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Final report

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1 Acknowledgments

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2 Executive summary

2.1 Background

River infrastructure, including dams, weirs and floodplain regulators are becoming increasingly used worldwide for food security and power generation. Any structure used to alter hydrology has inevitable environmental impacts; especially on fisheries sustainability. Construction of riverine infrastructure has been implicated in fisheries declines globally. The majority of structures block access to important spawning, feeding and nursery habitat thus preventing the completion of important life history stages. Fish need to move upstream, downstream and laterally, so it is important that any development activities allow fish to complete essential migrations.

Globally, fishways have been used to provide connectivity at riverine infrastructure which creates fish migration barriers. Fishways are a channel around or through a migration barrier which allow fish to move volitionally. Many designs are available to facilitate fish passage, but applying designs that have been developed for other species can lead to sub-optimal solutions that can limit recovery outcomes. It is important that any fish passage solution is based on the sound knowledge of local species and that design characteristics have been well formulated through scientific investigations.

The Lower Mekong basin is facing an unprecedented level of irrigation development. Many dams, weirs and regulators are being constructed on an annual basis and there are substantial concerns for the welfare of fisheries resources. There was little information available on (1) the level of current development; (2) information available on potential fish passage mitigation options or (3) social and economic impacts and benefits of maintaining fish passage. This project sought to address some of these knowledge gaps through the application of structured field research.

2.2 Project activities

The project sought to primarily develop the first criteria for fish passage developed for Lower Mekong species but also understand the extent of current irrigation development and quantify potential social and economic benefits. A series of field-based assessments was devised to specifically answer three research questions:

1. What is the current extent of floodplain development in Central and Southern Laos?
2. Can effective low-cost fishways be constructed to mitigate the negative social, economic and environmental impacts of floodplain regulators?
3. Does the construction of permanently-operating fishways provide quantifiable social, economic and environmental benefits to floodplain wetlands and communities?

The first question involved using a combination of desktop and field validation techniques to effectively enumerate, document and map fish passage barriers throughout two key catchments. The overall outcome was to generate a prioritised list that could be presented to donor bodies and investment banks to guide future restoration investment.

Question two was more focused on developing mitigation options for fish passage that could be applied at the range of identified and mapped barriers. A series of field experiments was devised to define the characteristics of fish passage that were preferred by Lower Mekong species. These characteristics were then used to construct a permanent demonstration fishway which was assessed to determine if it was possible to rehabilitate a floodplain wetland fishery.

The final question sought to determine whether it was possible to quantify if the fishway contributed to positive social and economic outcomes. These were assessed in two major ways. Firstly, to determine the overall value of the fishery to local communities. Secondly, to determine any perceived or real benefits arising from fishery recovery.

2.3 Achievements and new knowledge

Over 7,500 barriers to fish migration were mapped across two catchments; the Xe Bang Fai and Xe Champhone. Detailed characteristics of each barrier were documented and used to populate detailed geographic information systems databases. A prioritised list was generated and has been used to guide further investment opportunities in these catchments. The approach created a strong visual tool for highlighting the overall issue being addressed, which had been used in Australia with significant success

The project team developed the first design criteria, and fishway, for Lower Mekong species. The team demonstrated that an experimental *in-situ* approach was entirely appropriate for refining design criteria. Working with actual migrating fish in the field provided data that was unbiased from handling or laboratory effects. Fish were motivated to migrate which provided results that were directly applicable to effective design assessment. Constructing the first fishway designed for Lower Mekong species was a substantial achievement. Designed and built by the project team, with assistance from local labourers and contractors, the structure has provided passage for 177 fish species. Species passing through the fishway included three IUCN red-listed species, In addition, a range of larger catfish species was captured, mainly at night, providing hard information on the migratory habits of these species for the first time. Detailed information was also collected on small-bodied species, and also juveniles of large-bodied species entering nursery habitat. These are all new information that will help to advance the knowledge and management of Mekong species into the future.

