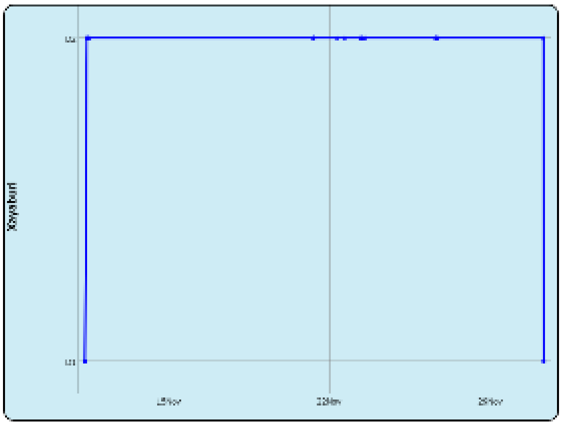
<u>Successful ascent examples</u>	**<u>Unsuccessful ascent / resident examples</u>**
***Hemibagrus filamentus*, tagged 24th November 2020** 	***Hemibagrus filamentus*, tagged 1st March 2020** 
***Mekongina erythrospila*, tagged 6th August 2020** 	**Pa keng; tagged 1st March 2020** 
***Gyrinocheilus pennocki*, tagged 10th June 2020** 	***Hypsibarbus* spp., tagged 5th August 2020** 

Figure 2.11. Examples of fish ascent data through the fish pass. Y-axis depicts the antenna (D1 – entrance; D2 – exit). X-axis depicts time since tagging. These fish were selected as examples of fish displaying complex behaviour within the fish pass.

Lock passage effectiveness

A total of 404 individual PIT tagged fish, comprised of 17 species, have been detected upstream of the locks at least once (and some multiple times) since the IO PIT system was installed on 25 September 2022 (and as of 19/4/24) (Table A2.7). But there was a significant period, during 2023, when the antenna system was non-operable. This has since been rectified and efficiency calculations over the entire fish pass facility will be a focus of the project extension (FIS/2023/133).

Figure 2.12 shows an example of an *Hypsibarbus malcomi* individual, ascending upstream through both the fish pass and lock. It was PIT tagged on 29 February 2024 and swam up and down the fish pass for the month of March. Then, within a few hours on the same day, it fully ascends the site (6 am entrance antenna, 9 am exit antenna, 10:45 am I/O antenna upstream of the lock). Two weeks later, it’s detected back at the I/O antenna, for a period of 2 weeks.

Table A2.7. Number of unique fish detections (individuals detected once or more) upstream of the locks since the IO PIT system was installed on 25 September 2022.

Species	Number
Cirrhinus molitorella	17
Hampala macrolepidota	2
Pa Khae-kwai	1
Labiobarbus leptocheilus	3
Hemibagrus filamentus	4
Sikukia gudgeri	18
Hypsibarbus spp.	159
Hypsibarbus malcomi	2
Scaphognathops bandanensis	19
Labeo chrysophekadion	6
Mekongina erythrospila	8
Puntioplites falcifer	83
Hampala dispar	1
Pa Ven	1
Barbonymus schwanenfeldii	50
Pa Vien Fai (Altus)	3
Unknown	27
Grand Total	**404**

