Charles Sturt University
Gulbali Institute
Agriculture Water Environment

Fish Passage Monitoring in Khone Falls for the Joint Environment Monitoring Program pilots (JEM)

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Disclaimer

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1 Executive Summary

The Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects proposed by the Mekong River Commission (MRC) is aimed at providing information about the availability and condition of the water resources and their linkages with environmental conditions in the basin and how these are changing under present and future hydropower developments. JEM provides guidance on how to collect robust, standardised, information over five themes, including, hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries. The pilot project in this document reports on a trial of acoustic tagging technology for monitoring fish movement and passage and its potential to be included in the JEM Programme for future application on upcoming mainstream dams.

Khone Falls is the largest waterfall complex in the world and includes several larger permanent waterfalls and channels and numerous smaller channels and cascades that flow mostly only in the wet seasons when the river level is high. The Don Sahong Hydro power station was built across the Sahong channel, effectively blocking a key migration route for several large bodied migratory fish species. Consequently, the Don Sahong Power Company invested in improving fish passage in alternative channels through Khone Falls but the efficacy of these remedial measures is unknown. This pilot project ultimately aimed to trial technology that may be used to assess the effectiveness of the alternative natural fish passages channels in the region. The project had numerous milestones and multiple levels of expected outcomes along the way to that goal. The project included capacity building and certification for MRC member country participants in Personal Integrated Transponder (PIT) systems and Acoustic systems for tracking fish movement. In the wet season of 2022 an acoustic systems pilot study was performed in the Khone falls region.

33 Acoustic receivers were deployed in the Khone falls region and 139 fish from 13 species were tagged and released between June and August 2022. We found that the technology was of limited use in the region, particularly in the shallower channels and near the power station. Main factors influencing the suitability were the amount of noise in the water near the powerhouse or below the falls; the extremely uneven bathymetry of the river and channels, and; the shallow water in the channels. The suitability was further constrained by the differences in flow regime and the detectability of tags between the wet and dry seasons.

Nevertheless, we made several valuable findings using the technology. 124 of the 139 tagged fish were detected after release, and 14 of the 15 fish not detected had been released near the mouth of the Sadam Channel. We documented 4 fish that migrated upstream via the Sadam channel and all of these had been released in the Mekong mainstem upstream o the Sadam channel entrance and attempted to migrate through the Xang Peauk channel at least once before drifting downstream to find the Phapheng and ultimately Sadam channels. We released 13 fish in the Sahong channel above the power station and 9 of these went through the powerhouse and were detected downstream. Another one of the 13 exited through the top of the Sahong channel and was last detected at Ban Parmouk, 48 km above the falls.

Overall, the acoustic systems technology was well suited to larger open channels and ultimately to monitoring long distance migration, rather than assessing specific migration routes through shallow channels. For example, we documented several fish travelling more than 80 km from Southern Laos downstream to Cambodia, and at least 5 fish tagged and released below Khone falls were detected at Ban Parmouk, 48 km above the falls.

Our recommendations for acoustic and PIT systems technology as part of JEM include;

- On a small spatial and small temporal scale in natural habitats, such as assessing passage efficiency of individual channels around Khone Falls, radio tags are the best option, albeit not trialed in the LMB yet.
- On a large spatial scale, such as assessing fish migrations over 100s of kilometres or across international boundaries, and a short temporal scale (less than 5 years), without assessing passage efficiency at structures, low frequency acoustic tags (69 kHZ) are the best option.
- On a large spatial scale over a long-term (up to decades) and including multiple structures such as fish passage structures at power stations or weirs, integrated PIT systems are the best option.
- On a small spatial scale (e.g. fish passage structure within a single power station) over a short or long-time period (from weeks up to decades), PIT systems are the best option.
- Assessing fish behaviour or movements in rivers/ponds above and/or below hydro power stations (e.g. are they attracted to the fish passage structure?) is best performed over shorter time periods (e.g. up to three years) with specialised (3-dimensional) tags and a high frequency acoustic (180 or 307 kHz) system.

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6 Abbreviations and Acronyms

ACIAR – Australian Centre for International Agricultural Research

AWP – Australian Water Partnership

BL – Body length

CSU – Charles Sturt University

DSPC – Don Sahong Power Company

DSHP – Don Sahong Hydropower Project

FADM – Fish Abundance and Diversity Monitoring

GIZDeutsche – Gesellschaft für Internationale Zusammenarbeit GmbH

GPS – Global Positioning System

HPP – Hydropower plant

HPD – Hydropower development

ICEM – International Centre for Environmental Management

LAK – Lao Kip

LARReC – Living Aquatic Resources Research Centre

LMB – Lower Mekong Basin

MRC – Mekong River Commission

NUoL – National University of Laos

PDR – Peoples Democratic Republic

PIT – Passive integrated transponders

PP – Power plant

PS – Power station

ROTR – Run-of-the-River

UMB – Upper Mekong Basin

WOM – Wonders of the Mekong project

XPCL – Xayaburi Power Company Limited

XPS – Xayaburi Power Station

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7 Introduction

7.1 Background

The Procedures for Notification, Prior Consultation and Agreement (PNPCA) processes of the hydropower projects being developed on the Mekong mainstream identified the potential changes in water resources and quality, river health and fisheries as one of the key impacts of hydropower development (MRC 2020). Lower Mekong member countries identified the need for joint environmental monitoring of hydropower developments and the Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects was proposed by the Mekong River Commission (MRC) in May 2019 (MRC 2020).

7.2 JEM overview

JEM is aimed at providing information about the availability and condition of the water resources and their linkages with environmental conditions in the basin and how these are changing under present and future hydropower developments. This information will provide a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development.

JEM provides guidance on what and how to collect robust, standardised, information over five themes, including, hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries. JEM aids in identifying effective and efficient mitigation measures and promoting sustainable management and operation of Mekong mainstream hydropower projects (MRC 2020). Jem fisheries monitoring includes abundance and diversity monitoring, Larvae drift and juvenile monitoring and relevant to the current project, fish passage monitoring.

7.3 JEM Pilot program

The two existing hydropower developers, at Xayaburi and Don Sahong, already carry out regular monitoring of fish passage (including external tagging and video (DSPC),video, sonar, in passage trapping and PIT tagging XPCL); however, the JEM monitoring programme requires a system to be developed independently of that used by the hydropower project developers (MRC 2020). JEM guidelines provide the basic design of the monitoring to be used or piloted in the two operational hydropower projects. Advances in knowledge gained from the pilot studies will thus be used to update the JEM Programme guidelines.

The current pilot project as reported in this document reports on a trial of acoustic tagging technology for its potential to be included in the JEM Programme for future application on upcoming mainstream dams. The results may be used to inform potential mitigation and management measures to complement the advice of Preliminary Design Guidance. The results may also be used to illustrate how monitoring can inform adaptive management of hydropower operations.

7.4 Don Sahong Hydropower station

The Don Sahong dam is located on a river channel of the Mekong River mainstream in the border area between Lao PDR in the upper course and Cambodia in the lower course of Khone Falls (Figure 1). This area is generally known as Si Phan Done (four thousand islands), a complex of islands along about 10 km of the Mekong mostly upstream of the Great Fault Line (GFL) (MRC 2019, 2020).

Khone Falls is the largest waterfall in the world at 10.9 km across. There are two major falls which have flow all year round, Khone Phapheng on the eastern bank and the Liphi Falls further west. Numerous smaller channels and cascades, flow mostly only in the wet seasons when the river level is high (Figure 2). Prior to construction of the HPP, Hoo Sahong (otherwise known as Sahong channel), also flowed year-round and was the largest branch without a major waterfall between the upstream and downstream sections of the Mekong. Hoo Sahong had a relatively even fall from upstream to downstream with only a small series of rapids, and consequently was extremely important for fish migration.

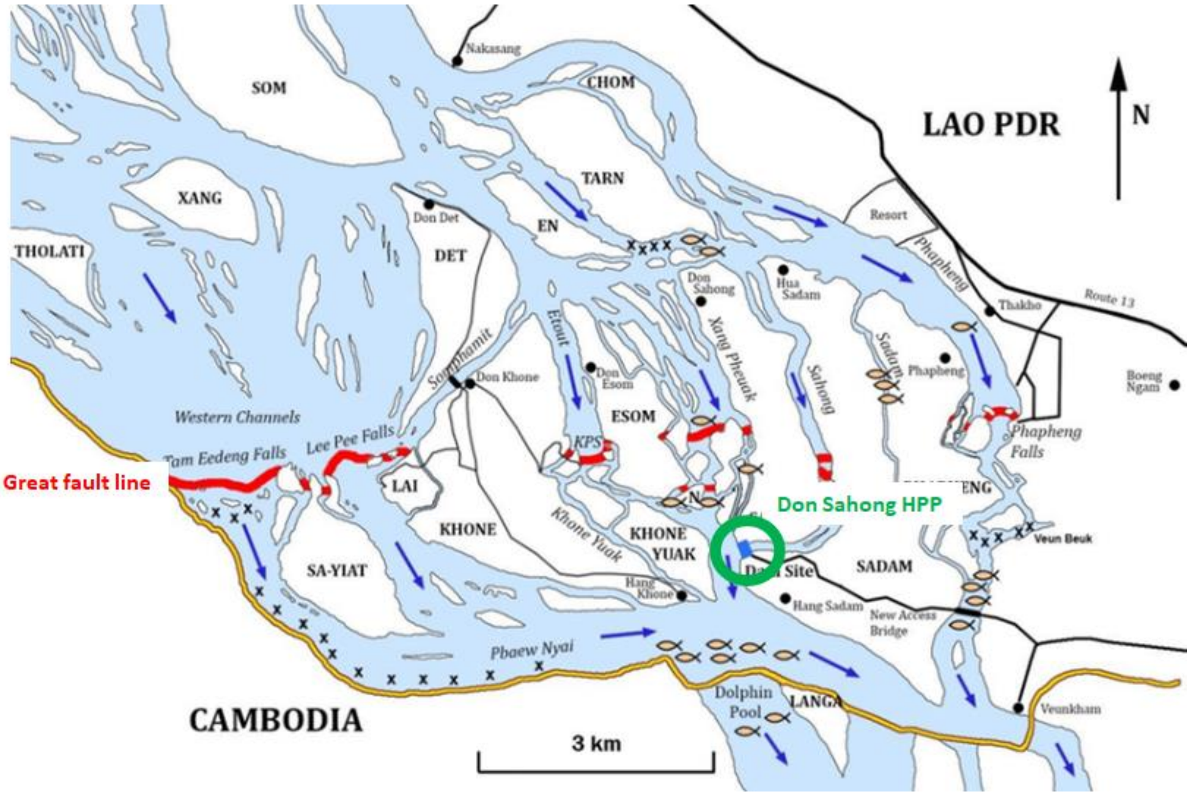

Figure 1. Simplified diagram of the Khone Falls region (circa 2008) with the location of the Don Sahong Hydropower plant circled (Modified from Hawkins et al, 2018).

Changes to fish passage in the Khone Falls region could potentially affect the long-term sustainability of certain migratory fish species in the Lower Mekong Basin. Fish productivity in the Great Lake Tonle Sap of Cambodia and fish migration through the Khone Falls area are intrinsically linked, most prominently through Hoo Sahong channel (MRC 2019). Some commercially important aquatic species such as *Pangasius krempfi*, an anadromous species migrate from the Vietnamese Delta through the Khone Falls area up into southern and central Lao PDR (MRC 2019, 2022).

Khone Falls has a series of water channels that allow for fish migrations at different periods of the year, depending mainly on the water level. Prior to the HPP, the Sahong channel was the only channel that allowed for both year-round migration and was large enough to support migration of big groups of large fish, including the Mekong giant catfish *Pangasianodon gigas*, and small fish, including the mud carp *Cirrhinus* species (MRC 2019).

Given the importance of Hoo Sahong for successful fish passage, the blocking of that channel by the HPP posed a serious threat to successful fish passage and could potentially upset the life-cycle of some species.

Migrating fish species are attracted to their chosen routes by flow, hence depending on the direction they approach from may enter and exit several channels whilst seeking successful passage. With engineered channel modifications above the Don Sahong HPP, there is increased flow through Hoo Sahong which makes it the most attractive fish passage option but the power house makes it impassable. Thus, there was an increased risk of reduced passage options (Figure 2) and increased harvest by fishermen targeting trapped fish, placing further pressure on the populations. Don Sahong Power Company (DSPC) subsequently developed activities to improve fish passage in nine channels across the Khone Falls region (Figure 3). The Don Sahong hydropower project presents a unique feature: the creation of nature-like bypass channels for fish to swim upstream despite the loss of the deepest channel Hoo Sahong, which was the most important route previously used by fish during dry season migrations.

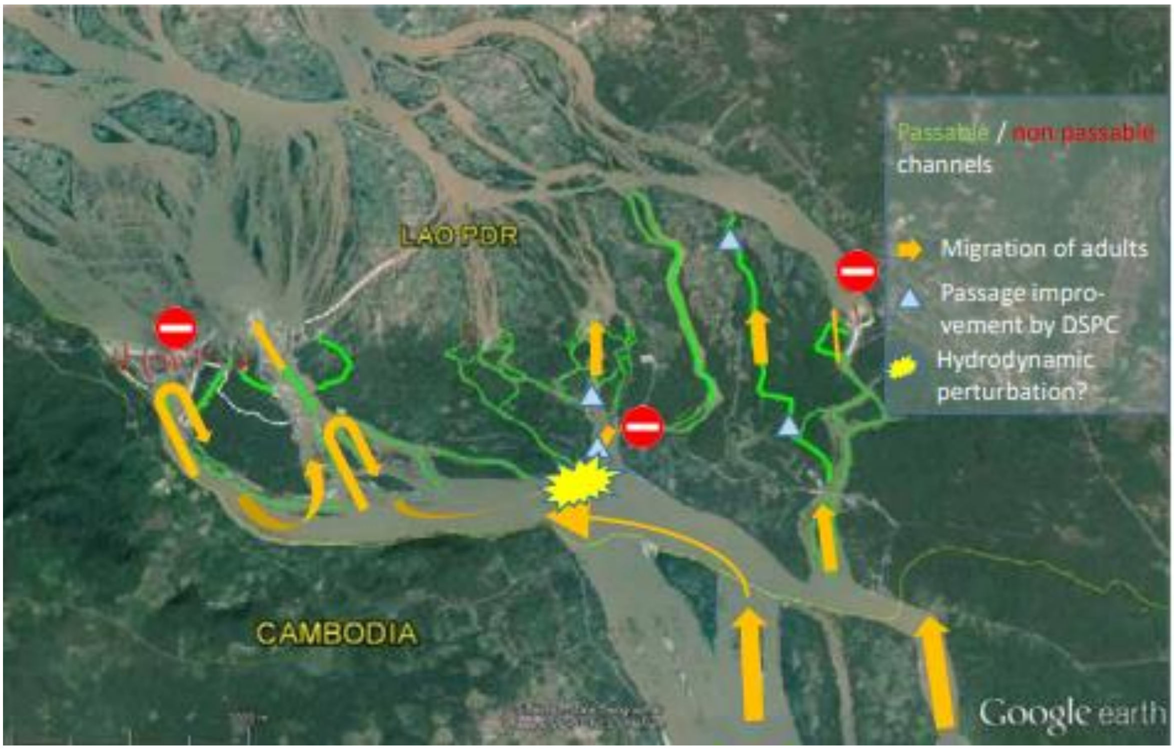

Figure 2. Synthesis representation of passage, migrations and obstacles at Khone Falls. The green represents flow and the orange represents fish movement patterns (source: MRC 2020). The thickness of the arrows represents volumes of fish using that route. Anecdotal comments on this diagram following the results of this study are included in Appendix A.

7.5 Monitoring moving fish

The fish passage monitoring component of the JEM pilots aimed to assess various aspects of fish passage at dam sites, including the efficacy of fish passage mitigation measures (MRC 2021). Monitoring requires tagging or uniquely identifying fish and monitoring their behaviour and fish passage around HPPs. An inception report concluded that a detailed desk study for tag selection was needed, and the resultant desktop analyses were reported in a MRC technical document (MRC 2021). The desktop analyses confirmed that Passive Integrated Transponder (PIT) tagging should be evaluated for the JEM project fish passage component at Xayaburi Power Station (XPS) where there is an artificial fishway, and to evaluate acoustic tagging technology for assessing fish movement in the Khone Falls region (MRC 2021).

Figure 3. The Don Sahong Power Company's fish passage improvement locations in the Khone Falls area (source: MRC 2020).

7.6 The pilot study

The pilot study in fisheries movement monitoring was required to include:

- the proposal of a simple methodology for fish migration study around dams informed by pilot activities,
- definition and feasibility design and analysis of a fish passage monitoring program using different types of tags and tagging techniques at DSPC dam in the Khone Falls area (MRC 2020).

The former was addressed by the Fish Abundance and Diversity Monitoring (FADM) developed by the International Centre for Environmental Management (ICEM) team, and the latter is the current project as described in this document.

The specific aim of monitoring fish passage at Don Sahong is to trial techniques which could detect whether the fish passage facilities are sufficient to mitigate the potential impact of the dam on restricting migration of fish, specifically in the Hoo Sadam, Hoo Sahong and Hoo Xang Peuak channels (MRC 2019). That is, impacts on fish populations downstream and upstream of the dam are accounted for in the FADM, but fish passage monitoring is independent of these and only targets [migrating] fish that reach the HPP, or associated channels.