Socio economic surveys demonstrated that wetland fisheries are valued by local communities but were perceived to have declined substantially since regulator construction. Overall the community felt that fishway construction was a positive outcome but also indicated that a strong management process will need to be in place to ensure long term success. Minimising overfishing, restoring habitat and implementing strategies to improve water quality were seen as valuable complementary actions to improve fisheries productivity. A survey following fishway construction revealed that fishers had caught species not observed for many years, indicating positive impacts.

2.4 Conclusions and recommendations

Developing robust fish passage outcomes requires an integrated and long term approach. Implementing a strategy that sought to identify the scale of riverine development, develop a widely applicable solution and also capture social and economic benefits was a sound approach that had wider support from government and investment agencies. Using migrating fish, under field conditions, to develop design criteria was a key factor contributing to project success. In fact, these design criteria have already been used to facilitate the construction of eleven other fishways in Southern Laos, under the auspices of the Lao Irrigation Department with funding from the World Bank.

In future work, it is strongly recommended that the project team disseminates the results widely to both government and donor bodies to improve opportunities for uptake at other sites. It is also important that barrier mapping work be continued in other key catchments to increase the spatial understanding of existing infrastructure development. Combining this information with an inventory of planned construction would provide a powerful tool for future investment opportunities.

Finally, it is recommended that any future fish passage work use local villagers and labourers as key project team members. Locals provided invaluable insights into regional issues. Their support and participation were key factors contributing to overall success.

3 Background

Rice production is important for Lao people. Approximately 50% of poor people in Lao PDR live in rural areas reliant on irrigation-assisted agriculture, mostly rice production, which comprises 12–15% of the gross domestic product and 73% of total employment (David and Huang, 1996). Most rice production occurs on floodplains, which contain the most fertile and productive soil. The Lower Mekong Basin has large annual water-level fluctuations that lead to floodplain inundation, which drives productivity and increased rice yields. However, uncontrolled inundation can limit rice production, because high water levels can drown and destroy crops. A common way to protect crops is to build regulators that protect crops by controlling the amount of water spilling onto the floodplain; however, these can block important migration pathways for fish.

Fish are an equally important commodity in Laos (Baird 2006). The average Lao citizen consumes 29 kg fish/year, which is 48% of total animal protein intake (Hortle 2007). Between 40 and 70% of the overall capture fishery depends on species that are considered migratory (Barlow *et al*. 2008). Developing wetlands for irrigation or crop protection can lead to substantial capture-fishery decline because fish cannot access spawning or nursery habitat; thus impacting river communities by reducing available protein and income.

The Mekong is one of the world's major catchment systems, and is generally recognised as the 10th largest in the world in both discharge and length (Bouakhamvongsa and Poulsen 2001). It drains a total area of 795,000km^2 and is approximately 4,000km in length. Over 60 million people reside within the catchment in the six countries it flows through. The river has immense importance in terms of benefits and ecosystem services (fisheries, soil fertility, navigation, irrigation, ground water recharge) and cultural values for the people of the region. It also contains some of the world's most unique aquatic communities, which include freshwater dolphins, giant catfish, stingrays, and approximately 850 freshwater fish species (Campbell et al. 2006, Valbo-Jorgensen et al. 2009).

Fisheries are immensely important throughout the lower Mekong basin (the LMB, which is the Mekong drainage within Lao P.D.R., Thailand, Cambodia and Vietnam). In food security terms, fish and other aquatic animals provide on average 48% and 79% of the animal protein intake in Lao P.D.R. and Cambodia respectively (see Table 1). From a livelihood perspective, more than 80% of rural households in the Mekong basin in Thailand, Lao P.D.R. and Cambodia are involved in capture fisheries, and up to 95% of the rural households in the Viet Nam delta (Hortle 2009). In economic terms, the capture fishery has a first-sale value of between US$2,000-4,000 million per year (Hortle 2009). The annual yield from the capture fishery in the LMB is about two million tonnes, which is approximately 2% of the total world marine and freshwater catch, and about 11 times the total yield of all of Australia's capture fisheries (Allan et al. 2005).

Table 1. Consumption of fish and other aquatic animals (OAAs) and selected meats in Lao P.D.R. and Cambodia. (Information derived from Hortle, 2007).