Complete Detection History for Tag 0982126057195229

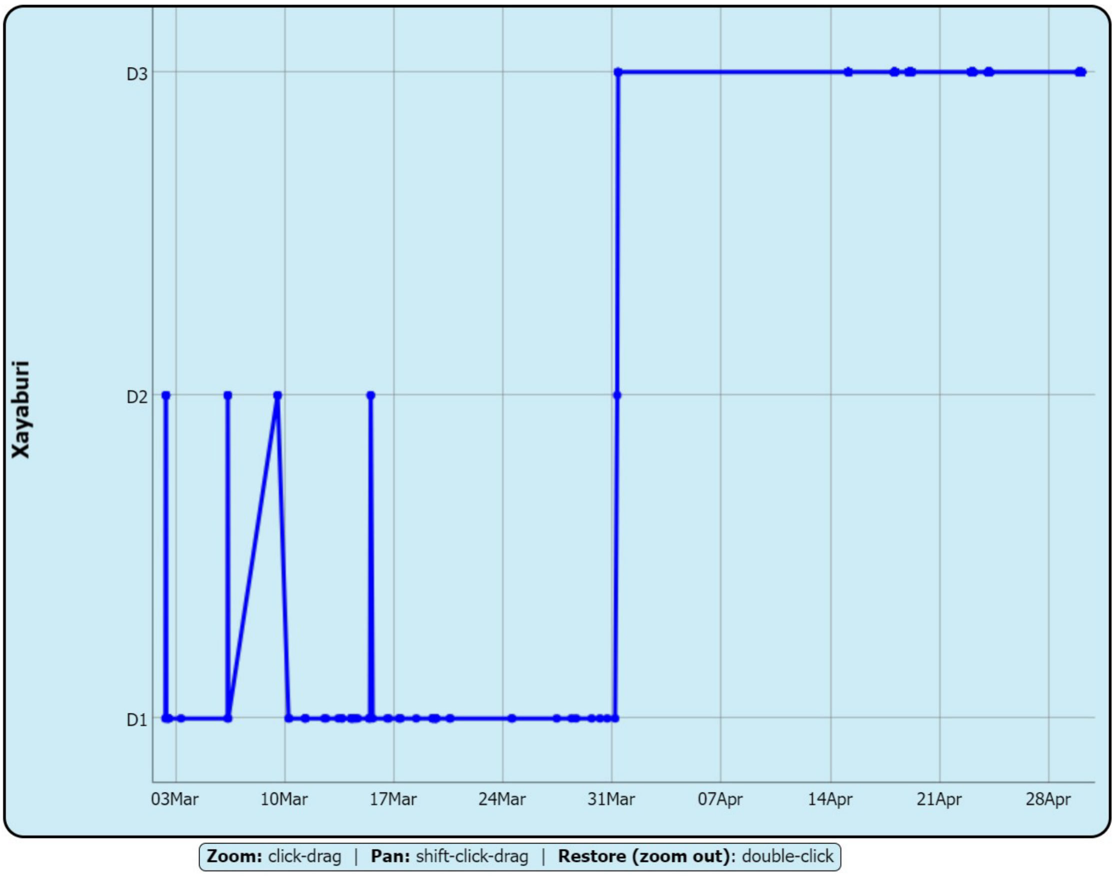


Figure 2.12. Example of fish ascent data for an *Hypsibarbus malcomi* individual, through both the fish pass and lock. Y-axis depicts the antenna (D1 – fish pass entrance; D2 – fish pass exit; D3 – I/O structure (upstream of the lock)). X-axis depicts time since tagging (for 2024).

Sensor Fish component

Pressure drops through the turbine runner were very sensitive to the elevation of Sensor Fish release, but collision rates on the runner were not. The frequency of occurrence of collision rates ranged from 8.2% to 9.3%.

Empirically measured magnitudes (by the Sensor Fish) validated the corresponding simulation outcomes with regards to the averaged magnitudes and their variability.

Discussion

The results suggest that most species are easily ascending the fish pass. Many are detected at the entrance and then again at the exit shortly after. They appear to be able to traverse the internal flows and slots easily and many are ascending in a few hours. However, the fish making complex ascents are more difficult to understand. They are either using the fish pass channel as a place of residency, possibly with the repeat up and down movements indicative of feeding on other fish in the channel. Alternatively, they may be having some difficulty ascending through the fish locks.

There is evidence of complex ascent behaviour from many species. Fish are frequently detected ascending the fish pass between the two antennas (entrance and exit) before descending again. Some fish then, seemingly, depart the fish pass before returning after a period and attempting again. These ascents are typically viewed as ‘unsuccessful’. However, it is difficult to determine the rational for this behaviour, and therefore it deserves further investigation. It could be because of fish pass operation, or it could be biological.

One line of investigation would be to correlate the periods of fish ascent with fish lock operation. If the fish ascend through the fish pass but reach the fish locks when it they are not in their attraction phase, then successful passage would not be possible, or the fish could be delayed. The fish lock synchronicity should be determined by comparing lock operation records to fish ascent data.

<u>Lock passage effectiveness</u>

Many individuals, and species, have been detected upstream of the entire fish pass facility (channel and locks) at least once (and some multiple times) since the IO PIT system was installed (and as of 19/4/24 when the most recent analysis was undertaken). A period of antenna downtime in 2023 limited the ability to provide a full appraisal of efficiency. Detailed analysis of fish lock operations and efficiency adjustments will therefore form the basis of FIS/2023/133. The system is currently online and new data is being generated.

<u>Sensor Fish component</u>

Flow simulations through the Xayaburi hydropower facility were performed based on current industry practices for designing turbines.

The hydraulic conditions measured by the Sensor Fish verified the associated simulation outcomes, providing confidence in the predictive power of using flow simulations for fish passage investigations.