Monitoring fish passage typically has two components: i) assessing fish approaching the dam or fish pass and locating the entrance (referred to as attraction efficiency), and; ii) assessing fish ability to enter and exit the fish pass, modified channels spillway or turbine (referred to as passage efficiency). These apply to both upstream and downstream migration.

- attraction efficiency requires data on fish approaching the dam.
- passage efficiency assesses how successfully the fish pass through channel after they find it.

The objectives of the fish migration and fish passage studies in Don Sahong were to:

- assess if fish passed through one or both of two "natural" fish passage channels (Hoo Sadam and Hoo Xang Peuak, in particular during the dry season)
- generate reliable fisheries data and information on transboundary fish species, and their migration patterns,
- assess fish catch/yield and value in the Hoo Sadam, Hoo Sahong and Hoo Xangpueak channels.

The second and third points above are covered by the FADM and a frame survey/fish migration study summarised by ICEM (MRC 2019 - DSHPP pilot, page 33).

7.7 This project and report

This project ultimately aimed to pilot technology that may be used to assess the effectiveness of the two natural fish passages channels (Hoo Sadam and Hoo Xang Peuak). The project had numerous milestones and multiple levels of expected outcomes along the way to that goal, and these are described in the implementation section below.

Plate 1. Fish tagging below at Wat Hang Sadam in August 2022.

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8 Implementation

8.1 Project implementation timetable

The COVID-19 pandemic resulted in delays in the project by hampering the importation of goods, and transport of project staff, to Lao PDR. Procurement began in March of 2021 and equipment arrived gradually up until April 2022. The implementation of activities is described in Table 1. Ultimately, the project proceeded in 2022, but after the dry season.

Table 1. Timeline of activities undertaken during the fish movement monitoring component of the JEM pilots.

Timing	Activity	Location
September 2021	PIT systems training workshop	LARReC, Vientiane
September and October 2021	PIT tagging trial	LARReC, Vientiane
February 2022	Acoustic systems workshop	LARReC, Vientiane. Ban Na, Champasak
February 2022	Reconnaissance for suitable locations and options for deploying acoustic receivers	Si Pan Done, Champasak
March and April 2022	Acoustic tagging trial	Ban Na, Champasak
April to July 2022	Receiver deployments	Si Pan Done, Champasak
June to August 2022	Fish tagging and releasing	Si Pan Done, Champasak
June 2022	Acoustic systems demonstration including tagging and receiver deployment demonstrations for VIP guests of the MRC	Don Sahong Power Company fishery centre
July 2022	PIT and acoustic systems workshop, demonstration of tagging and receiver deployment for MRC member country participants	Don Sahong Power Company fishery centre
November 2022	Receivers retrieved and downloaded	Si Pan Done, Champasak
February 2023	Receivers retrieved and downloaded	Si Pan Done, Champasak

9 PIT systems training/workshop

The PIT systems workshop was held at the Living Aquatic Resources Research Centre (LARReC) in Nong Taeng, Vientiane. The workshop included two days of theory and three days of practical. The number of attendees was limited to 20 Lao PDR nationals because of COVID-19 restrictions (Table 2). The first two days were streamed on the internet for MRC and international attendees.

Table 2. Participants at the PIT training workshop at LARReC in Vientiane in September 2021. LNMC = Lower Mekong National Committee; DLF = Department of Livestock and Fisheries; DOI = Department of Irrigation.

Name	Role	Department
Mr. Bounsong Vongvichit	LARREC Host	LARReC
Mr. Thavone Phommavong	Workshop student	LARReC
Mrs. Vannida Bouarapha	Workshop student	LARReC
Mr. Somphanh Pilavong	Workshop student	LARReC
Mr. Saleumphone Chanthavong	Workshop student	LARReC
Mr. KeoviLay Botdavong	Workshop student	LARReC
Mr. Sisommout Sichanh	Workshop student	LARReC
Mr. Norkeo Phetsanghan	Additional	LARReC
Mr. Sommanoxay Soulivanh	Workshop student	LNMC
Mrs. Nokkeo Souksan	Workshop student	Kong District
Mr. Somkit Douangmala	Workshop student	Kong District
Mrs. Soukmixay Phommachanh	Workshop student	Champasak Province
Mr. Aloun Thepkaisone	Workshop student	Champasak Province
Mrs. Mayvong Sayatham	GIZ invite	GIZ
Dr. Wayne Robinson	Workshop instructor	CSU
Mr. Garry Thorncraft	Workshop instructor	CSU
Mr. Phousone Vorasane	Workshop instructor	NUoL/CSU
Ms. Somphou Phasulath	CSU invite	DLF
Mr. Sithixay kaylath	CSU invite	NUoL
Mr. Vaviyo Simonkhoun	CSU invite	DOI
Mr. Amphone Keosengthong	CSU invite	NUoL

9.1 Outcomes – PIT systems training workshop

9.1.1 Training workshop – setting up a stationary PIT system

Participants in the September 2021 workshop received practical training in antenna installation and setup, including tuning the antenna to 23 mm or 12 mm full- or half-duplex tags (Plate 2). In June 2022, Mrs. Vannida Bouarapha (LARReC staff trained at the September 2021 workshop) set up and tuned a PIT antenna in the field at Don Sahong to demonstrate PIT systems to the staff from MRC member country partners.

9.1.2 Training workshop – tagging fish in a tag retention trial

Forty-seven *Hypsibarbus malcomi* were used, 15 were untagged (control) and 32 were tagged with 12 mm tags using a specialised tag insertion gun. Forty-four *Pangasius hypophthalmus* were used; 30 of those were syringe tagged with 23 mm tags and 14 were control fish (Plate 3). All participants tagged at least 2 fish each.

Plate 2. Workshop participants received theoretical and practical training in stationary PIT systems and antenna installation and tuning.

Plate 3. Workshop participants received theoretical and practical training in tagging fish using 12 mm (top) and 23 mm (lower) PIT tags.

9.1.3 Training workshop – PIT tag retention trial findings

Fish and tanks were checked daily, with rejected tags and mortalities logged and fish preserved. At the conclusion of the trial (after 35 days) all remaining fish were euthanised and an autopsy carried out to assess, condition, tag position and probable cause of mortality (if not euthanised) (Plate 4).

Hypsibarbus malcomi

- Are a hardy species for PIT tagging with 12 mm tags, the mortalities in this trial were minimal given the inexperience of the taggers.
- Lost condition during the trial because:
    - the quality of fish used was low
        - as indicated by the prevalence of disease at the start, and
    - the housing was less than optimal
        - as indicated by the generic decrease in condition across both tagged and untagged fish during the trial.

Pangasius hypophthalmus

- Are suitable for tagging with 23 mm PIT tags. The mortalities in this trial were minimal given the inexperience of the taggers used.
- Lost condition in the trial reflecting that the housing was less than optimal
    - as indicated by the generic decrease in condition and mortalities across tagged and untagged fish during the trial.

Plate 4. Students from the National University of Laos assisted in the euthanising and autopsies for all fish used in the tag retention trial. Note the very poor body condition of the *Pangasius hypophthalmus* in the images.

9.1.4 PIT tagging and PIT systems demonstration to VIP and LMC partners

The visits both took place at Don Sahong fishery centre. The VIP trip (Plate 5) included an overview of PIT and acoustic tagging systems and external marking using T-bar tags. The LMC partners visit (Plate 6) included antenna installation and tuning and tagging demonstrations.

9.2 Fish PIT tagged during the JEM pilot

There were 137 individual fish from 14 species PIT tagged during the JEM pilot study in the Don Sahong region between June and August 2022 (Table 3). All of these fish were released with an acoustic transmitter at the same time (see section 13). The unique PIT tag number was uploaded to the MRC JEM pilot database. Whilst there were no active antennas in the region at the time of tagging, these tags will remain viable for the life of the fish and may be picked up at any time in the future. The tag data were also lodged with the XPCL database in case a tag migrates all the way to that power station fish ladder.

Plate 5. Workshop-trained team members demonstrated PIT tagging to VIP visitors to Don Sahong region in June 2022. Guests participated in releasing tagged fish.

Plate 6. Workshop-trained team members demonstrated antenna setup and tuning, and PIT tagging to LMC partner visitors to Don Sahong region in July 2022.

Table 3. Numbers of fish of each species PIT tagged with each PIT tag size near Don Sahong during the JEM pilot study. Tag numbers and fish details are lodged with the XPCL database.

Species	12 mm	23 mm	Total
Bagarius bagarius	3	2	5
Bagarius yarelli	4	1	5
Cosmochilus harmandi	0	1	1
Helicophagus leptorhynchus	1	10	11
Hemibagrus filamentus	1	7	8
Hemibagrus wyckii	0	2	2
Hemibagrus wyckioides	2	5	7
Hypsibarbus malcolmi	0	1	1
Hypsibarbus wetmorei	1	0	1
Micronema cheveyi	0	1	1
Pangasius conchophilus	10	49	59
Pangasius larnaudii	14	19	33
Puntioplites falcifer	1	1	2
Scaphognathops bandanensis	1	0	1
Total	38	99	137

10 Acoustic systems training/workshop

The workshop included theory sessions held at LARReC, Vientiane capital, 11–15 February 2022, which were streamed for MRC LMC members. The national delegates then moved to the Ban Na Hatchery, Champasak for practical training from 16–20 February 2022.

10.1 Outcomes – acoustic systems workshop

Delegates (Table 4) received training in acoustic systems technology, deployment, tagging, data collection, data analyses, and reporting.

10.1.1 Acoustic tagging trial

At the end of the theory and practical training, five fish taggers that had all been trained in tagging, surgery and fish husbandry technique as part of this project took part in an acoustic tagging trial at Ban Na hatchery. The trial also included capacity building in husbandry, fish surgery and recovery, autopsy and fish biology for local staff members at the Ban Na hatchery (Table 5).

Fish were tagged between 17th and 21st of February and held at the hatchery until the trial was completed on 31 March 2022.

Table 4. Delegates attending the theory and practical acoustic training workshop in February 2022. DAFO = District Agriculture and Forestry Office; PAFO = Provincial Agriculture and Forestry Office.

Participants	Affiliation	Position
Instructors:		
Dr Wayne Robinson	CSU	Tag trial expert
Mr Garry Thorncraft	NUoL	Lao PDR fish passage expert
Mr Sithixay Kaylath	NUoL	Surgery expert
Technical assistants:		
Phousanne Vorasane	NUoL	Tagging equipment & logistics
Somphanh Pilavong	LARReC	Fish management
Sombath Sensavath	DAFO	DLF Fish management
Amphone Keosengthong	NUoL	Surgery assistant
Mrs. Vannida Bouarapha♀	LARReC	JEM project technical staff
Mr. Saleumphone Chanthavong	LARReC	JEM project technical staff
CSU invitees:		
Thonlom Phommavong	NUoL	Laos fish passage technical staff
Sinsamout Ounboundisane	Fishbio	WOM project technical staff
Somphone Phommanivong	DSPC	DSPC technical staff
Vaviyo Simonkhoun	DOI	CSU student
Somphou Phasaluth♀	DLF	CSU student
Regional staff:		
Aloun Thepkaisone	PAFO	Dept of Fisheries technical staff
nominee♀	PAFO	Dept of Fisheries technical staff
nominee♀	DAFO	DLF technical staff
MRC invitees:		
LNMC participant	MRC	JEM representative
Vanna Nuon	MRC	JEM Administration
Phetdala Oudone	GIZ	JEM Administration
Mayvong Sayatham♀	GIZ	JEM Administration
LARReC staff:		
Mr. Bounsong Vongvichit	LARReC	Associate Director
Mr. Thavone Phommavong	LARReC	JEM project technical staff
Online attendance:		
Prof Lee Baumgartner	CSU	Fish passage expert
Dr Emma Zalcman♀	AUSVET	Surgery expert
Dr Hugh Pederson	INNOVASEA	Acoustic telemetry expert

Table 5. Participants in the fish acoustic tagging trial at Ban Na hatchery in February 2022.

Participant	Affiliation	Position	Activity
Dr Wayne Robinson	CSU	JEM pilot project manager	Tag trial design, logistics and supervision
Mr Sithixay Kaylath	NUoL	Veterinary lecturer	Fish surgery and autopsy
Mr Phousanne Vorasane	NUoL	CSU/NUoL technical staff	Fish surgery
Mrs. Vannida Bouarapha♀	LARReC	JEM project technical staff	Fish surgery
Mrs. Phonaphet Chanthasone♀	LARReC	JEM project technical staff	Fish surgery
Mrs. Phousamone Phommachan ♀	LARReC	JEM project technical staff	Fish surgery
Mr Bountong Chantamaly	PAFO	Hatchery manager	Fish husbandry
Mr Sombath Sensavath	DAFO	DLF fish management	Fish husbandry and autopsy
Mr Sakda Keoboualapha	PAFO	Hatchery assistant	Fish husbandry
Mr Khamphat Sengphachan	PAFO	Hatchery assistant	Fish husbandry

10.1.2 VIP demonstration tour

Forty high level participants from all MRC member countries attended the VIP demonstration tour. The participants included ambassadors or their representatives from Australia and Germany, project stakeholder representatives (including from GiZ, MRC, AWP, DSPC), and country delegates. The visit encompassed presentations about the JEM project and the acoustic technology, and *in-situ* demonstrations of PIT, external and acoustic tagging technologies. Fish surgery was performed at the DSPC fishery centre by LARReC surgeons and fish were released by workshop participants (Plate 7).

Plate 7. Annette Knobloch, German Ambassador to Lao PDR and Dan Heldon, Deputy Australian ambassador to Lao PDR were among the high-level visitors to Don Sahong in June of 2022. Participants learned how acoustic tagging systems work and watched surgical insertion of acoustic tags and aided in the release of fish to the river.

10.1.3Lower Mekong Member Country field workshop

Twenty participants came from Vietnam, Thailand, Cambodia, Lao PDR and Myanmar to observe and join *in-situ* demonstrations of PIT, external and acoustic tagging technologies in July 2022. Participants were trained in setting up PIT system antennas and given a live demonstration of all fish tagging methods (Plate 8).

Plate 8. LMC visitors to Don Sahong learned how PIT and acoustic tagging systems work and watched surgical insertion of PIT and acoustic tags into fish that were then released to the river.

11 Results – acoustic tag trial

The trial aimed to gain a preliminary understanding of the effects of four tagging treatments, anaesthetic/surgery, acoustic tagging, PIT tagging and external tagging. Typically, a tag trial requires about 200 fish per treatment, but this pilot study had only 50 fish available. This small sample meant the only option was to use an additive approach, where the effects of each tagging treatment are compared to other treatment combinations without the ability to assess interactions (whether the influence of one tagging factor is dependent on another factor). The allocation of the 5 possible treatments to the 50 fish is documented in Table 6.

Table 6. Numbers of fish allocated to each treatment type for the tagging trial at Ban Na in February 2022. A surgery control fish was not tagged but underwent anaesthetic and surgery including an incision and stitching. A true control was only anaesthetised and handled.

	Procedure					Number of unique fish receiving treatment
Treatment Description	**Surgery**	**Acoustic tag**	**PIT tag**	**External tag**	**Anaesthetic**	
Full treatment	✓	✓	✓	✓	✓	**26**
Acoustic & PIT	✓	✓	✓		✓	**6**
Acoustic & external	✓	✓		✓	✓	**6**
Surgery control	✓				✓	**6**
True control					✓	**6**
Number of fish receiving procedure	**44**	**38**	**32**	**32**	**50**	**50**

The results are further confounded by varying fish species, fish sizes, acoustic tag sizes, external tag types, suture types, starting conditions of fish, different holding tanks, inconsistent fish identifications and five different surgeons used in the trial. The species available from the river in February were mostly scale fish, and these were rare in the later tag out at Don Sahong between June and August.

Tagging (Plate 9) was done over a four-day period. After 32–35 days, all surviving fish were euthanised and autopsied (Plate 10) to assess tag positioning, loss or gain in weight, and to evaluate the various types of sutures, and the time taken for internal and external healing or wounds.

11.1.1 Acoustic tag trial summary

All the results were treated as exploratory only because of the limited scope and sample size. The main benefit was the additional experience in surgery and anaesthetic times and doses. Additionally:

- *Cyclocheilichthys* and *Cosmochilus* spp. are unsuitable for tagging without further trials
- *Hypsibarbus* and *Scaphognathops* spp. are suitable for tagging
- Braided sutures are not suitable for surgery
- Chromic catgut sutures are suitable for surgery
- Gut tagging is ideal for all suitable species
- All anaesthetic equipment and methods, including 12V DC options for anaesthetic gill pumps, manual aeration devices and teamwork, were adaptively managed and optimized for the future field component.

Plate 9. A surgeon inserting an acoustic tag into an anaesthetised fish during the Ban Na acoustic tag trials in February 2022.

Plate 10. Autopsies were carried out on every fish used in the Ban Na acoustic tag trials in February 2022.