Country	Fish and OAAs Kg/person/year	% animal protein	Beef Kg/person/year	Pork Kg/person/year	Chicken Kg/person/year
Lao P.D.R.	29	48	5	6	5
Cambodia	37	79	2	3	2

The impact of water management structures on fisheries production

The Mekong supports a large population of subsistence farmers and fishermen who rely heavily on regular flooding of floodplain areas to increase productivity. Increased irrigation development in the four LMB countries has led to construction of numerous (in excess of 10,000 in Thailand alone) low-level (generally less than 6 m) water regulation devices which limit the movement of migratory fish (Daming and Kung 1997). Weirs were installed for water management purposes to improve water security/irrigation, but had a negative impact on fish migration (Le et al. 2007). Consequently, the fish cannot move between rivers and floodplains, which is essential for completion of their lifecycles. The proliferation of structures such as roads and irrigation weirs can cost anywhere between several thousand to several million dollars per site depending on size of the structure.

Unfortunately, construction of these structures can individually (and cumulatively) delay or prevent fish passage onto the floodplain at the onset of the wet-season, thus reducing the habitat area available for fish reproduction and growth (Baumgartner 2005). In addition, they create artificial aggregations of pre-spawning fish below these barriers which are extremely vulnerable to overexploitation and disease. These fish either spawn at the wrong time in the wrong place or do not spawn at all. Over time, these impacts reduce the diversity and productivity of the fishery and the benefits of development projects (such as improved road transport and more secure water supplies) are thus negatively offset by lost fisheries productivity.

Many fish species within the region are highly migratory, and require connectivity among river reaches to maintain access to feeding areas, spawning grounds and refuge habitats (Jensen 2001). The creation of barriers on these important pathways can interrupt important life-cycle stages and can result in large-scale population collapses. For instance, following construction of the Pak Mun Dam (Mun River, Thailand) daily fish catches in upstream reaches had declined by 60-80% (Roberts 2001). Overall, the construction of the dam led to the disappearance of 169 fish species from upstream reaches. This can be particularly damaging to rural communities as their livelihood strategies are generally reliant on wild fisheries productivity.

Opportunity to use fish passage technology to reconnect wetlands

In other areas of the world, fishways are effectively used to maintain pathways for migratory fish in order to prevent large-scale fish community declines (Clay 1995). Fishways are simply channels around or through an obstruction that permit fish to pass with undue stress. Fish swim through these channels and are able to complete their migrations. In particular, the development of upstream fish-passage facilities has advanced considerably in Australia over recent years (Stuart and Berghuis 2002, Mallen-Cooper and Stuart 2007, Barrett et al. 2008, Baumgartner et al. 2008). Work underway in Australia is directly relevant to the Lower Mekong Basin. Developing a formal collaboration on fishway development issues is important to ensure the long-term sustainability of these economically and socially important and ecologically unique fish community assemblages.

There is strong evidence to suggest that advancing fish passage work in the Lower Mekong could have substantial fisheries productivity returns. A fish yield of 67-137 kg/ha/year has been estimated for wetlands in the LMB, and a first sale value of AUD1.20-2.00/kg (Hortle and Suntornratana 2008, Hortle 2009). Using these data, restoration of a hypothetical wetland of 1,500-2,000 ha to full fisheries productivity would return a value greater than the cost of the project within 5-10 years. Such a target is feasible, given the potential involvement of large donor agencies (e.g., ADB and World Bank) in implementing the results of the proposed project in separate interventions.

The estimated economic benefit is based on first sale price only, so it does not include multiplier effects from trade, nor any estimate of the associated livelihood benefits (nutrition/health and employment) from the increased fish supply. It is also important to appreciate that the fish are produced by the functioning ecological system requiring little or no human input, unlike an aquaculture or other animal husbandry operation.