The availability of empirically validated simulation approaches such as flow simulations can, in turn, enhance the development of ‘fish-friendly’ hydropower technologies.

Key messages

- The Xayaburi fish pass provides excellent fish passage efficiencies for key Mekong species.
- The Xayaburi locks have also facilitated the passage of more the 400 individual fish (and some multiple times).
- Our Sensor Fish study provided certainty about the predictive power of flow simulations for fish passage investigations, and these simulation approaches can subsequently facilitate the advancement of sustainable hydropower technologies.

11.2.6 Study 6 – Applying the learnings from the monitoring and evaluation to optimise the operation of the Xayaburi fish pass (Objective 2)

Study aim

The aim of this study was to optimise the effectiveness of the Xayaburi fish pass using the learnings from the preceding studies (particularly the M&E study (Study 5)).

Study approach

Step 1 was to obtain baseline information on fundamental factors influencing fish passage, including:

1. the seasonal timing of upstream migrations for key Mekong species – to determine the key times of fish passage for those species.
2. seasonal changes in water temperature and discharge through the Xayaburi hydropower facility – to determine if they have any obvious relationships with fish passage.

The second step will be to use this baseline information to optimise fish pass operations – during FIS/2023/133 (i.e. the follow-on study).

Results and Discussion

Seasonality of fish migrations and discharge and water temperature patterns

The preliminary data collected so far is showing that some species have defined migration seasons (Figure A2.13).

The overall number of fish detections in the fish pass appears to be greatest in the wet season months, and especially the period from May–July.

Likewise, for the period from 2020–2024, discharge was greatest in the mid-to-late wet season months of July, August and September (Figure 2.14).