12 Receiver deployments

Receiver deployments involved multiple teams and staff members from CSU, LARReC, DAFO, PAFO, DSPC, and local villagers over approximately 120 days. Initial work included range testing at multiple sites to assess suitability for receiver locations (Figure 4). Factors that affected the suitability of a location to position an acoustic receiver include, the level of background noise, the water depth, the discharge (m^3/s), channel substrate and evenness, accessibility/likelihood of tampering, acceptance by local community, interference with traditional fishing grounds, and relevance to fish passage or fish passage improvements by DSPC, including proposed locations from MRC (2021), Ounboundisane (2021), and the JEM pilot for the Don Sahong fish passage monitoring project brief.

Thirty-three receivers were deployed in the main channel and small fish passage channels (Figure 5) using various methods, depending on location (Plate 11). Another 32 receivers were deployed by the WOM team in Cambodia in July and August 2022.

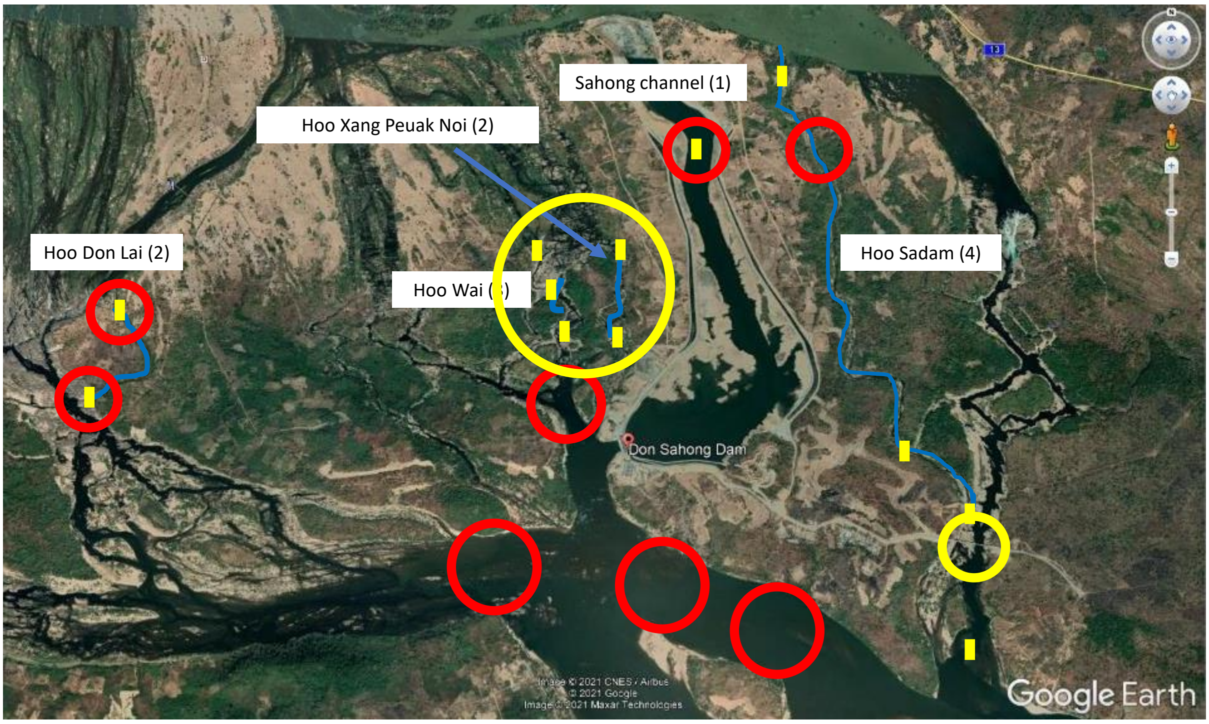

Figure 4. Locations recommended by ICEM for receivers pre deployment (yellow squares) and locations investigated for suitability (circles) prior to deployment. Red circles are locations range tested using the acoustic receiver system and yellow circles are areas physically inspected without deploying test receivers.

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12.1 Range tests

All sites where receivers were deployed were range tested in April or May and several of the receivers were range tested again prior to recovery in February 2023. Summary details of range tests are included in Appendix B.

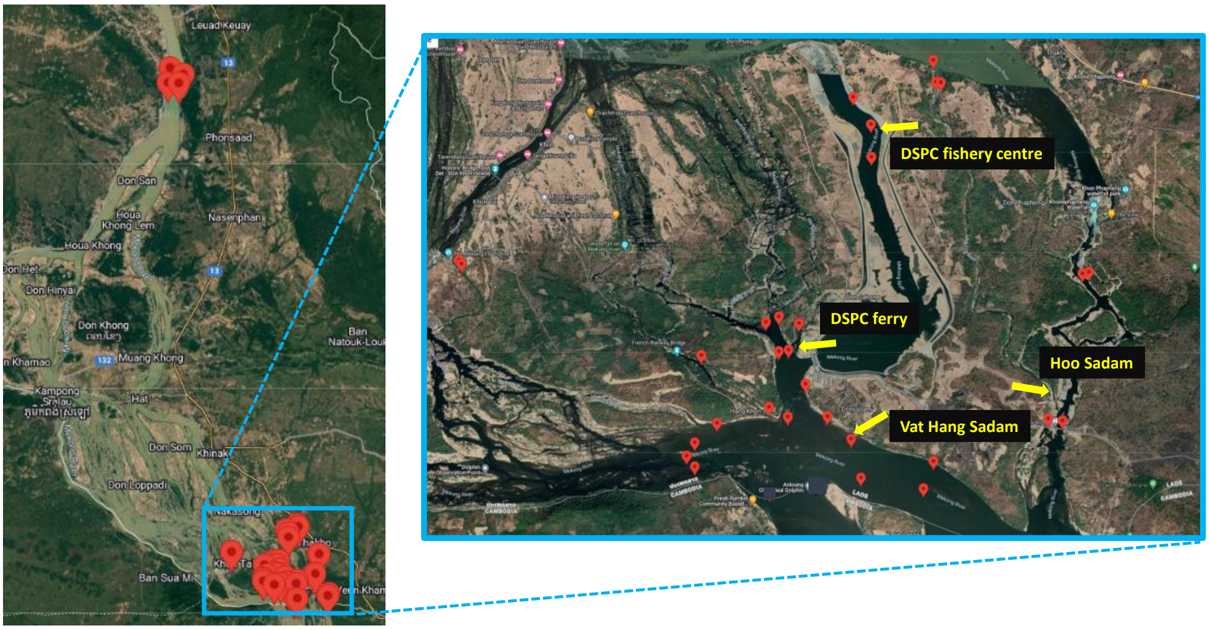

Figure 5. Locations of receivers (red flags) deployed for the JEM acoustic tracking pilot in the Don Sahong region of southern Lao PDR in 2022. Yellow arrows indicate the four locations for releasing tagged fish later in the study.

Plate 11. Methods used to deploy the receivers included attaching them to existing structures or rocky outcrops in channels or using an anchor and receiver tower structure in the Mekong mainstem.

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12.2 Receiver deployment summary

Final receiver locations are shown in Figure's 5 and 6. Two receivers in the Sahong channel to monitor fish from the first fish release as part of the high-level MRC visit on 6–8 June were removed on 23 June (Figure 13). All the receivers that would be exposed in the dry season were removed in November 2022, and most of the remaining receivers were removed in February 2023 (Figure 13). Five receivers were considered lost during the project, two of those are still in the river in known locations but currently irretrievable, and the other three have vanished .

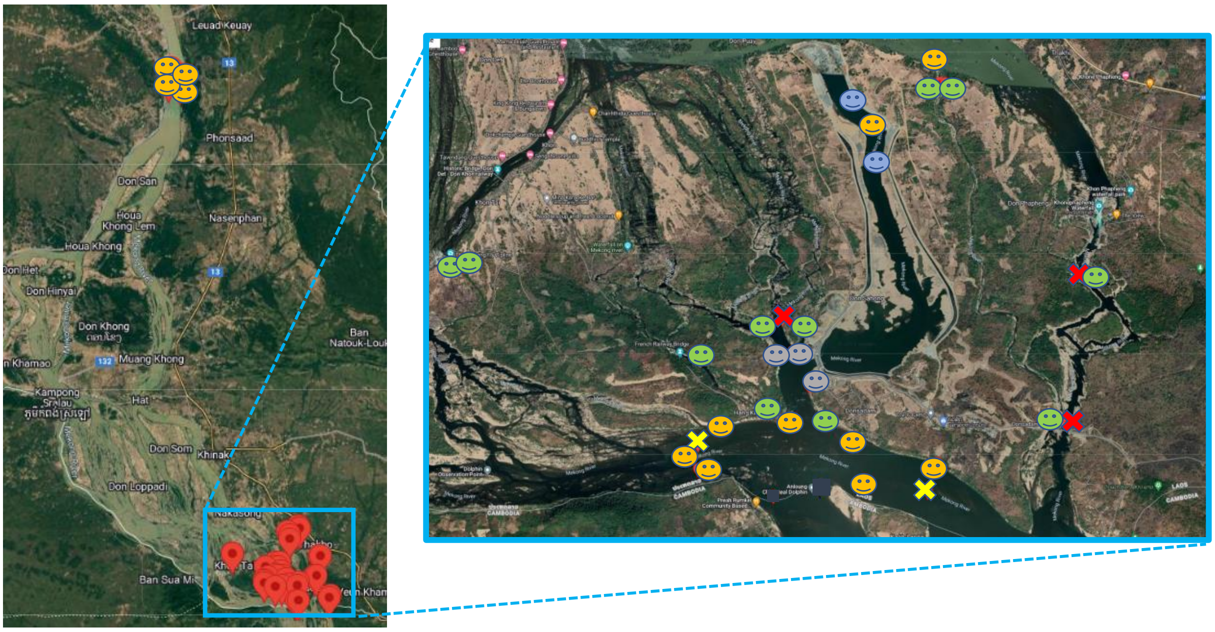

Figure 6. Final JEM pilot receiver locations and retrieval status. ✕ = vanished receiver. ✕ = irretrievable receiver. = retrieved June 2022, = retrieved November 2022, = retrieved February 2023, = retrieved February 2023, but had moved location during the study.

13 Tagging fish

13.1 Summary of fish tagged

The surgery team (acoustic) tagged and released 139 fish in the Don Sahong region over four trips covering a 70-day period and there were four main release locations (Figure 5). There were three sized tags [V7 = 44 tags, V9 = 50 tags, V13 = 39 tags] used. Fish were procured from local fishermen and only healthy fish were tagged and released. A further 154 fish were tagged and released between the Lao PDR-Cambodia border and Stung Treng in Cambodia by the WOM team within the JEM pilot study timeframe (Figure 7).

The 139 tagged and released fish in the JEM project were from 12 species (Table 7) and most fish were released in the main channel near Wat Hang Sadam (Table 8). Fish released near Wat Hang Sadam were released either from the shore in front of the temple, or mid-channel between Lao PDR and Cambodia (near receiver 487225), or 800 m downstream (Hang Sadam Taban).

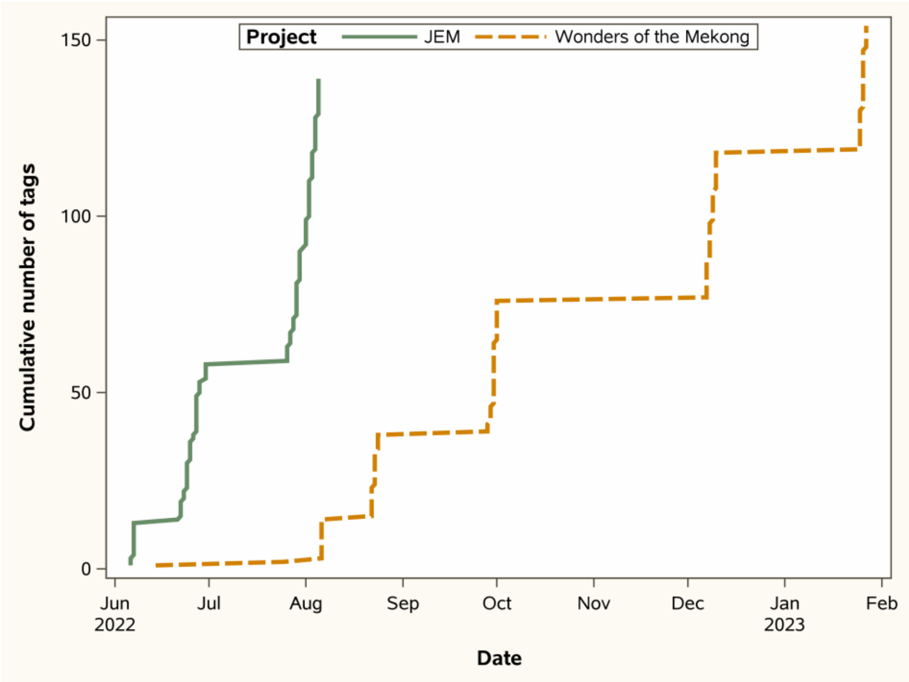

Figure 7. Cumulative number of acoustic tagged fish during the JEM pilot near Don Sahong in Southern Lao PDR. The Wonders of the Mekong project tagged fish in the Mekong River in nearby Cambodia or close to Stung Treng (40 km downstream from the Lao PDR border) during the same timeframe.

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Table 7. Number of fish of each species tagged and released in the JEM pilot study near Don Sahong.

Species	Laos common name	Tagged and released	Detected
Bagarius bagarius	Goonch	5	2
Bagarius yarelli	Goonch	5	5
Helicophagus leptorhynchus	Pa na nou	8	7
Hemibagrus filamentus	Pa kot reung	9	8
Hemibagrus wyckioides	Pa kheung	8	7
Hemibagrus wyckii	Pa kot mohr	2	2
Hypsibarbus malcolmi	Pa pak	1	1
Hypsibarbus wetmorei	Pa pak kham	1	0
Micronema cheveyi	Pa naeng daeng	1	1
Pangasius conchopholis	Pa kae	64	59
Pangasius larnaudii	Pa pung	33	30
Puntioplites falcifer	Pa sakang	2	2

Table 8. Number of fish tagged and released per location in the JEM pilot study near Don Sahong. Release locations ae shown in Figure 5.

Species	Hoo Sadam	DSPC fishery centre	DSPC ferry	Wat Hang Sadam
Bagarius spp.	2	0	4	4
Pangasius conchopholis	9	9	0	46
Hemibagrus spp.	2	1	0	16
Helicophagus leptorhynchus	1	3	0	4
Micronema cheveyi	0	1	0	0
Pangasius larnaudii	6	0	8	19
Puntioplites falcifer	0	0	0	2
Hypsibarbus spp.	1	0	0	1
Total	21	14	12	92

13.2 Summary of fish detected

One-hundred-and-twenty-four of the 139 released fish were detected at least once during the duration of the project (Table 7). All three tag sizes were well detected (V7: 44 tags 91% detected, V9: 50 tags, 88% detected, V13, 45 tags = 87% detected). Fish that were detected were detected between 1 and 56,000 times (Figure 8). Detected fish were picked up on an average of 6.1 receivers each (min = 1, max = 16) (Table 9). *Micronema* (1 fish on 10 receivers), *Pangasius* (6.7 receivers/fish) and *Hemibagrus* (4.9 receivers/fish) species were detected on more receivers than *Puntioplites* (3 receivers/fish), *Bagarius* (3.3 receivers/fish) and *Hypsibarbus* (2 receivers/fish).

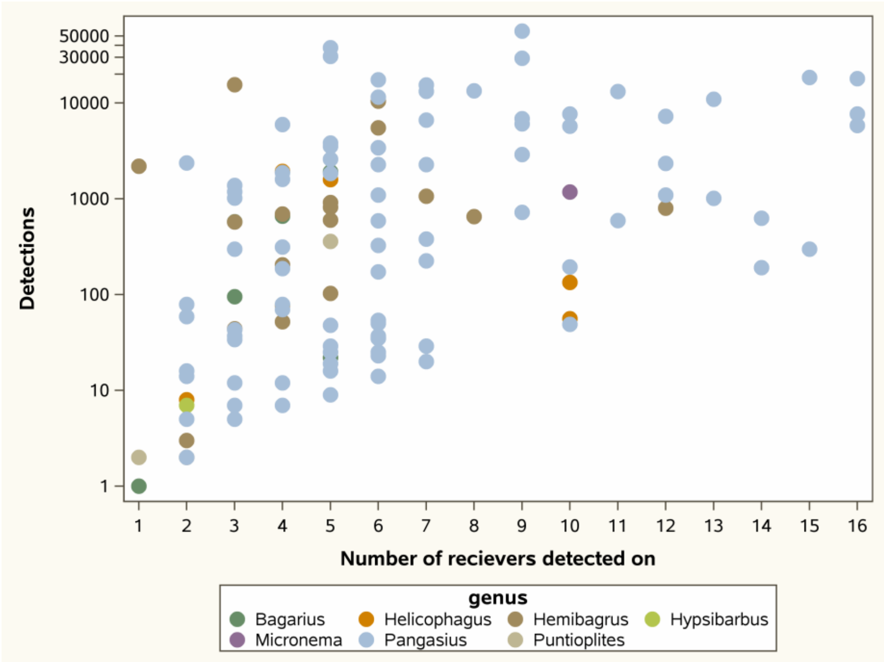

Figure 8. Summary of detections and receivers detected on for the 124 JEM project tags that were detected between 6 June 2022 and 8 February 2023.