This project

Our project sought to determine whether a fishway could be applied as a technology to rehabilitate degraded floodplain fisheries in the Lower Mekong Basin. There were three major focus areas that were required to develop multiple lines of evidence supporting fishways as a tool to rehabilitate fisheries, firstly:

(1) To understand the scale of wetland development in several key catchments;

(2) To determine if engineering solutions can help fish recover from the effects of floodplain development;

(3) To understand the social and economic issues of impacted, and rehabilitated, floodplain fisheries.

The focus of our project was to determine if an integrated approach could be used to document the overall impact, solution and benefits of obstructed fish passage at a demonstration site in the Lower Mekong Basin.

4 Objectives

4.1 Objective 1: Analyse and prioritise water infrastructure barriers to lateral fish migrations between the Mekong River and floodplain habitat

There has been little published on the extent of floodplain development in the Lower Mekong Basin. Despite the recent floodplain development, much of the Lower Mekong Basin is difficult to access, and thus difficult to survey. Understanding the extent of floodplain development is required to understand the full extent of the need to rehabilitate depleted fisheries. We hypothesized that, given the difficult nature of work, that much irrigation infrastructure in the Lower Mekong Basin was largely undocumented. We piloted a combined remote detection and on-ground validation technique to document the degree of irrigation infrastructure in two key catchments.

4.2 Objective 2: Research the effectiveness of low-cost fishways at floodplain barriers in the lower Mekong basin

Floodplain fisheries diversity and productivity would have declined from a reduction in lateral connectivity between the Mekong River and the Pak Peung floodplain following regulator construction. The main reason is because important opportunities to perform lateral migrations to access important floodplain habitat became obstructed. We hypothesised that it would be possible to restore these migrations if the migration ecology, and swimming abilities of local target species was known. Work focused largely on understanding local fish ecology and applying this knowledge to the development of engineering solutions.

4.3 Objective 3: Quantify the ecological and socio-economic benefits of floodplain rehabilitation using fish passage technology

Once the extent of floodplain development was quantified (focus area 1), and an engineering solution identified (focus area 2), it was then important to understand the potential social and economic benefits should those engineering solutions be implemented. Focusing on the study site we hypothesised that local fishers would experience increased total catches and diversity, and that fishing behaviour may change should the fishery recover. A series of modelling and fishing household surveys were conducted to quantify potential benefits near the study site.