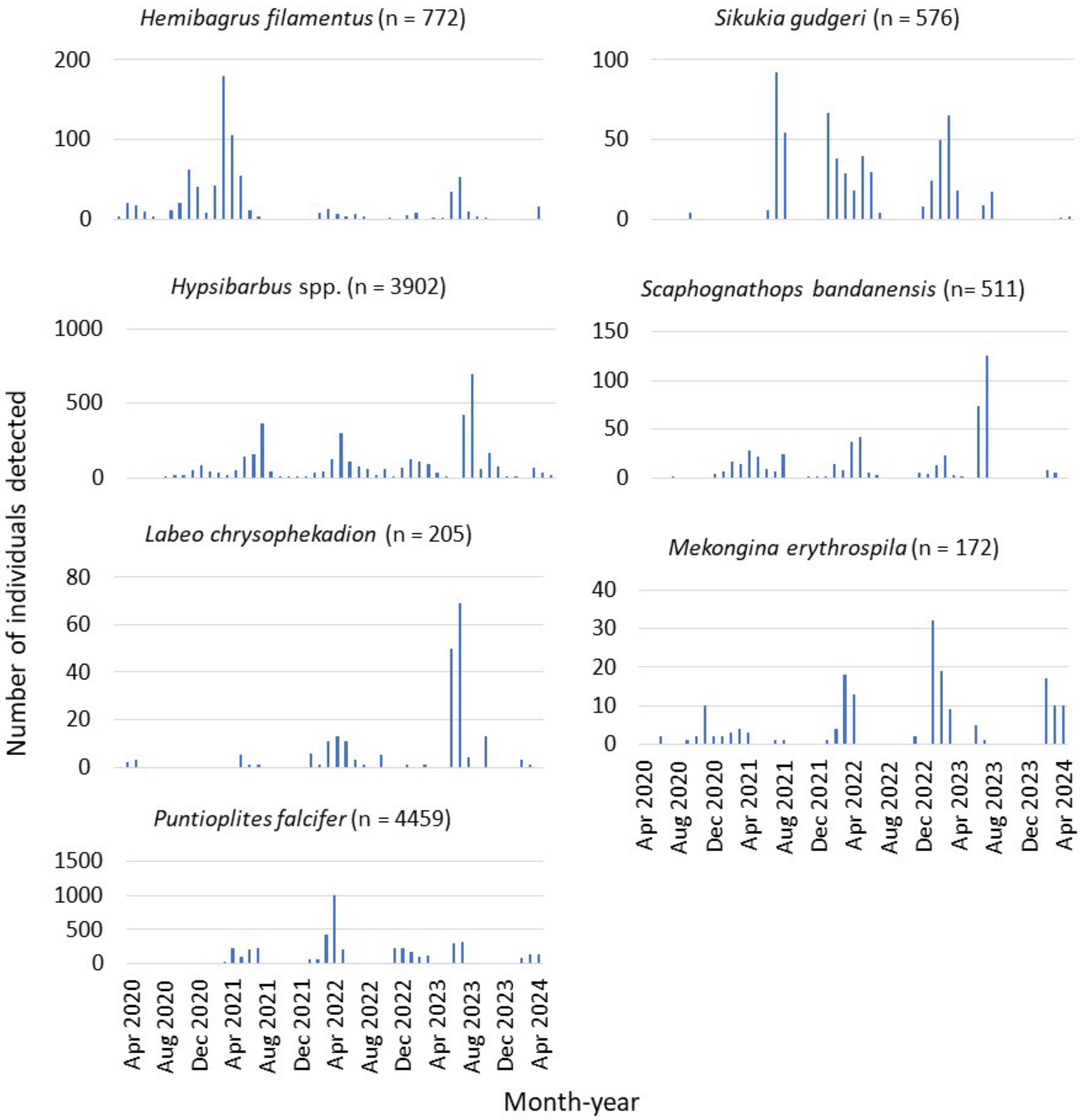


Figure 2.13. Migratory seasonality of species that occurred in all five years, based on PIT detection data within the fish pass (as of 22/4/24). Y-axis depicts total number of individual fish detected. X-axis provides the month-year detected.

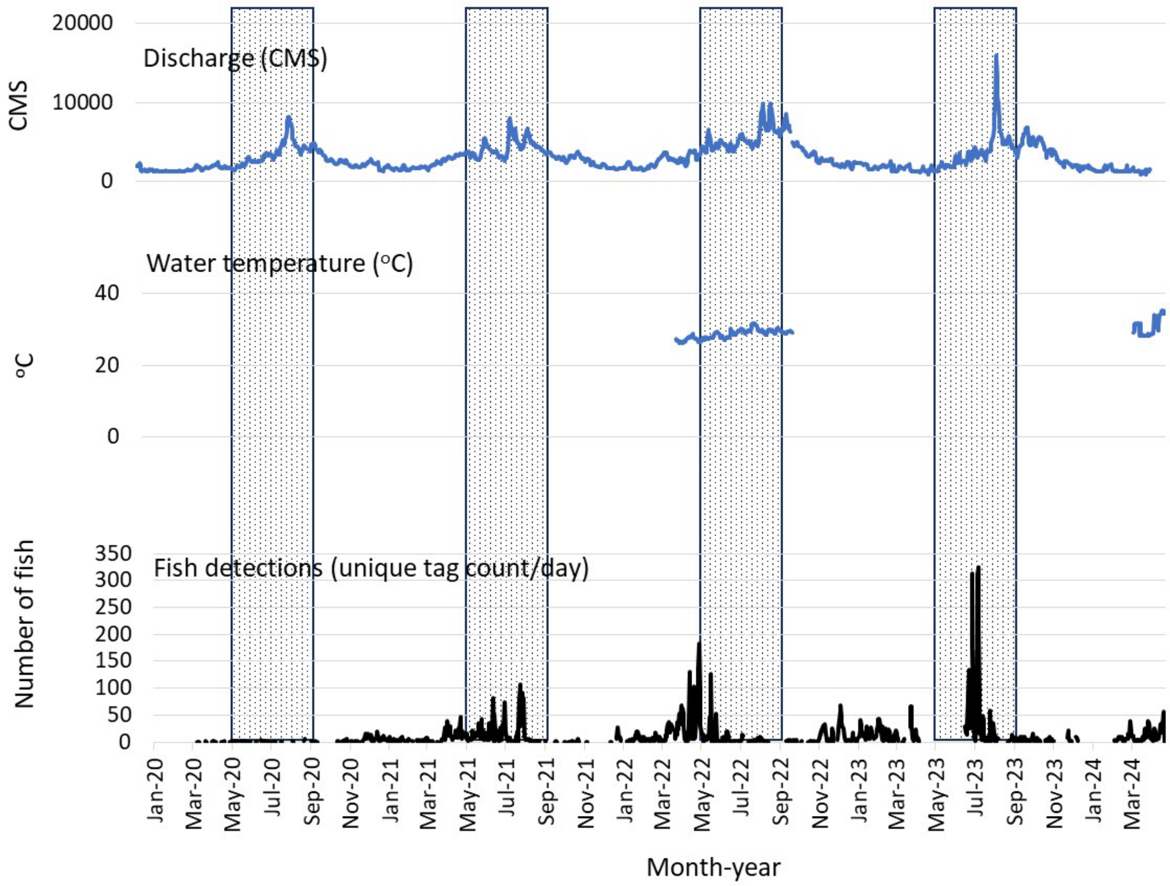


Figure 2.14. Total number of fish (all species) detected over time in the fish pass (as of 22/4/24), in relation to water temperature and discharge through the Xayaburi hydropower facility. Shaded periods represent wet seasons. The discharge and water temperature data were supplied by XPCL.