Table 9. Summary of detections for 124 fish tagged and released and subsequently detected by the acoustic receivers in the JEM pilot study near Don Sahong between June 2022 and February 2023.

Summary variable	Min	Median	Max
Number of detections	1	576	56349
Number of receivers detected on	1	5	16

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13.3 Receivers with detections

Twenty-five of the 29 recovered JEM receivers detected at least one tagged fish. There were no tagged fish detected at Liphi Falls swimming pool (2 receivers) or on the left had side at the top four receivers (Ban Chan side of river), 48 river km above the falls. The location of detections informs us where most fish activity was (Figure 9). Most fish were released in the main channel east of the power plant and this is where the most detections were (Figure 9). However, at least four tagged fish were able to successfully pass upstream through Hoo Sadam and none of these were released near Hoo Sadam. These four fish (3 *Pangasius larnaudii* and 1 *Hemibagrus filamentus*) were all detected on the receivers at Ban Parmouk (48 river kilometres) within three days of passing Hoo Sadam.

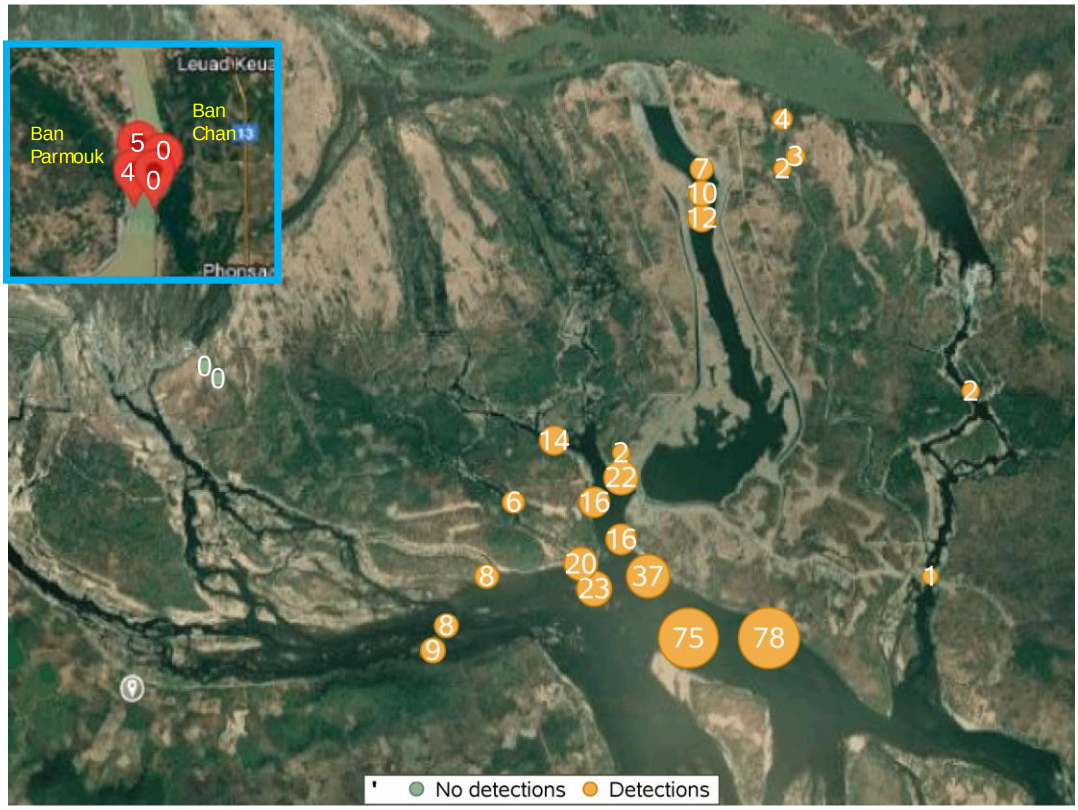

Figure 9. Number of unique tags identified at each downloaded receiver during the JEM pilot study in the Khone Falls region between June 2022 and February 2023. Note that the tags in Sahong channel are from the fish released there on the VIP tagout from 6–8 June. Whilst there were two hits on the receiver in Hoo Phapheng (far right channel above), one was erroneous (recorded pre-deployment). All four fish that exited the top of Hoo Sadam, and one of the fish that exited the top of Hoo Sahong were detected at Ban Parmouk (48 km north- top left insert).

There was a lot of downstream migration by JEM tagged fish after release (Figure 10). One 'hotspot' receiver [station name KSCN2] detected 24 JEM tagged fish between 25 June and 10 August 2022 and a further 2 JEM fish by December. This included 13 *Pangasius concopholis*, 10 *P. larnaudii*, and one *Helicophagus leptorhynchus*.

One individual *Pangasius concopholis* tagged and released at Wat Hang Sadam on 26 July, was detected at the hotspot on 27 July and further downstream at Koh Preah in Cambodia on 28 July. This is a downstream migration of approximately 80 river kilometres in two days.

Figure 10. Number of unique JEM project tags detected at WOM receivers in Cambodia up to February 2023. There are five more receivers at various distances further downstream that also detected JEM tagged fish. A hotspot for JEM tagged fish was receiver KSCN2, located to the North of the Stung Treng tributary which detected 26 JEM tagged fish.

13.4 Transboundary movements

All 25 JEM-deployed and recovered receivers with detections had JEM-tagged fish detected on them and seven JEM receivers had WOM fish detected on them. All of these WOM fish detected in Lao PDR were in the main channel between the two countries with the exception of one fish. One individual *Bagarius yarelli* tagged at Koh Sraulai on 25 July was detected eight times at Nokasoung Noi, in Xang Peuak above the power station, on 29 September 2023. Twenty-four of the 28 WOM receivers (86%) had JEM-tagged fish detected on them and 22 of the 28 (79%) WOM receivers had WOM-tagged fish detected on them.

Fifty-five percent of the 124 JEM-tagged and detected fish team were last detected in Lao PDR, and 45% (n=56) of JEM-tagged fish were last detected in Cambodia.

13.5 Use of Phapheng/Sadam channels

Of the 15 tags never detected after release, 14 were in fish tagged and released in Hoo Phapheng, within 20 m downstream of the lower end of Hang Sadam channel. Twenty-one fish collected in Phapheng were released at the lower end of the Sadam channel and included nine *Pangasius* *conchophilus*, six *P. larnaudii*, two *Bagarius* spp., one *Helicophagus leptorhynchus*, one *Hypsibarbus wetmorei*, and two *Hemibagrus* spp.. None of the fish released at the bottom of Hoo Sadam were detected at the top of Hoo Sadam. At the time of writing, only seven of these 21 tags had been detected, including four *P. larnaudii* and three *P. concopholis*. The seven detected fish were detected across 15 receivers ranging from 80 km downstream (below Stung Treng), up to the Van Nokosoung Noi (Xang Peuak (XP)), Hoo Yuak (alternate route to Hoo Wai), to Hoo Wai Noi, to Khone Phapheng.

Unfortunately the receiver on the bridge covering the main channel was lost and fish entering or leaving the Phapheng channel were not detected. The wet season only receiver on the west side of the bridge only detected one fish between 8 May and 26 November. The water was shallow in that area and the detection range small. Also, it was less probable that migrating fish used that side most of the year.

Four fish were detected at the top of Hoo Sadam, including one *Hemibagrus filamentus* and three *Pangasius larnaudii*. All were travelling upstream and entered the Mekong River mainstem above the Sadam channel when detected. Two had been released at the ferry landing in Xang Peuak above the DSPP and two had been released in the Mekong River downstream of Ban Hang Sadam. The fish ranged in size from only 30.1 cm and 185 g (*H. filamentus*) when tagged with a V7 tag, up to 61 cm and 3.1 kg tagged with a V13 tag (*P. larnaudii* – Plate 12).

Plate 12. Four tagged fish that were later detected exiting top of the Hoo Sadam channel. Main picture and bottom right were released into Xang Peuak above Don Sahong power plant and the other two were released in front of Ban Hang Sadam.

The four fish that exited the top of Sadam channel had similar behaviours before and after finding the channel. All four fish spend 2–4 weeks after release in the main Mekong channel area between the dolphin pool and Xang Peuak/ Don Sahong channel outflow. The *Hemibagrus* then drifted downstream and up through Phapheng and Sadam channels. All three *Pangasius larnaudii* spent some time moving up and down the Xang Peuak channel before then rapidly traveling downstream and entering the Phapheng channel and moving up and out the top of the Hoo Sadam channel. All four fish were then detected within three days at the limit receivers at Ban Parmouk, some 48 kilometres upstream. Two of the routes are documented in Figure 11.

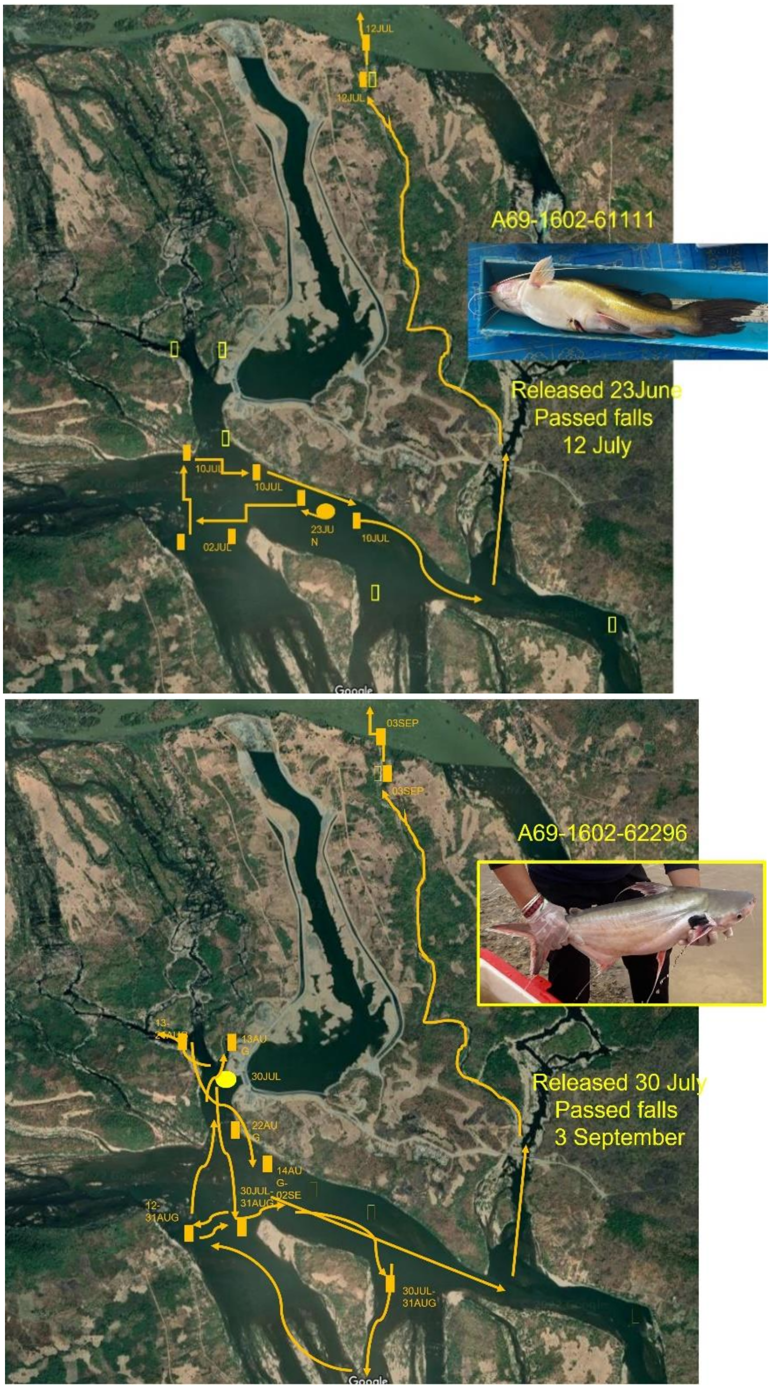

Figure 11. Routes taken by two of the four fish that were documented to ascend Khone Falls through the Sadam channel in 2022. The top example is for a *Hemigabrus filamentus*, whilst three *Pangasius larnaudii* had very similar patterns to the one in the lower example above. The larger circles are the release points.

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13.6 Hoo Sahong channel/pond

Between 6 June and 21 June 2022, there were 13 fish released near the DSPC fishery centre, which is in the Sahong channel, above the power station (Table 10). Fish could only exit by swimming out the top or by passing through the turbines at the bottom of the channel. Of the 13 fish, two stayed in or left via the top and two others were last detected between the receivers and the powerhouse (approximately 4 km) and on the same day of tagging. As there is no fishing in the channel, these latter two fish are considered as probable tagging mortalities or possible powerhouse mortalities. The two former fish included a *Pangasius concophilus* that was detected in the channel sporadically up until December 2022, and one *Hemibagrus filamentus*, which left the top of the channel after 25 days and was detected five days later at the limit receivers at Ban Parmouk, 48 kilometres to the north. This was the largest of the fish released at this location, at 455 mm length and 888 g in weight. No other individuals left the channel via the top, and the remaining nine fish were all detected at least once below the power station (Table 10).

Two of the nine fish that were known to pass through the powerhouse were still being recorded regularly in December 2022 and February 2023 (Table 10). These two fish were remarkably similar in size — with the *Micronema cheveyi* 285 mm long and weighing 105g, and the *Pangasius conchophilus* being 280 mm long and 125 g. The other seven fish that were detected below the powerhouse all disappeared within 24 hours of first being detected below the powerhouse. It is not possible to determine whether these fish actually survived and then succumbed to powerhouse related issues or were harvested or migrated out of the area. Further complicating the interpretation, five of these fish left the release site (i.e. Hoo Sahong channel fishery centre) within a few hours of being released and could actually be suffering from tag-related injuries as well.

13.7 Use of Xang Peuak system

The Xang Peuak (XP) system is a very difficult location to deploy receivers mainly because of the volume and energy of water coming through the power station year-round, and the volume of water in XP above the power station junction during the wet season. This is highlighted by the difficulties in placing receivers in those stretches (Plate 13). One receiver attached to a tree was lost, and three others attached to trees were displaced during the study. In one case, the tree itself was moved, but the receiver retrieved, and in the other three cases, the receiver was actively forced off the tree by the energy of the water. The chains around the trees were still in place, but the steel cables holding the receiver in position were worn through.

Nevertheless, there were informative data collected. The uppermost receiver that remained intact was the one at Vang Nokasoung Noi, the branch in Xang Peauk where upstream migrating fish could attempt the Hoo Wai Falls to the right or veer left towards the Etout Falls and channel (Figure 1; Plate 13). This receiver had 153 detections from 15 different fish, including one *Bagarius Yarelli* tagged and released by WOM project at Koh Sraulai in Cambodia in July and detected in September (36 km north of, and 65 days after release). Also at that receiver were nine *Pangasius larnaudii*, two *P. concophilus*, two *Helicophagus leptorhynchus* and another *B yarelli*. Apart from the Cambodian fish, JEM fish detected at Nokasoung Noi had been released below the Sadam channel (n=3), at the DSPC fishery centre (one – also passed through the turbine), at the Ferry landing (n = 4), and in front of Ban Hang Sadam (n = 6).

Table 10. Fate of 13 fish deliberately released into the Don Sahong channel, approximately 5 km up stream of the powerhouse and 1.6 km downstream of the inflow from the main Mekong River. Fish were deemed to survive the downstream passage through the powerhouse turbines if they were detected below the powerhouse and either; swimming upstream; detected on more than three downstream receivers; or detected for at least one week after the initial downstream detection. Fish with V7 tags were all under 300 g and V13 fish ranged from 170–888 g.

Species	Tag size	Detected below power station	Survived downstream passage	Days above power station	Notes
Micronema cheveyi	V7	Yes	Yes	< 10	Twelve hundred detections on 10 different receivers. Mostly stayed near dolphin pool. Still there in January 2023.
Helicophagus leptorhynchus	V7	Yes	Survived at least initially	> 26	Swam upstream in Xang Peuak after passing the powerhouse. Disappeared within 90 minutes, possible mortality from harvest, or delayed powerhouse effect, or successfully navigated upstream.
Helicophagus leptorhynchus	V7	Yes	Survived at least initially	0.5	Swam upstream in the Sahong channel then back down and through the powerhouse and turned left towards Ban Hang Sadam for just one detection.
Pangasius conchophilus	V7	No		0.5	Last seen in Sahong channel downstream of release point. Possible tagging or powerhouse mortality.
Pangasius conchophilus	V7	Yes	Yes	< 30	One-hundred-and-seventy-three detections on five receivers in Cambodia. Resident at Kok Snam Chey (36 km downstream) in July and Koh Preah (80 km downstream) in December.
Pangasius conchophilus	V7	Yes	Survived at least initially	1	Initially swam upstream in the Sahong channel then back down and through the powerhouse and turned left towards Ban Hang Sadam for just one detection.
Pangasius conchophilus	V7	Yes	Survived at least initially	0.25	Initially swam upstream in the Sahong channel then back down and through the powerhouse and turned left towards Ban Hang Sadam detected on one downstream receiver three times.
Pangasius conchophilus	V13	Yes	Survived at least initially	0.25	Swam down Sahong channel and through the powerhouse and turned left at Ban Hang Sadam. Detected seven times on two downstream receivers.
Pangasius conchophilus	V13	Yes	Survived at least initially	0.1	Swam down Sahong channel and through the powerhouse and turned left at Ban Hang Sadam. Detected 25 times on two downstream receivers.
Pangasius conchophilus	V13	Yes	Survived at least initially	0.1	Swam down Sahong channel and through the powerhouse and turned left at Ban Hang Sadam. Detected seven times on three downstream receivers.
Pangasius conchophilus	V13	No		0.5	Stayed near release point, swimming up and down the channel then disappeared. Possible tagging or powerhouse mortality.
Pangasius conchophilus	V13	No		180	Still in the channel after 180 days but with only 78 detections. Probable resident moving up and down.
Hemibagrus filamentus	V13	No		25	Detected at Ban Parmouk five days after exiting the top of Sahong channel.