5 Methodology

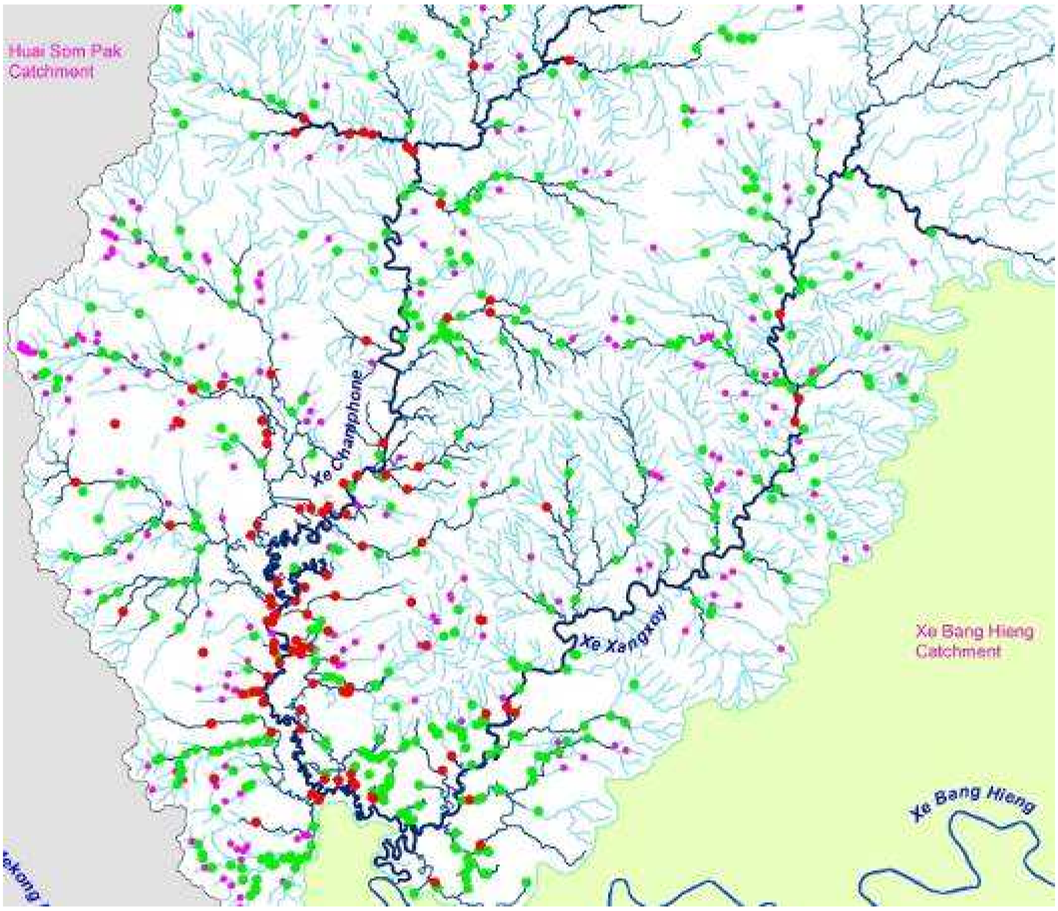
5.1 Barrier mapping

The barrier prioritisation process used in this study was developed to ensure limited resources are efficiently utilised to identify barriers (Figure 1) having the greatest impact on fish migration which were suitable candidates for remediation. The prioritisation process achieves this through a comprehensive five stage process that evaluates fishery, economic, social and eco-system benefits of barrier remediation. These five stages include:

a) Identification – using available information and satellite imagery
b) Remote Assessment – GIS analysis of five attributes of the potential barrier
c) Field Appraisal – record physical attributes of high priority potential barriers
d) Biological Assessment – GIS analysis of five properties of the barrier and site
e) Socio-economic Assessment – consideration of four socio-economic factors

One of the advantages of this approach is the ability to assess and prioritise thousands of potential barriers prior to requiring site visits. An initial desktop study employs the efficiency and unique decision making capabilities of an automated GIS system to assess wide-ranging temporal and spatial habitat characteristics associated with each potential barrier. The approach allows limited resources to be directed towards assessing the highest ranking potential barriers after the initial GIS stage, rather than a more arbitrary approach of visiting unknown and often less critical barriers based on limited local knowledge.

Figure 1. Location of barriers to fish migration in the Xe Champhone catchment.



This prioritisation uses an optimised score and rank system that utilises the five stages of assessment in conjunction with an automated GIS process (Figure 2). The system takes into consideration the importance of various migration patterns and the likelihood of localised extinctions caused by the barrier. As a result, the process is designed to favour barriers located close to the Mekong River. After each stage all barriers are assessed and only those of the highest priority are assessed further. In this way the prioritisation can quickly reduce the numbers of barriers considered down to a manageable number that small teams can consider.

The first stage of the process requires the identification of all fish migration barriers to include in the barrier prioritisation. It is critical that ALL barriers are included at this stage as any barrier not included may render provision of fish passage at other barriers useless. To this end the prioritisation process aims to identify each and every structure that could potentially impact fish passage within a catchment, even if at a later stage it is proven to not be a barrier. These potential barriers are all included in the analysis process during the initial stages to allow a refined list to be created for the field assessment stage for a more efficient use of on-ground resources.

Figure 2. Flow chart representing the various stages of the prioritisation process.