<u>Fis pass management optimisation measure</u>

When the water levels reach 242 m in the fish pass, the fish pass becomes inefficient and is consequently bypassed. Fish then use the two locks exclusively.

Key messages

- Baseline information forms the foundation of any monitoring study – and is especially critical in settings like the LMB – where there are currently no other empirical data on hydropower mitigation measures yet.
- The learnings from the baseline information collected during FIS/2017/017 will provide significant opportunities for fish pass optimisation during the follow-on project, FIS/2023/133.
- For example, knowledge of seasonal fish migrations by Mekong fishes could be used to 'manipulate' fish pass entrance and flow settings, at various times of the year, to maximise fish passage during peak periods.

11.2.7 Study 7 – Providing a standard for monitoring and constructing other mainstem fish pass facilities in the LMB (Objective 3)

Study aim

The aim of this study was to develop recommendations for optimising the efficacy of fish pass facilities for other mainstem hydropower plants in the LMB.

Study approach

All of the monitoring protocols developed during Study's 1-4, and fish pass M&E knowledge gained from Study's 5 and 6, were collated and applied to develop the recommendations for this study.

The monitoring approaches for PIT antenna design and testing, PIT tag retention testing, boat electrofishing, PIT tagging, using Sensor Fish, and applying the sustainable PIT tagging model, were all included, along with the learnings from the Xayaburi fish pass M&E study.

Results and Discussion

The following key recommendations were developed from FIS/2017/017 (more details on each can be found in the respective Appendix 2 study sections that they came from):

1. PIT antenna technologies can be successfully designed, installed and used to assess the passage effectiveness of large Mekong fish pass facilities and lock systems on mainstem hydropower plants (Study 1).

2. Most key Mekong fish species (*Sikukia gudgeri, Hypsibarbus lagleri, Hemibagrus filamentus, Puntioplites falcifer, Barbonymus schwanenfeldii*, and *Scaphognathops bandanensis*) are suitable for PIT tagging
    a. However, some (*Mekongina erythrospila*) appear to be susceptible to mortality after tagging, and/or are difficult to maintain (*Pangasianodon hypophthalmus*) in captivity, presumably because of their dietary and/or behavioural requirements (Study 2).

3. Boat electrofishing can be used to effectively capture large numbers of Mekong fish for PIT tagging in the LMB in a safe and non-harmful manner (Study 3).

4. Large-scale PIT tagging programs can be established for Mekong fishes, to facilitate fish passage investigations (Study 4).

5. A sustainable PIT tag population model should be used to estimate the number of fish that need to be PIT tagged every year to maintain target populations of tagged fish in the wild (Study 4).

6. Fish pass facilities can be used as mitigation measures to facilitate high passage efficiencies (>85%) for Mekong fishes – if they are suitably designed and operated for the local species and conditions (Study 5).

7. Flow simulation models and Sensor Fish can be used as hydraulic assessment tools to advance fish-friendly hydropower technologies (Study 5).

8. Many Mekong fish species have defined migration seasons. The collection of baseline data on these patterns will provide significant opportunities for fish pass

optimisation into the future because, for example, entrance and flow settings could be ‘manipulated’, in various seasons, to maximise fish passage during peak periods (Study 6).

In addition, the MRC recently released the Fish Passage Monitoring Manual (Mekong River Commission 2023). This manual provides M&E standards for assessing fish passage facilities throughout the LMB and has been released in multiple languages for engineers, scientists, government staff, and operators of infrastructures related to fish pass activities in South East Asia.

Fish-Friendly Irrigation

Fishway Monitoring Manual

Key messages

- FIS/2017/017 has facilitated the development of a series of scientifically defensible standards for achieving fish-friendly outcomes from future LMB hydropower developments.
- These recommendations will be expanded during FIS/2023/133, and could be used to compliment those in the MRC’s Fish Passage Monitoring Manual (Mekong River Commission (2023)) and the MRC Hydropower Mitigation Guidelines (Mekong River Commission, 2020).

11.2.8 Study 8 – Knowledge uptake (Objective 3)

The outcomes of this study have been reported in the Impacts section (Section 8).