A receiver placed at the limit to upstream migration for Hoo Wai Noi (Plate 13) only picked up two fish during the study, both *Pangasius larnaudii*. These two large fish (> 1.3 kg) were very active during the study. The first of the two fish was released at the bottom of the Sadam channel but spent its time in the Dolphin pool and XP region, being detected more than 11,600 times. The other fish, documented in Figure 11, was released at the ferry landing adjacent to Hoo Wai Noi and had more than 15,000 detections during the study before travelling downstream, then up through the Sadam Channel and North to Ban Parmouk.

Plate 13. Receivers deployed in the Xang Peuak region during the study. Green = deployed and retrieved without incident, red = lost, yellow = moved during the study, orange = deployed and retrieved but with limited read range because of changed conditions. The red line indicates a road crossing weir that is impassable most of the time (bottom left box) and the top box shows the pool that forms above the road crossing weir, where a receiver was placed. The blue arrow shows a route taken by several *Pangasius larnaudii*.

There were two receivers deployed in the ephemeral channel next to Ban Hankhone (Khone Yuak – incorrectly called Hoo Khone Lai in the deployment). The receiver at the mouth had a read range of up to 300 m into the Mekong itself and less than 25 m into the channel. The channel is interesting because the main road from the ferry landing on this part of Don Khone crosses over it with the aid of a culvert system (Plate 13). Upstream passage is not possible most of the year as there is no flow. Early in the wet season as the Hoo Wai complex floods, there is still no passage option as the culvert discharge is elevated above the downstream channel (Plate 13). However, in the peak of the wet season when the downstream water levels rises, there is a short window where the culvert is drowned out and fish passage is possible. Above the culvert section is a deep semi-permanent pool that is several hundred metres in length. The second receiver was positioned here with a read range of over 100 m in any direction.

Six fish were detected in the semi-permanent pool above the culvert, including one *Micronema cheveyi* in August (this fish was released in the Sahong channel and passed through the powerhouse), and five *Pangasius larnaudii* in July and August 2022. All fish were detected multiple times and over one or two consecutive days. Three of the *P. larnaudii* were detected on the receiver at Vang Nokasoung Noi soon after being detected in the swimming pool, suggesting that there was a connection between those channels, and no simple option to migrate further north from Khone Yuak.

Overall, there were 30 different fish detected in the XP system, with 13 of them having V13 tags, seven having V7 tags, and ten having V9 tags. These numbers are not in proportion to the relative abundance of each tag size in the population of released fish. The numbers suggest that smaller fish are less likely to be detected in XP, which may or may not be because they are less likely to enter XP than larger fish.

13.8 Travelling west

The receivers across the channel near the dolphin pool only recorded eight or nine JEM-tagged fish each (Figure 9), suggesting that that pool was used less, by fish, than the XP complex. This is probably the case as fish may be more attracted to XP by the discharge there. However the channel bed in this west channel region is complex and there is probably imperfect detection in this region, meaning it is possible that fish may pass without detection. Further, one receiver was not retrieved and is still under a sand slug and there may be more data available if it is able to be retrieved.

Overall there were 18 different JEM fish and seven WOM fish detected by the three receivers in the west channel region. JEM-tagged fish detected in the west main Mekong channel consisted of *Helicophagus leptorhynchus* (one), *Hemibagrus filamentus* (two), *Micronema cheveyi* (one), *Pangasius conchophilus* (nine), and *P. larnaudii* (five). These fish were released from the bottom end of Sadam channel (two), in the DSPC channel above the powerhouse (one), and in the Mekong river east channel, below Ban hang Sadam (15). The detected tags were disproportionate to their relative abundance and the opposite trend to that for XP. Smaller fish (V7 tags) were relatively more detected in this region. As smaller tags have smaller read ranges, these results can *only* be interpreted as smaller fish being more likely to occur in this region than larger fish.

Out of the 124 JEM-tagged fish that were detected during the study, only three had their last detections on one of these three main channel receivers. These three fish (one each of *Pangasius larnaudiii*, *P. concophilus*, *Hemibagrus filamentus*) were all detected in November or December 2022, and may actually still be in the system.

The pilot study had two receivers further west, at the top of Hoo Don Lai in the Liphi Falls swimming pool, and neither of these detected any tags during this study.

Whilst the sample sizes are small, there are some interesting observations made on the differences between XP and the west channel (Table 11).

Table 11. Observations on differences in detections between the Mekong west channel and Xang Peuak channel.

Observation	Possible explanatory factors
WOM fish more likely to head to the west Mekong channel than go to Xang Peuak	Which channel they arrive from Species differences
Smaller fish more likely to be detected in the west channel	Smaller fish less likely to go up the Xang Peuak channel system

14 Knowledge gained about logistics

Large fluctuations in water level, discharge, turbidity, substrate consistency and potentially high background noise levels made the study site challenging. The location is one of the most demanding environments that the acoustic systems suppliers [VEMCO/INNOVASEAS] have ever tried to install an acoustic network. The project was also one of the first to look at using the technology in the Mekong River system and fish responses to tagging were difficult to predict in advance. The political and government structure of Lao PDR requires intricate knowledge of procedures and permits required a strong in-country partner such as LARReC.

A large component of this project was capacity building and, in that area alone, the project has been a resounding success, but at the same time the demands on the international partners have been extreme. The global pandemic of 2020 placed additional strain on the project and its timelines. This was most apparent in the supply chain when procurements were much later to arrive than desired, and China was the source of many products as overland transport was still operating to some extent. In the end, the quality of the products supplied was often below the specifications requested by the AWP-funded team. These two impacts affected the project and its timeline considerably.

This section looks at some of the lessons learnt from this project and the next section makes some recommendations about acoustic technology as a tool for monitoring fish movement and fish passage in the LMB in general. Some guidelines for future use of acoustic technology in monitoring fish passage or movement in general in the LMB are made in the final chapter of this report.

14.1.1 Receiver security

The initial deployment intended for LARReC to liaise with one village to monitor the condition and security of each receiver. Some villages would be able to monitor several receivers. This method was not successful. Return trips to the regions even early on in in July and August found much of the equipment such as buoys and ropes connecting the receivers missing, and only a couple of these had been reported prior to our visit. The incentive for locals to look after the receivers was low, hence buy-in to the project for local stakeholders was also low.

14.1.2 Lost receivers

Nevertheless, of the receivers that were missing, none were believed to have been from foul play. All of those missing were deemed to be a result of the poor-quality cable and chains used to hold them in place (Plate 14). Whilst the padlocks, chains and steel cables were prescribed as tungsten and stainless steel, respectively, none were. The energy of the flow of the Mekong River around Khone Falls in the wet season put the lesser quality products under strain.

14.1.3 Receiver *in-situ* range tests

The majority of the receivers deployed were Innovasea VRTx models, which are equipped with an internal transmitter, that was set to ping at the same signal strength as a V13 tag at 10 minutes intervals during the deployment (it is actually a random delay of between 9min30sec and 10min30sec between signals). This has the benefit of allowing nearby receivers to listen for the pings and give us an estimate of detection probability of a tag of known signal strength, at a known distance, throughout the deployment. Importantly, it allows an estimate of the variability in detectability of tags throughout the changes in conditions experienced in the wet season. Two receivers within perfect range of each other should receiver close to 144 pings per day from the other receiver. This will vary slightly when there are more fish in the area, as ‘collisions’ of overlapping pinging tags occurs.

As an example, consider the receiver at the junction of Hoo Khone Yuak and the Mekong mainstem just upstream of the Xang Peuak junction. This receiver was 248 m away from a receiver at a French navigation marker in the Mekong mainstem with an even substrate between them. Apart from transmitter detections, each receiver logs the water temperature, background noise levels and tilt (whether the receiver is upright) every 10 minutes. By plotting the tilt, temperature and noise data together we can see that the noise levels at the junction were very high from July to mid-November, and extremely high most of August, September and October (Figure 12). At the same time, we can see that the receiver was able to detect signals from the internal transmitter of the receiver at the French navigation marker occasionally in June and July, and for about a week in November (Figure 12). In simple terms, fish with tags would have to come quite close to this receiver in the wet season to be detected.

Plate 14. Badly rusted and worn receiver security chains and cables in November 2022, after just 6 months in the river. The receiver cable on the right is worn through in several places. Stainless steel chain and cables were requested but not available.

A similar pattern can be seen on the graph of fish detections per day for the 22 different fish detected by the Hoo Khone Yuak /Mekong junction receiver during the study (Figure 12). Most fish detections were before mid-August, then detections became sparser (Figure 13) and this coincided with higher background noise levels (Figure 11). Most of the detections in the latter half of the study came from a single resident *Pangasius concopholis*, that was obviously spending a lot of time near the receiver.

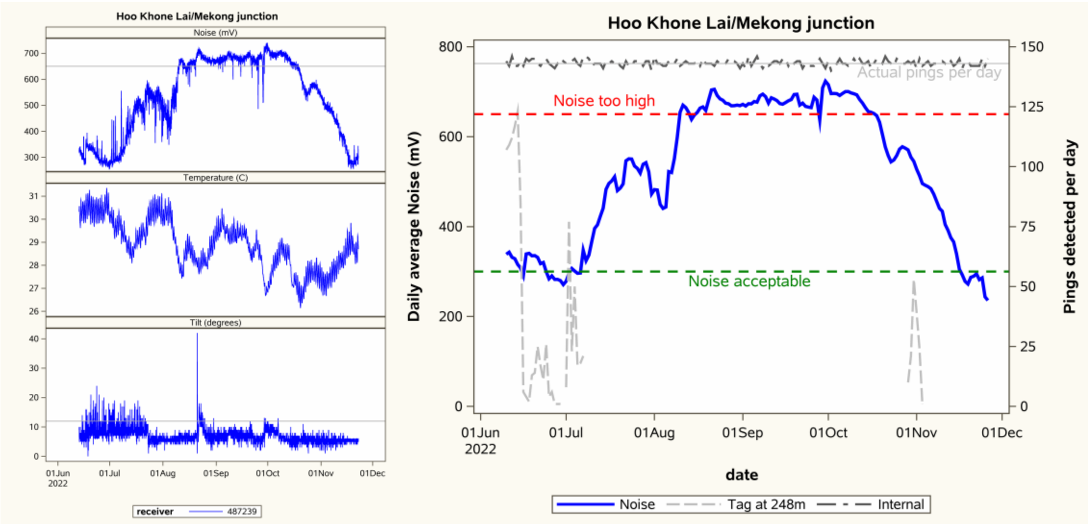

Figure 12. (Left) Receiver diagnostics for receiver 487239, located at the junction of Hoo Khone Yuak (incorrect label in graph title) and the Mekong River. (Right) relationship between background noise (left hand axis) and ability to detect tag pings (right hand axis). The actual pings per day are the internal pings sent and detected by the receiver itself. The light grey pings are those sent by the receiver at 248 m away that were detected by this receiver.

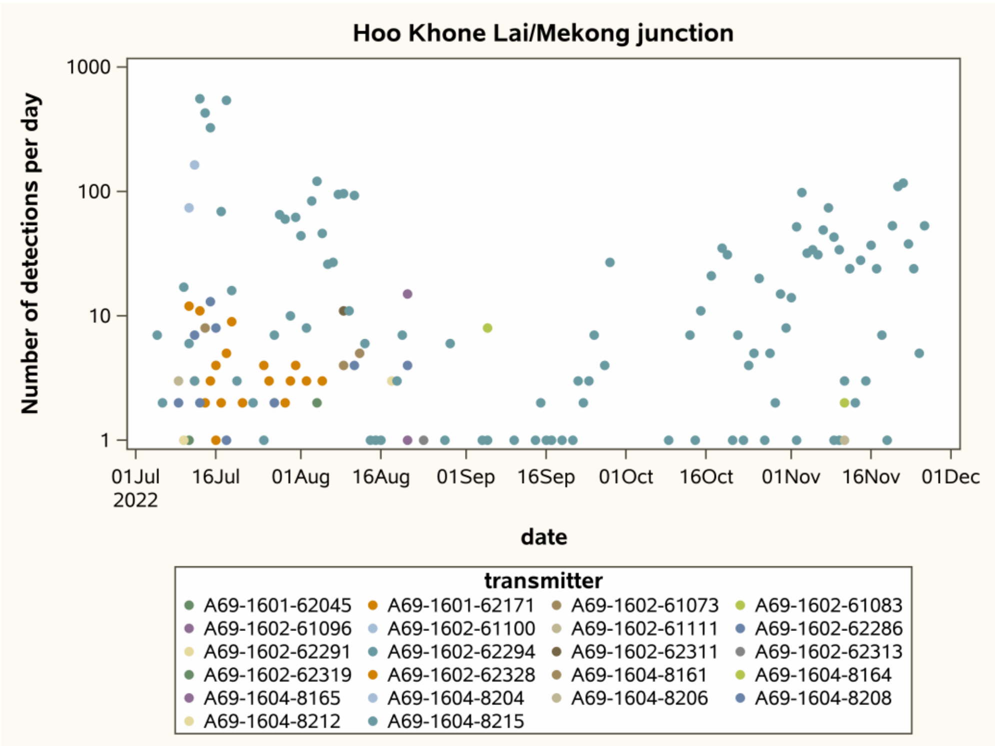

Figure 13. Fish detected by receivers at the Hoo Khone Yuak/Mekong junction during the JEM pilot acoustic study near Don Sahong. Note the incorrect label in the graph title.

14.1.4Tag sizes

Overall the three different sized tags sent out during the study were detected in approximate proportion to their relative abundance and all tag sizes will work in Mekong River fish in future main channel studies. Nevertheless, disproportionate detection of tag sizes in some habitats allowed us to make some useful observations about the size of fish using certain locations or habitats (Table 11).

14.1.5 Fish species

The tag trials were not ideal as only scale fish were available in large numbers in February in southern Laos. Procurement methods for scale fish generally involve netting, which can easily damage the fish. We procured 260 fish, but less than 60 were suitable for the tagging trial. Not all scale fish are easily handled in a tag trial as some tend to rub on the bottom of the holding tank, which interferes with the surgery and suturing. Consequently, we recommended against using some species for the tag out; however, we note that the WOM project has tagged predominantly scale fish with a high success rate.

The two *Pangasius* species, *P. larnaudii* and *P. concophilus,* were abundant and easily collected. The former and *Hemibagrus* spp. were easily caught using lob traps, which caused minimal damage, and both species were ideal for this project. *H. filamentous* have been a very successful fish to PIT tag in the Xayaburi power station (W Robinson pers. obs.) and all three *Hemibagrus* species tagged in this project are considered very hardy to the surgery and suitable for ongoing projects (Table 12). *P. concophilus* are generally abundant throughout Lao PDR and we had previously PIT tagged more than 150 of these around Vientiane. In the Don Sahong and Vientiane regions, they are typically captured by long lines with baited hooks; thus, care must be taken to inform fishers in advance and to only select undamaged fish. However, they are hardy to tagging and surgery, and are good candidate species for many research projects because of their migratory and widespread nature.

We tagged 10 individuals from two *Bagarius* species with mixed results. The species are highly predatory and hence need to be transported separately to other fish. Rather than use a separate container for each fish, Lao fishermen typically leave them out of water in the bottom of the boat, for up to several hours at a time. This means that they may have arrived to us in less-than-optimal condition. Overall we found the fish very 'soft' and weak when exposed to anaesthetic, and we did not recover several individuals. Anecdotally, they were detected on fewer receivers than other species after release, which could suggest less movement (they tend to be a sit and wait predator anyway) or a lower survival rate (possibly related to being a bottom dweller and the surgery wound can become affected if dragged on the substrate). We note that the WOM team also tagged one *Bagarius yarrelli* near Koh Snam Chey in August that was detected at Nokasoung Noi in Xang Peuak in September.

We had logistical issues handling large fish of two species, *Pangasius krempfi* and *Wallago attu*. The former are large, highly migratory species that cannot be easily restrained by any method. Even when an individual was collected in good condition, keeping them in a stress-free environment was not possible and there was no chance of transporting or anaesthetising them. Our maximum tank was 200 L, and a considerably larger one would be required. *Wallago* are predatory large-bodied species that need to be kept away from other fish for predation reasons. The individuals we tried to transport were about 5 kg each and appeared to die from the stress of a contained environment. In both these species, tagging only of smaller fish would be possible, and for *P. krempfi*, this may involve collection from the estuarine or coastal Mekong regions. For *W. attu*, this is plausible as they are frequently occur in smaller streams, canals and floodplains.