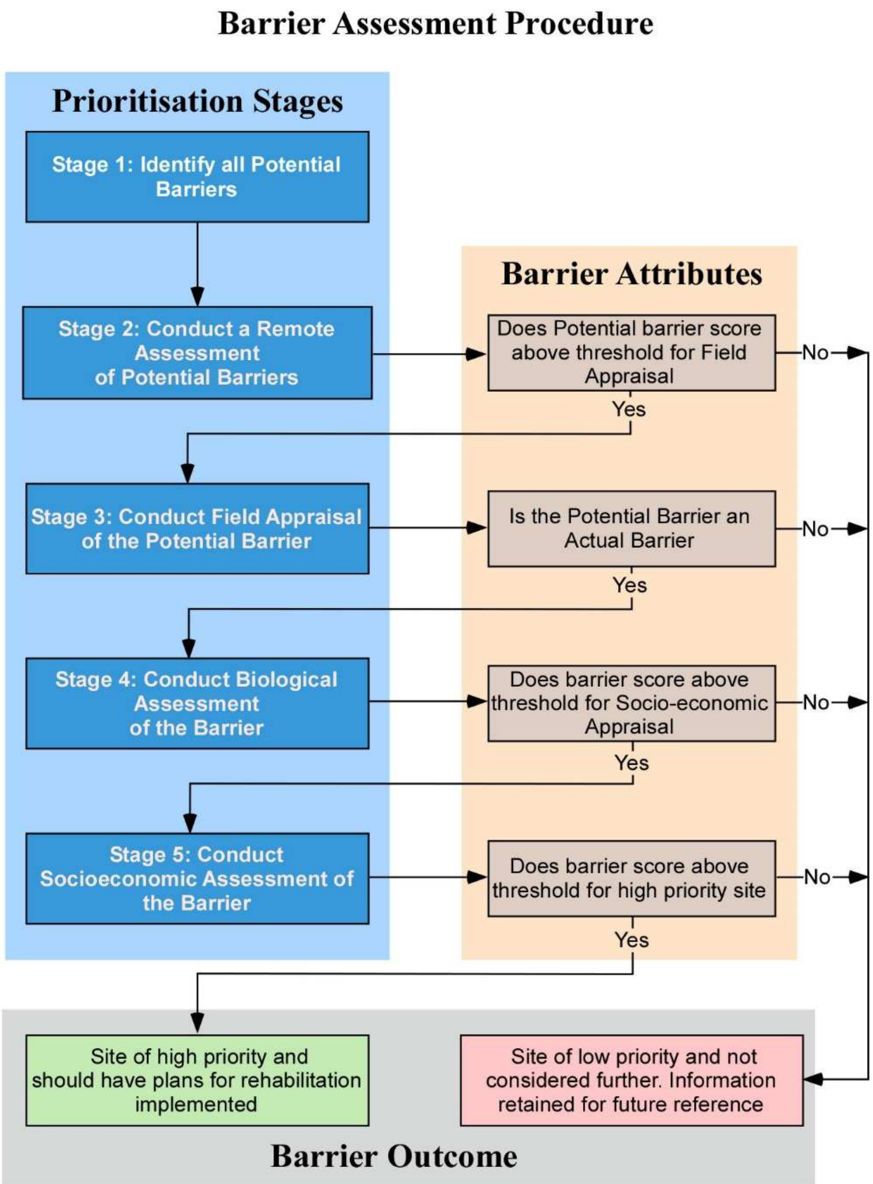
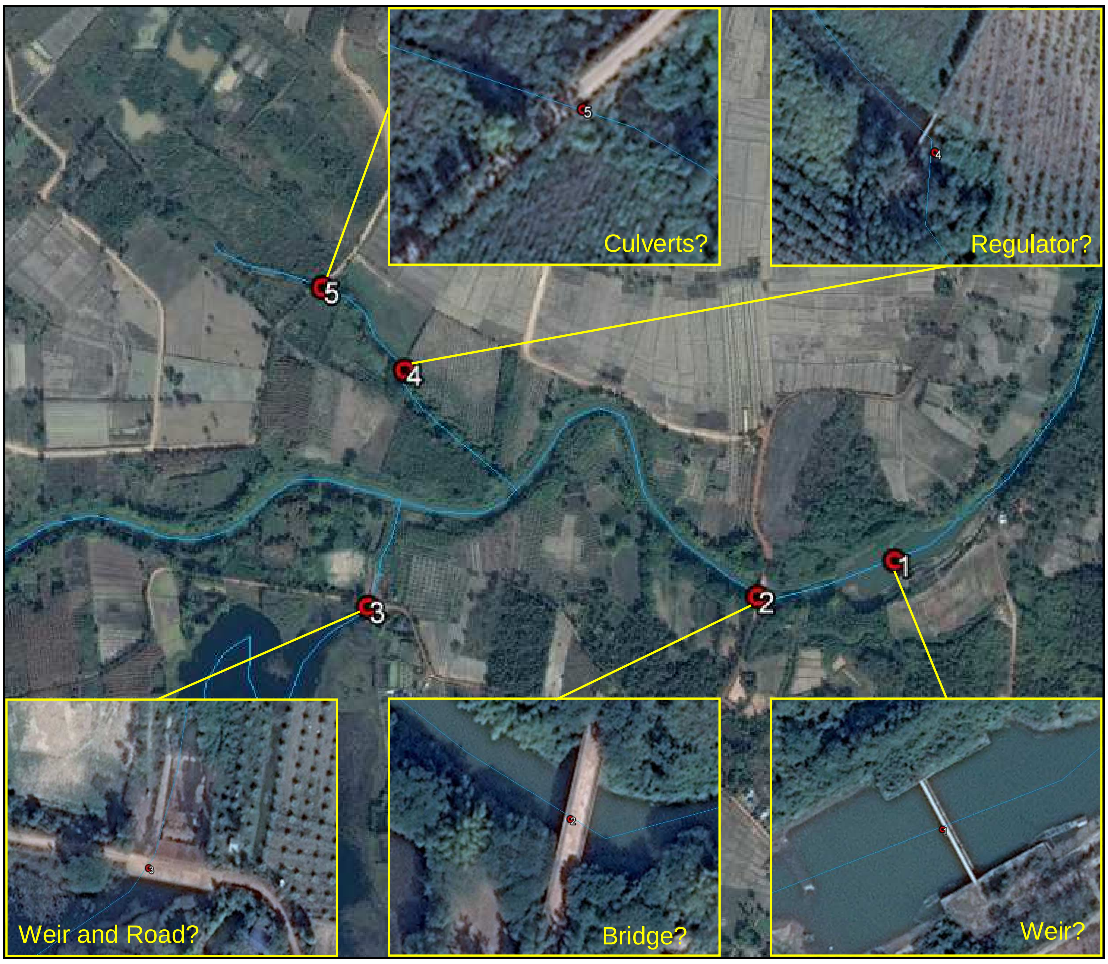