Table 12. Indicator species from this study that are suitable for an acoustic monitoring program under the MRC Preliminary Design Guidance (PDG) migration guild's 2 and 3 (MRC 2023). The list only includes species evaluated in the current project and is not meant to be exhaustive.

Migration guild	Suggested species	Approximate distribution
2 - Migratory main channel (and tributaries) resident guild	*Pangasius larnaudii*	Vietnam to Central Lao PDR
	Pangasius concophilus	Vietnam to Northern Lao PDR
3 - Migratory main channel spawner guild	*Hemibagrus filamentous* *Hemibagrus wyckii* *Hemibagrus wyckioides*	Vietnam to China

Plate 15. A team member from AUSVET International tags an Asian red-tailed catfish, *Hemibagrus wyckioides*, at Vat Hang Sadam in June 2022.

15 Recommendations for monitoring fish passage using acoustic technology.

15.1 Fish passage versus fish movement

We make our recommendations under two different definitions. For this report, fish movement generally refers to large-scale movements, such as migrations and typically occurs at scales of 10s to 100s or 1000s of kilometres. Fish movement can also refer to habitat use by fish, or the propensity to use or avoid some sections of a habitat, such as a river, in a selective manner.

For fish passage on the other hand, we generally refer to scales of kilometres or less and passage past a structure or barrier, possibly through a structure such as a fish ladder or natural or modified channel.

For example, in the JEM pilot study, we considered fish *passage* in several channels including Hoo Phapheng, Hoo Sadam, Hoo Khone Yuak and Hoo Don Lai. At the same time, we were able to consider fish movement in the Mekong River between receivers in Cambodia and Ban Chan, 280 kilometres apart and in this section also refer to *movement* between passage options.

15.2 Fish tracking

Whilst the acoustic monitoring network used in the JEM pilot allows tracking of movement and passage to some extent, it uses a passive monitoring system. That is, actual paths taken cannot always be identified. The acoustic technology can be used in a live tracking framework, but that was not an option considered here. Also, fine scale movements and 3D pathways can be performed using the same receiver technology as this pilot but require depth-sensing tags that were not used here.

15.3 Pilot study findings

This was merely a pilot study and so definitive answers to all questions are not possible. The guidelines here are meaningful findings from a very small pilot study conducted in only one season.

15.4 General requirements for effective acoustic systems

The 69 khZ acoustic system is proven to work extremely well in marine and lacustrine freshwater environments and in large river systems. Typical characteristics of locations returning good performance by the system include deep open water, not many submerged structures (such as rock out crops, vegetation or winding channels). Shallow depth, especially when the flow is fast, can cause the signal to bounce and become refracted, and ultimately not-decodable. Similarly, rocky bottom can also increase signal bounce, which may distort the code on its way to the receiver. Acoustic signals have a very limited range through air, and so oxygen or air bubbles in the water column may also distort the signal, resulting in poorer reads.

The Khone Falls region of Southern Lao PDR has a mix of habitats and landscapes. Notably there are deep open water in the channels in the mainstem of the Mekong, through to shallow turbid channels with lots of rapids, and of course many waterfalls. To attempt to use acoustic technology here was very ambitious, and receiver deployment locations needed to be chosen quite selectively.

15.5 Fish passage

15.5.1 Channelised system such as the many options through Khone Falls

This pilot only considers the natural use of the channels, not the success rate of fish attempting access the channel. In order to assess channel efficiency, there is a requirement to use multiple receivers along a channel's length, and to use an experimental design, such as releasing large numbers of tagged fish at various points along the channel.

Overall, the channels are difficult to monitor for several reasons; namely they:

- are shallow
- have fast moving water, often with many riffles and air bubbles and high levels of background noise
- are often well-vegetated and fish are likely to use the vegetation areas for slower water and protection when migrating
- provide fish passage via fissures and cracks in the rocks that can prevent the signal from reaching the receiver
- have extremely variable thalwegs between wet and dry seasons.

These limitations mean that placing receivers throughout the channel systems could result in minimal detections and poor results. However, there are some options to allow the technology to work better in these systems. For example, isolating channels could be assessed in other ways, such as by placing receivers above and below the entrance and exit and then using deduction to determine how the fish passed. In the JEM pilot, we positioned a receiver in a deeper pool just above the Sadam channel. Fish hitting that receiver had to either have come up the Sadam or Phapheng channels or be migrating downstream. Comparing the detected tag numbers to those in Phapheng or the upstream receivers can help to answer the question as to which of the three options is more likely. In Hoo Phapheng and Hoo Don Lai, we positioned receivers in a manner that would detect fish using a resting pool or slower water section when migrating upstream (Plate 16).

The method of using resting pools could not be called a success based on Hoo Don Lai or Phapheng, as the two receivers at Hoo Don Lai did not detect any tagged fish during the study, and one receiver at Hoo Phapheng was lost, while the other only detected one fish. The recovery team was unable to do a range test before removing the remaining receivers, and it is not known how many tagged fish, is any, were in the channels during the study.

Plate 16. Use of slower water areas in Hoo Phapheng to give greater detection probability of fish migrating upstream. In this case, the centre of the channel is very fast flowing and detection is not covered. Nevertheless, most fish will stay near the edges and use the resting pools where the receivers are located. The pools also align with gaps in the vegetation to aid in detectability.

On the other hand, the receiver in the pool above Hoo Sadam did detect four tags, and all of these were detected on at least one of the receivers about 120 m downstream before hitting the top one (Plate 17). This result was unexpected, as much of the channel was not covered by the receivers (Plate 17). That is, it was expected that a tagged fish would be detected on one of the lower receivers but not the top one, or vice versa. A well-designed fish ladder or modified natural channel for fish passage typically has several resting pools along its length. Ensuring these pools are incorporated in future channel modifications would allow much more efficient use of acoustic technology as well.

Having all detected fish detected at both Hoo Sadam locations had two major benefits: (1) – it validated the assumption that targeted receivers near the edges of these channels, but where there is a resting pool and a gap in the vegetation, can detect passing fish; and (2) an assessment of the direction of travel of the fish detected could be made (as opposed to having hit only the top *or* lower receivers).

A side note. The receiver in the channel at the nearby Hoo Sahong was primarily placed there to see if fish exiting the Sadam channel, merely went down the adjacent Sahong channel. Pleasingly, this did not occur and all fish that exited Hoo Sadam were detected at Ban Parmouk, some 48 km upstream.

Similarly, fish that exited the top of Hoo Sahong channel were not detected migrating downstream to Hoo Sadam.

Plate 17. Three receivers were placed at the top of Hoo Sadam. The top receiver had a known good range because of engineering to increase depth and level the substrate. It would perform well in the wet and dry seasons. The lower two receivers only targeted upstream migrating fish and were positioned near resting pools and gaps in the vegetation. In the wet season the water in the channel to the right of the photo is up to 1.5 m deep and it is possible for fish to exit at the top without hitting the top receiver. In the dry season, all fish must enter or exit within 20 m of the top receiver, but the other two receivers are out of the water.

15.5.2 Summary for using acoustic systems to study fish passage in natural or modified channels

- Is difficult because of the types of depth, flow, substrate and vegetation.
- It requires targeted placement of receivers and the network is likely to have gaps where fish can pass undetected. In the Khone Falls region, there are no channels that could be guaranteed to have 100% coverage of detecting passing tags.
- If enough fish are tagged, then there are still valuable data to be collected.
- A full-scale evaluation (passing efficiency, areas of blockage, areas with high harvest levels, etc.) of any specific channel would be possible as long as the channel has enough points with good coverage, such as resting pools (with deeper, slower water) and a uniform substrate surface.
- Any in-channel receivers should be supplemented with receivers above and below the channel, and preferably other nearby channels as well.

15.5.3 Acoustic systems in fish ladder/artificial structures

The use of acoustic receivers near fishways or powerhouses was not studied in detail in this pilot. However, we did see that the background noise levels near the powerhouse are high and there was a limited detection range within 75 m of the DSPC. Typically, the noise issue can be overcome with a higher frequency acoustic system. That is, 307 kHz acoustic networks have been used successfully in powerhouse settings overseas (e.g. Columbia River USA). A trade-off with the 307 kHZ system is that tag life is considerably lower than that for the 69 kHz system.

The acoustic system, even at 69 KhZ as used in the JEM pilot, does typically have a higher read range than a PIT system, so can readily detect fish at different points in a fish ladder without the fish being within proximity to the receiver (as opposed to a PIT antenna). However, the largest trade off is that the PIT system can detect tags at up to 32 reads per second, whereas the acoustic system cannot. Using current technology, setting an acoustic tag to sound more often enhances detection probability but has several disadvantages. First, the battery life of the tag is reduced; and second, it means there will be an increased potential for tag collisions when several fish are present, hence fewer fish can be tagged. An acoustic system in a narrow space such as a fish ladder is more likely to <u>not detect</u> passing fish than a PIT system.

PIT systems are more advantageous for studying passage in artificial structures with a narrow channel, such as fish ladders.

15.6 Fish movement

The acoustic receiver array was able to detect large-scale movements of fish remarkably well. The main concerns of receiver security, background noise levels, and deployment strategies are related to the seasonal fluctuations in discharge.

15.6.1 Receiver security and deployment strategies

High quality materials are required to ensure receivers remain *in situ,* and less-than-optimal quality products made the receivers in this study vulnerable to the elements.

The anchor and chain to secure the receiver in position was semi-successful in this study. The anchors worked well, remained in position and withstood the elements. However, the chains were not up to the standard we ordered, were worn very quickly, with some breaking, and many of the remaining receiver towers currently have their base and chain buried under much sand.

All the main channel receivers were on towers up to 1.8 m tall, and almost all fell over within the first month or two of deployment. This is a direct result of the extreme flow velocities or being struck by large debris coming down the river. A fallen over or heavily tilted receiver has a reduced read range.

If in a similar environment, the next deployment should consider a double or triple anchor system, with shorter, high-quality stainless-steel fixings and the receiver hard-and-fast in position and lower in the water column. Lower receivers, however, require a more detailed substrate mapping before deployment to avoid chasms and ridges.

We note that the WOM team used surface floating and multiple anchored systems, and have suffered multiple receiver losses already as well.

15.6.2 Background noise levels

The changes in flow between seasons can seriously affect the background noise levels and hence, the read range of the receivers. Other downloaded receiver noise traces not shown in this report show significant daily fluctuations from rain spatter. That is, daily rainfall events create noise at the surface, which regularly pushes the background noise levels into the too high range, and seriously reduces read ranges.

15.6.3 Probabilities of detection

Apart from the issues with tilt and noise levels, the detectability of fish in the Khone Falls region is influenced by the water depth and the nature of the bottom of the river. There are large sections of the river that have heavily channelised bedrock, making complete coverage very difficult. At the same time there are other sections that have enormous and transient sand slugs, which can partially block a receiver’s read range. In addition, the region undergoes massive changes in discharge and water depth (hence available habitat – riparian vegetation – becomes inundated) every year.

The read ranges of any receiver, and hence probability of detection of any tag, are extremely variable at different times of the year in the Khone Falls region. Further, given that fish have access to different passages in the wet season (e.g. inundated vegetation, or behind now inundated rocky outcrops), a secondary receiver system is required in different seasons.

15.6.4 Summary of using acoustic receivers for monitoring large-scale fish movement

We have shown that the acoustic system can detect fish, and we suggest that many of the issues identified in the JEM pilot are Khone Falls-specific and would not apply in other parts of the LMB.

- Acoustic 69 KhZ receivers can detect fish in the Mekong main channels and in some locations had read ranges over 1.2 km

- Receiver locations that have ideal substrates and bathymetry should be identified and used where possible using pre-deployment range tests.
- Equipment to deploy and position receivers should be extremely durable.
- ‘Custodian’ or ‘sentinel’ receivers should be placed where possible to allow detection of changes in detectability throughout the deployment.
- Regular range testing throughout the deployment of the system should be performed to document changes in read range through time. This is as simple as taking an hour to trawl a ‘synch tag’ or transmitter set to ping at 10 second intervals (whilst simultaneously attached to another receiver and a GPS) for several hundred metres above and below the receiver before each download.

15.7 Alternatives to acoustic/PIT systems

Radio tags were not trialled in the JEM pilot study at Don Sahong. These tags are particularly more suitable for monitoring fish in shallow waters and would allow multiple read points along any of the channel systems in the Khone Falls region. Their only real trade-off with acoustic systems is that the receivers are a little more expensive and need to be stationed on land (and are therefore more susceptible to theft or forces of nature such as floods or winds). Nonetheless, they can hear and decode the signal in air or in water and readily detect fish in shallow water (up to 20 m depth).

Radio tags can require larger fish in general and the tag life is less than that of acoustic tags. However, all things considered, radio tags are well-suited to small spatial- and temporal-scale studies, especially in shallow water.

15.8 Tag mortality is a constraint to all fish tagging methods

Without knowing the natural or fishing mortality for each fish, expected tag life is generally unknown. Tag trials allowed us to estimate tag rejection and tag-induced mortality for several species, but with experienced taggers, surgery-related tag losses are negligible in comparison to the potential harvest by fishermen/women. Natural mortality can be estimated if the species has a known length at age relationship and the length is recorded during tagging. However, removal of tags from the system by fisher harvest remains largely unknown.

The fishing pressure in the LMB is extremely high. The thousands of long lines with hooks, gill nets and traditional traps in some places made procuring healthy fish and safe receiver deployment very difficult in the current project. Yet, there are no published studies of the mortality rate from fishing for any Mekong species.

If a tag is released in a location where there is little chance of harvest, before the data are collected, there is no cause for concern. For example, if the tagged fish is released into a fish ladder to assess passage efficiency and the fish ladder is a no fish zone, there is no concern. Once the tagged fish has left the monitoring area, what happens to the tag is immaterial. If however, the tagged fish is released into a natural channel to assess passage efficiency and fish are harvested in that channel, then passage efficiency <u>cannot</u> be estimated.

Quantifying total harvest using fisheries dependent data is of no value to the JEM fish movement monitoring program, as the harvest rate (proportion of the population), and hence tag harvest rate, remains unknown. Harvest rate estimates can be made by running a tag return program, but these are very resource demanding and extremely complex in a spread out multi-national area like Khone

Falls. This is further complicated when the target species can migrate over large distances, as in the JEM program. Some estimates of external tag return on a very small scale were performed in Cambodia in 2003 (Hogan et al. 2006) and the WOM are running a tag return program in conjunction with the current project. However, these studies are only small scale, in the sense that they only estimate the harvest rate of the tagged fish within a short distance (10s of kilometres) of release.

Given the enormous number of people harvesting fish in the LMB, monitoring catch for tag returns will require a very thorough and complex survey design. However, for any tagging program, in order to answer most questions in an efficient manner, it is essential to estimate how many tags remain in the system at any time.

- A coordinated large-scale, multi-collection point, multi-release, multi-species, international tag return program is cost prohibitive at this stage.
- Species-specific, small spatial scale harvest rate studies are feasible.

15.9 Tagging and surgery mortalities and migrating fish behaviour

All fish tagging methodologies involve surgery and or anaesthetic, and the recovery from the tagging is critical for the success of the program. All three (internal, PIT, external) tagging methods when performed by experienced taggers on hardy fish are likely to have very low mortality, if recovery conditions are favourable. That is, starting with very healthy fish, optimal anaesthetic conditions, prompt handling, and 100% recovery before release. These factors can be refined in tag trials, however, releasing fish back to the river system is a different situation. Putting previously migrating fish into a forceful discharge river system like that below Khone Falls, directly after surgery, has an unknown effect on the fish’s behaviour and survival rate. The JEM pilot tag retention trial found that bottom dwelling species are more likely to suffer ruptures to the tagging wound as they brush along the bottom of the tank. The same issue is likely to occur in the *Hemibagrus* and *Bagarius* species tagged in the JEM pilot.

By contrast to acoustic tagging, PIT or external methods are much faster, require less handling (and hence allow faster recovery), and do not require sutures to the fish.

16 JEM fish movement pilot project overall recommendations

The major recommendation for JEM monitoring fish passage relative to HPD in the LMB are:

- On a large spatial scale over a long-term (up to decades) and including multiple structures such as fish passage structures at power stations or weirs, PIT systems are the best option.

Other recommendations specific to monitoring fish passage are:

- On a small spatial and small temporal scale in natural habitats, such as assessing passage efficiency of individual channels in the Khone Falls region, radio tags are the best option, albeit not trialled in the LMB yet.
- On a small spatial scale (e.g. fish passage structure within a single power station) over a short or long-time period (from weeks up to decades), PIT systems are the best option.
- On a large spatial scale, such as assessing fish migrations over 100s of kilometres or across international boundaries, and a short temporal scale (less than 5 years), <u>without assessing passage efficiency at structures</u>, acoustic tags (69 kHZ) are the best option.
- Assessing fish behaviour or movements in rivers/ponds above and/or below hydro power stations (e.g. are they attracted to the fish passage structure?) is best performed over shorter time periods (e.g. up to three years) with specialised (3-dimensional) tags and an acoustic (307 kHz) system.

Recommendations for the JEM fish passage *program* are:

- Understanding how many tags are in the system at any time gives optimal power of analyses and we recommend that any fish tagging and monitoring program, whether internal or external, electronic, or not, should contribute resources to a fishery harvest rate program.
- Training and capacity building are essential for large spatial-scale or large time-frame programs. This includes maintaining currency of staff with advances in technology and learnings from other programs.
- Ongoing maintenance of the fish movement monitoring program includes maintaining the number of tags, regularly replacing batteries, ongoing team member training, regular community and government liaison, frequent downloading and uploading data and QA/QC of databases. It is essential that the program includes continual analyses and evaluation of results that are fed back to HPP operators and other stakeholders including, the community, government agencies, other developers, and cross-jurisdictional agencies, such as the MRC.

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18 APPENDIX A: Comment on (wet season) fish passage at Khone Falls

The synthesis presentation of the fish passage and obstructions shown in Figure 2 earlier are not in agreement with the limited data collected in this study. Consider Figure 2 now with the six receivers set by the Wonders of the Mekong (WOM) team just on the Cambodian side of the border (Figure A1). Figures 2 & A1 are generic a representation but different species migrate at different times and the migration patterns on the graph should be interpreted with caution. .IF the arrows on the figure were to be believed, then most fish coming up from Cambodia would arrive to the Khone Falls region via the east and mid channels (as indicated by the width of the arrows on the figure). Now consider how many individual migrating fish coming upstream from Cambodia were detected on the receivers (Figure A2).

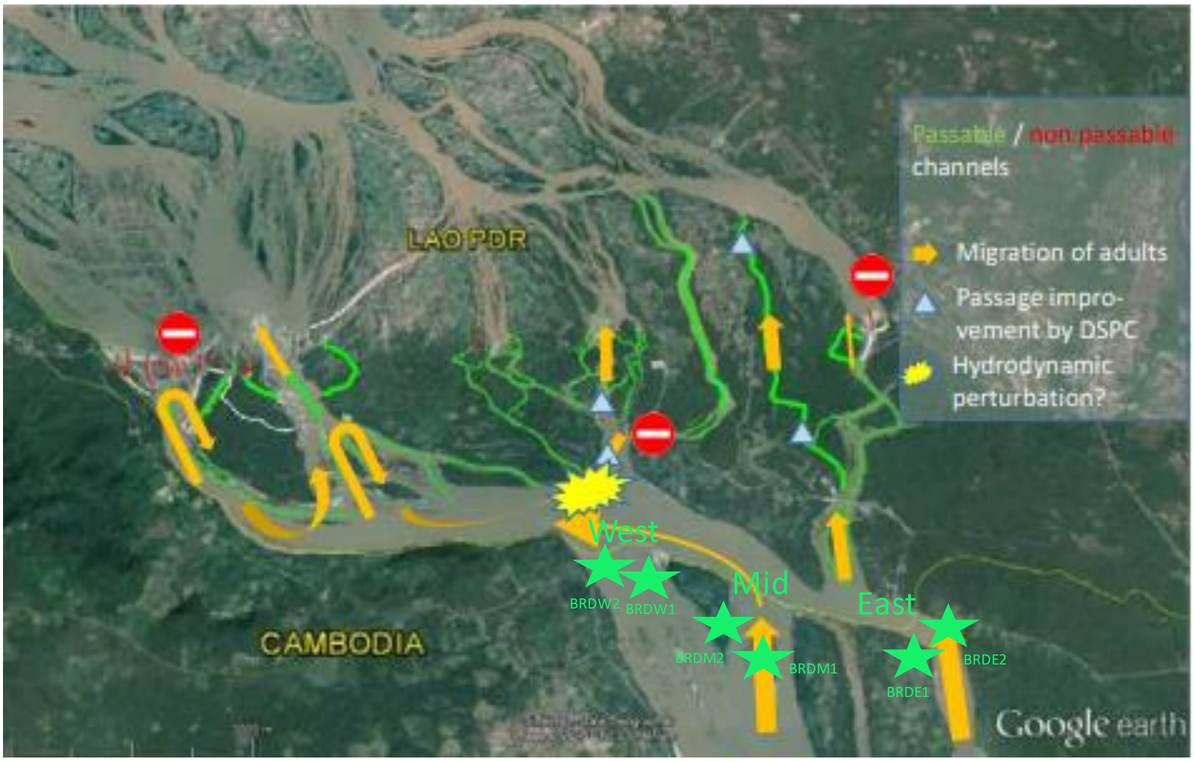

Figure A1. The perceived representation of passage, migrations and obstacles at Khone Falls (source: MRC 2020). The green represents flow and the orange represents fish movement patterns. The thickness of the arrows represents volumes of fish using that route. Stars are receivers deployed by the WOM team in Cambodian waters.

All the WOM fish were released more than 30 km from the border – where there is only one channel - the numbers of fish detected by the below border receivers in Figure A1 indicates channel use by fish that are migrating in an upstream direction. Clearly the western most channel attracted the most fish, while relatively few fish used the mid and east channels (Figure A2). This aligns with the general observation that the highest volumes of water in the wet season are coming through the Xang Peuak and Sahong channels and straight down the western most channel of the Mekong. In the dry season, an even greater proportion of the discharge comes though Sahong channel, with the West Mekong stem and Phapheng channels contributing very little to total Mekong flow.

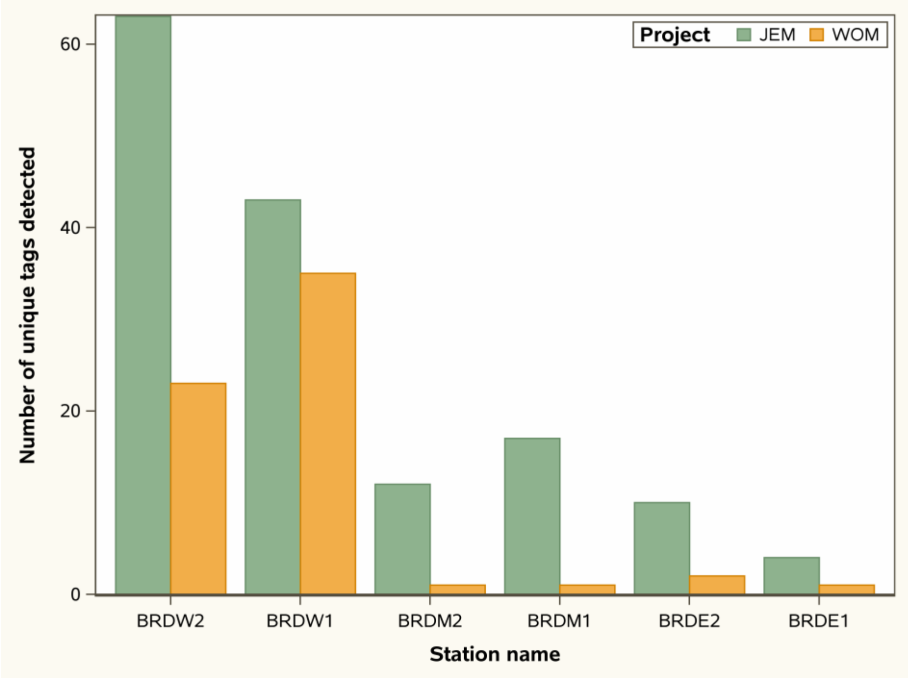

Figure A2. Number of unique fish detected on each receiver shown in Figure A1. The order of the receivers from left to right match the stars in Figure A1.

The flow coming down Hoo Sadam is vastly over-represented in Figures 2 and A1. The flow though Phapheng Falls, the furthermost right stem on the figures is substantially greater than that going down Hoo Sadam. The flow going down the Sahong channel and through the power station was always an order of magnitude greater than that going down Hoo Sadam during this study (February 2022 to February 2023), regardless of season.

These flow observations relate to fish passage in the region in general. Migrating fish are attracted to flow and when artificial fish passage is provided, it is an essential design component that the entrance to the fish passage (e.g. the ladder or lock) is at the 'limit of upstream migration'. Clearly the channel at Hoo Sadam can pass fish, as several fish in this study found that channel were able to pass it. However, the major problem is that there is little incentive for fish to find that channel, and in this study, only fish that had already attempted to pass through the Xang Peuak and/or western channels and then drifted downstream could find Hoo Sadam. Most migrating fish are likely to come up the westernmost of the three channels from Cambodia and are going to be primarily attracted to the XP/Sahong flows. Even fish that do enter Hoo Phapheng from the Mekong are expected to be more attracted to the flow through Phapheng Falls then the much lower flow coming out of the Sadam channel. Whilst smaller channels around Phapheng falls can pass some fish, it has a short operating window and only under extreme flows. We released 21 fish within 20m of the entrance of Hoo Sadam and only 7 of these fish were detected again (downstream). In other words, none of these 15 fish successfully migrated up the Sadam channel. They may have travelled downstream (unfortunately, the receiver at the bridge 400m downstream was lost during the study) or may have been attracted to the larger flows from Hoo Phapheng.

The relative size of the arrows in Figure 2 and 1A predict that the number of fish finding passage through Hoo Wai is less than that through Hoo Sadam. Unfortunately for the pilot study, Hoo Wai was just not appropriate for an acoustic system. Anecdotally, however, we can say that the three *Pangassius larnaudii* that went through Hoo Sadam had all tried and failed to go through XP channel towards Hoo Wai. There were six fish whose last detections were on the tree at Nokasoung Noi, just below the Hoo Wai complex. The other nine fish that were detected there were later detected downstream. The two fish that were detected at the bottom of Hoo Wai Noi were also later detected downstream. Given that all five fish that we know exited the top of the Sadam or Sahong channels were detected upstream at Ban Parmouk, it is unlikely that the six fish that were last detected at Nokasoung Noi successfully passed upstream through the Hoo Wai complex – or we would expect that at least one would have been detected upstream. Nonetheless, these are very small samples and only really offer enough data to generate hypotheses, not test them.

In summary, we suggest that Hoo Sadam passes fish and maybe the best passage option in the region. However, it does not attract many fish at its entrance; it is more than 2.5 km from the limit of upstream migration; and it has limited attraction flow. In the wet season, migrating fish can find the Hoo Wai complex, but it does appear to offer relatively poor passage efficiency. We understand that DSPC are continually investing in improving the fish passage efficiency at Hoo Wai and we look forward to the monitoring results from those works. At the completion of the study, the JEM pilot contributed one dozen gabion walls to aid in improving the directing of fish towards the predicted optimal fish passage routes through Hoo Wai.

19 APPENDIX B: Range tests

Pre-deployment range tests were carried out at the end of April and beginning of May. It was recognised that the flow conditions are different from then to the wet season but were the best practice to estimate ranges before deployment. The April/May tests were to identify deployment logistical issues in advance and find unsuitable locations early on. After range testing the pilot study locations were identified and receivers deployed. To compensate for potential changes in read ranges from changes in flow between seasons, we set the receivers in ‘synch tag’ mode with sentinel tags pinging every 10 minutes between closely positioned receivers which could be used to estimate detection range in changing conditions over the duration of the deployment.

Hoo Wai and the downstream end of Hoo Don Lai were unsuitable for acoustic monitoring because the former had multiple not well-delineated passage routes in very shallow and fast flowing water, whilst the latter was very narrow and shallow in April, yet deep in the wet season with heavy vegetation that would give the receiver an extremely short read range.

Range tests comprised of two components, measuring background noise levels and estimating detection range. Up to 6 receivers were placed in the river section up to 300m apart for each assessment, which were mostly just a snapshot over a few hours on a single day. To estimate range we listened for the tag that is inside the receiver (V13 equivalent) with the VR100 omni directional hydrophone on a boat, and/or attempted to communicate with the receiver using the VR100 from a known distance and/or assessed detections of internal tags between nearby receivers during the same range test. Background noise levels are logged by the receiver when turned on and we isolated the noise levels for each receiver when it was in the river. As a general rule, the background noise below 300mV is desirable to maximise the number of transmitter pings that are detected and levels above 650 result in very few detections.

19.1.1Hoo Don Lai

The Mekong end of Hoo Don Lai was assessed but the water level was prohibitively low (Figure A1), where acoustic signals may become distorted and from surface reflections and not able to be decoded. The lower channel is inherently unsuitable for receivers because of intense vegetation cover, unless the receivers are positioned in the pool connecting to the Mekong river. The pool was range tested but a receiver there that would not allow assessment of whether the fish entered the channel or swam past. There was no suitable locations for an acoustic receiver between the lower Mekong and the Liphi Falls swimming pool.

The Liphi swimming pool had acceptable levels of background noise and a read range of up to 25m which is greater than the width of the channel. It was decided to place two receivers at this site. A receiver at each of the top and bottom of the pool location could allow direction of passage to be assessed.

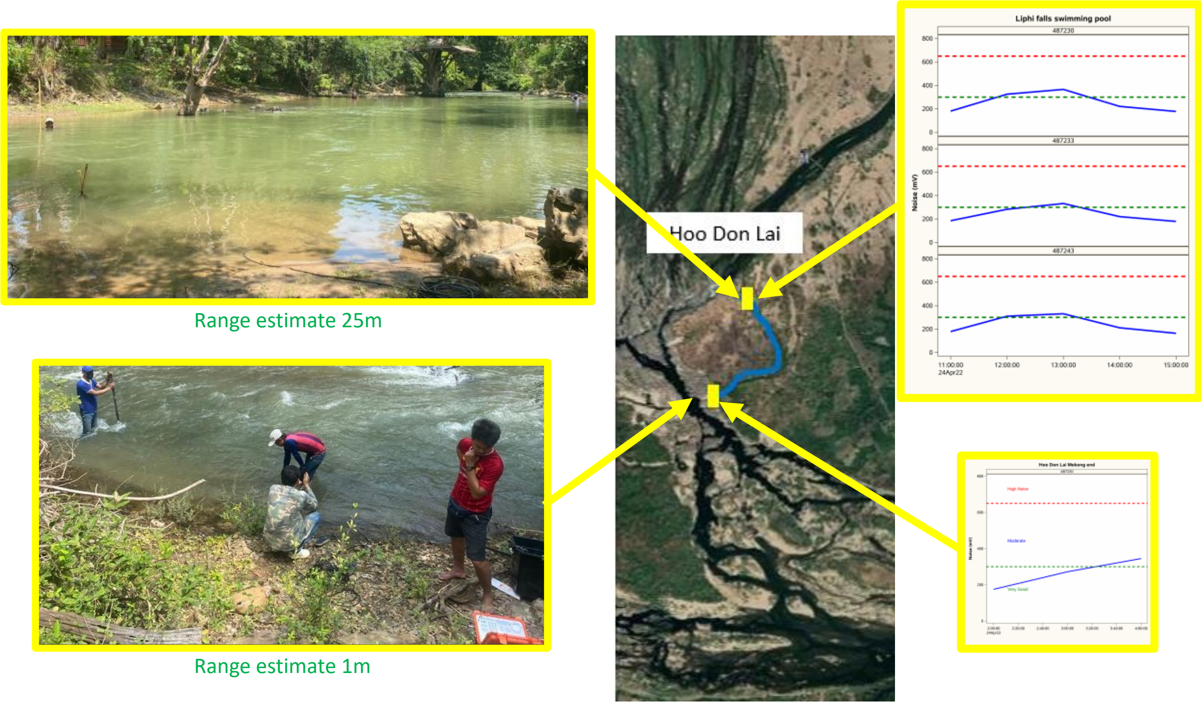

Figure A1. Range tests in Hoo Don Lai in April of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.2 Hoo Sadam

Background noise levels in Hoo Sadam in typical dry season flow were good to moderate, typically at about 320 mV (Figure A2). However, the shallow water (typically less than 1m meant that surface reflection could be problematic. The range test included 5 receivers and tags at 20m spacing and the estimated read range was 20m for a V7 tag and 35m for a V13. Given the very fast flow in this channel, the chance of detecting downstream passage is very low. The channel was only 12m wide during the trial and may be 120m in the wet season.

19.1.3 Hoo Sahong/pond

The pond above the power station seems an ideal location as it is always > 6m deep, the bed is very flat, the channel relatively straight, and the channel width consistent at about 270m. The range test suffered from the receiver towers falling over because of the strength of the flow, and the noise levels were higher than the smaller natural channels (Figure A2). Overall, the location is good and it is expected that a single receiver can cover the width of the channel effectively as the centre of the channel is 135m from each bank, much less than the 250m range experienced in the range test. Even downstream migrating fish should be detected comfortably.

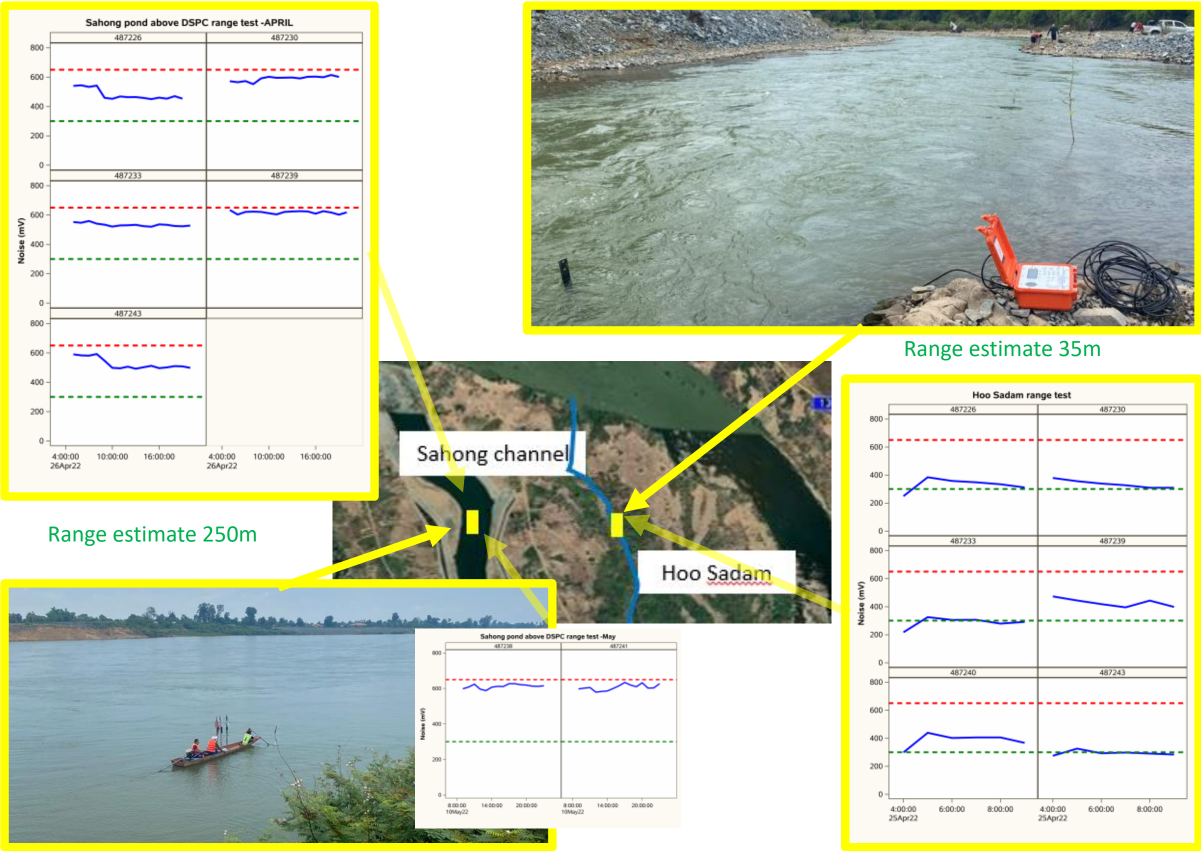

Figure A2. Range tests in Hoo Sadam and the Sahong pond in April of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.4 Hoo Xang Pheuak

Access to Hoo Wai and Hoo Wai li is extremely difficult in the dry season, and virtually impossible in the wet season. It is inherently not suitable for an acoustic receiver system because it is heavily braided in the dry season, yet flooded in the wet season, flow is fast and shallow reducing read range to less than a few metres, and there are lots of rocks and vegetation for fish to use for shelter when migrating. The chances of detecting tags there are extremely low. The alternative is to detect fish below and above the system and above the Hoo Wai complex. Hence we range tested a receiver array in Hoo Xang Pheuak. In the dry season, there is very little flow in these channels as the DSPC takes almost all of the available water coming into the region, and background noise levels were very low (Figure A3). The range was about 200m and restricted by the bedrock surface being very channelised and uneven with depths varying from 4 to 18m. Receivers at the PS outflow and the Xang Pheuak back water also had low noise levels in an upstream direction, but a smaller range as the water on that side was generally less than 1.5 m deep.

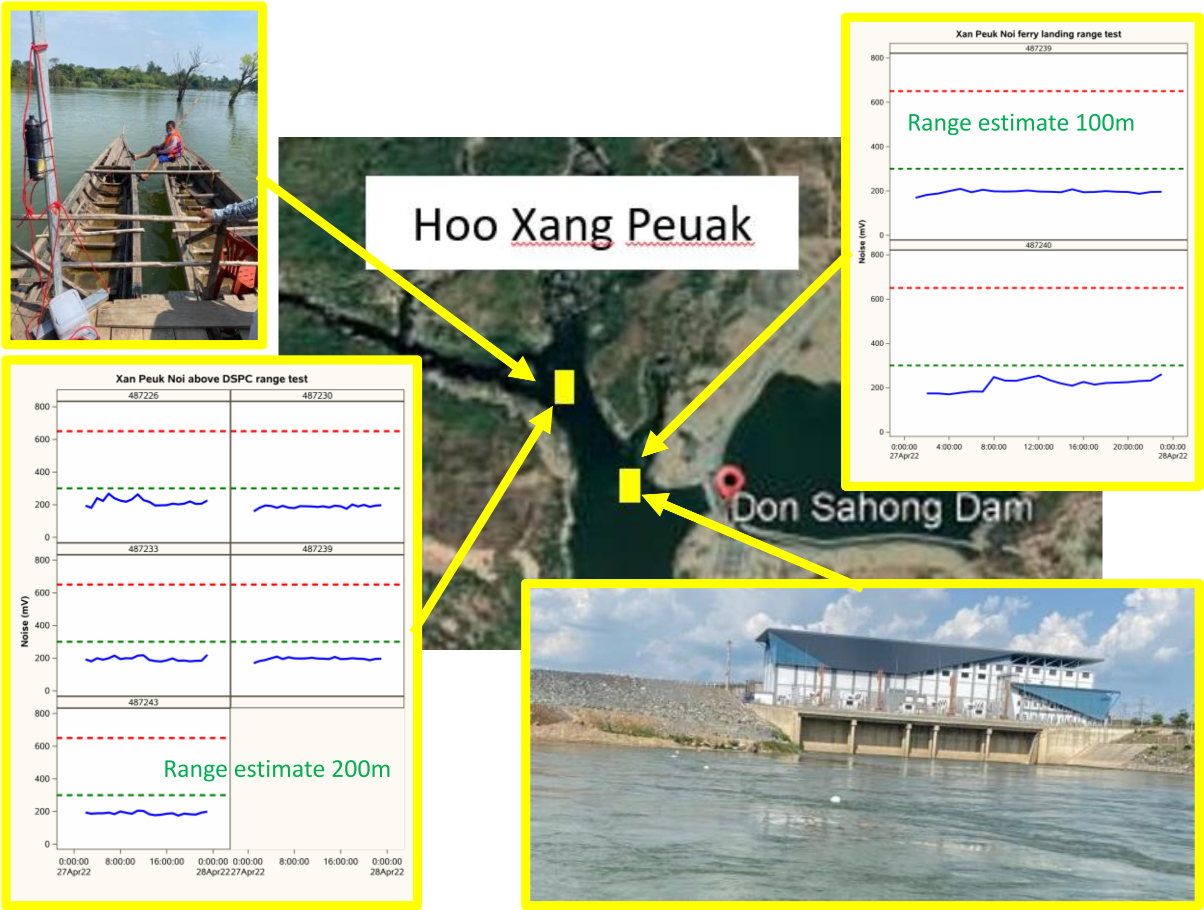

Figure A3. Range tests in Hoo Xang Pheuak above the Sahong junction in April of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.5Hoo Xang Pheuak and Mekong junction

The receiver in the channel above the outflow from the powerhouse had a read range of at least 100m even in water less than 1.5m deep, and more than 200m in the deeper channel.

Two receivers placed on opposite banks (about 90m apart) downstream of the power-house by about 75m did not detect each other across the channel even once in a 24 hour period. With internal transmitters sounding every 90 seconds, this corresponds to 143 undetected transmission each. The noise levels were good at only a bit over 300mV (Figure A4), but the acoustics may have been affected by bubbles/air in the water column.

The French navigation marker receiver was retrieved after 5 days as it had fallen over and was not able to communicate with the mobile hydrophone on the boat from only 5m away. The noise levels were very high (Figure A4) and the chances of detecting fish near there very low. However, it is noted that this receiver was in the Mekong Main Channel and these data are from the dry season when almost all of the water in the Mekong is coming through the powerhouse, resulting in a large cascade of riffles near this navigation marker as the flowing water hits the almost stationary water in the Mekong. Even to the human ear above the surface the noise is extreme for several kilometres. In the wet season, the riffles disappear and the water level in the Mekong rises by several metres and the noise levels may drop substantially.

Figure A4. Range tests in Hoo Xang Pheuak near the Mekong junction in April of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.6Main Channel East

Noise levels in this channel were lower than the navigation marker as they were downstream by about 1 km (Figure A5). The water is 9m to 18m depth and the range test extended 300m over a deeper channel and a sand bar, giving quite inconsistent detection levels depending on the depth and surrounding topography that the receiver ended up in. There will be four receivers deployed in this region to enable very high coverage rate and the ability to detect direction of movement of tags when they are detected.

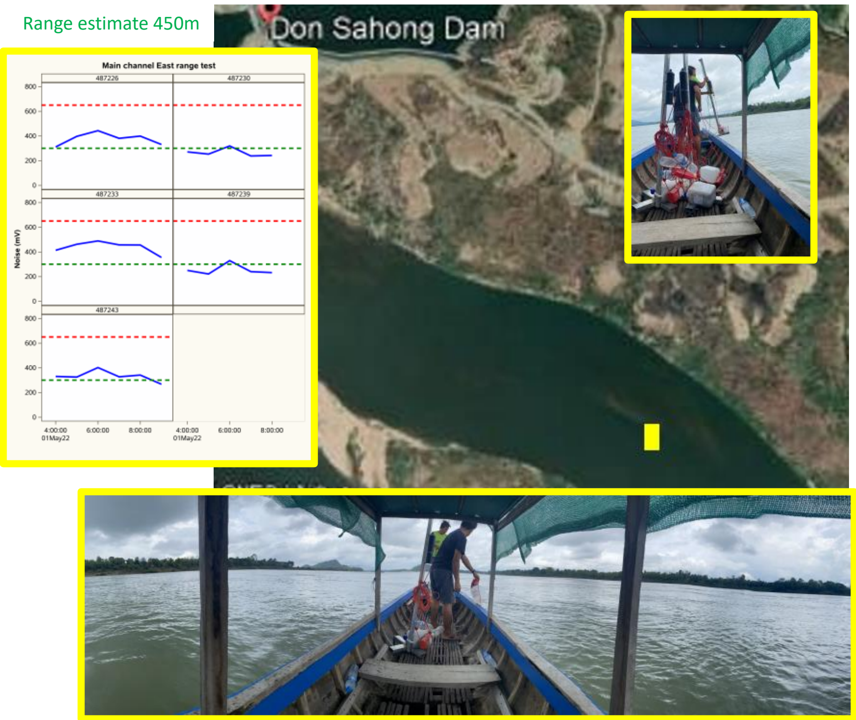

Figure A5. Range tests in the Mekong river east of the DSPP in May of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.7 Main Channel West

In late April and Early May there is very little flow in the west channel and consequently the background noise levels are low (Figure A6). Nevertheless, the bedrock substrate is hard rock and very uneven and difficult to assess. The range test line was 300m long and included a depth profile variation of between 4m to 18m and the range test towers were difficult to deploy, regularly falling over on the uneven and rocky substrate. The best estimate of detection range was 180m and it is thought that at least 4 receivers will be needed to cover the width of channel in the wet season.

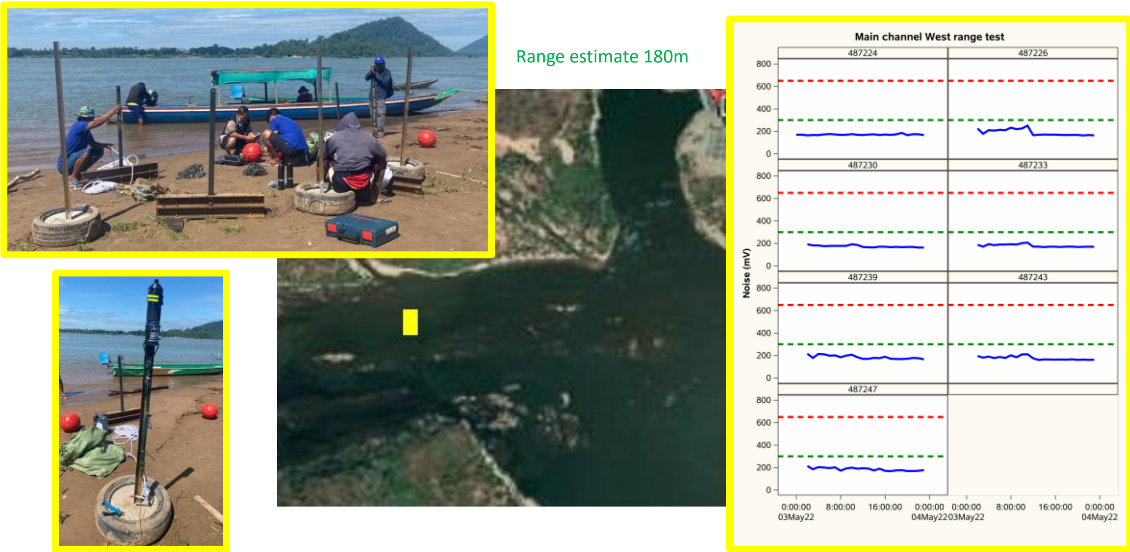

Figure A6. Range tests in the Mekong river west of the DSPP in May of 2022. Graphs are background noise levels and values below the green reference line are desirable.

19.1.8Main Chanel North

The area above the falls is heavily braided and the substrate markedly channelised bedrock (Plate A7). Wide scale coverage by acoustic receivers in the channels immediately above the falls is logistically impossible. DSPC had engineered a pool in the Mekong River at the top of Hoo Sadam that was about 2.5 m deep and 60m width. The project placed one receiver in that pool to detect fish exiting Hoo Sadam (Plate A7). The receiver was expected to detect any tags in the pool (noise levels are not recordable on this model receiver). A test tag was detected with 100% detectability at 200m in the channel below this receiver before it was retrieved on 8th February 2023.

Plate A7. A receiver was placed in the diversion pool of the Mekong River at the head of the Hoo Sadam channel for the JEM pilot. The diversion pool has a smooth, engineered substrate for efficient flow into Hoo Sadam. Note the heavily channelised rocky substrate in the background which typical of the Mekong River above Khone falls.

The project placed a further four receivers north of the 4000 islands (Si Pan Done) near Ban Chan, some 40 km above the falls where the Mekong returns to a single channel. These four receivers form a 'gate' where the direction of movement can be assessed. As deployment then recovery was logistically unachievable, no official range test was performed. Ranges were estimated using the internal tags and the omni directional hydrophone during deployment (Figure A6). These four receivers, north of the Si Pan Done, give exceptional coverage with estimated read ranges up to 1.4 km during deployment.

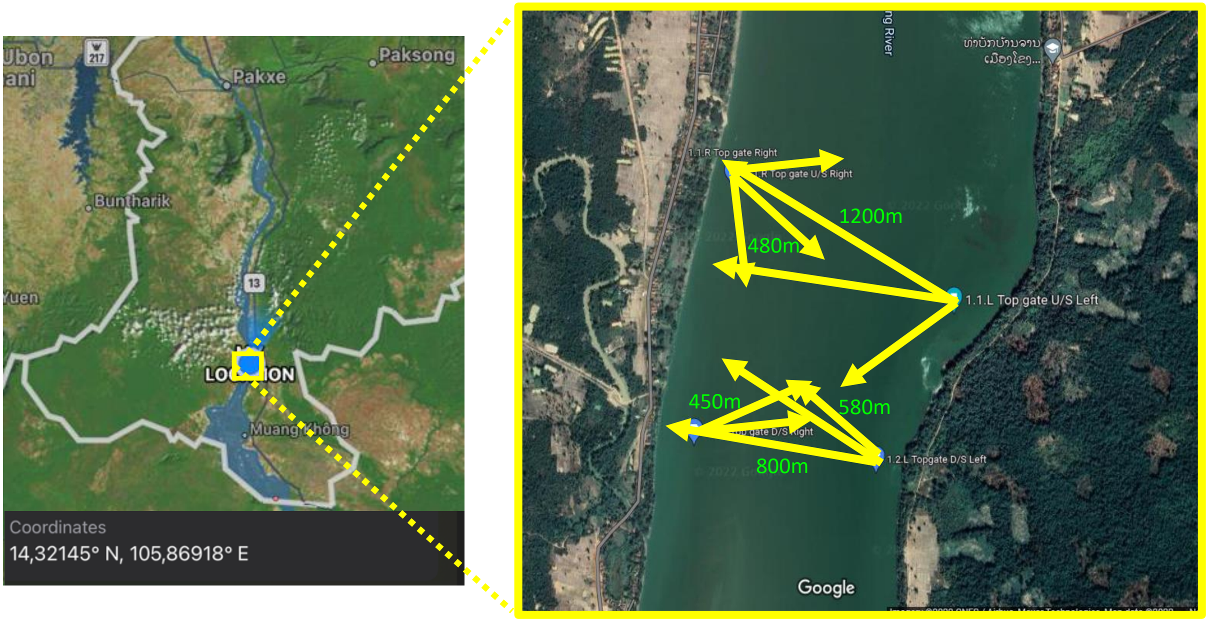

Figure A6. Range tests the Mekong River near Ban Chan, north of Khone falls in May of 2022. Arrows are verified distances from each receiver that its internal tag could be detected by another hydrophone after deployment on 12th May 2022.