Figure 3. Potential barriers identified from remote imagery and other GIS sources.



To identify potential barriers, satellite imagery and aerial photography is analysed for each of the target catchments, identifying any structure that intersects a waterway and appears to create a barrier (Figure 3). This is corroborated with any secondary vector data available that identifies structures likely to be a barrier such as irrigation infrastructure or road crossing data layers. From this information, a potential barrier waypoint is created for each and every potential barrier and assigned a unique geo-referenced identification number that remains with the barrier throughout the five stage prioritisation process.

Stage 2 of the barrier prioritisation incorporates a desktop GIS process to efficiently investigate spatial and temporal habitat characteristics associated with each potential barrier identified in stage 1, without the need to visit the site. This initial GIS process allows the prioritisation to set an achievable target of potential barriers for field appraisal in stage 3 of the process.

The following attributes will determine if a potential in-stream barrier is a high priority after stage 2 of the selection criteria process:

a) Barrier located in the lower reaches of the river system – as barriers have the greatest impact on upstream movement and the large habitats of the Mekong or South China Sea contain the most fish, barrier close to these sources will have the largest impact on fish communities;

b) Located on a large river or wetland – large rivers provide the best and most diverse habitats, maintain refuge pools throughout the dry season and have the most diverse fish communities, so barriers on these rivers are likely to have a greater impact on a larger range of species;

c) Minimal to no barriers located downstream – barriers downstream of a site restrict the movement of fish up to the site. As it always harder for fish to move upstream past a barrier, having many barriers downstream reduces the number of fish that can make it to a site, making the downstream barriers more critical;

d) Good catchment condition – fish communities in catchments with minimal adverse surrounding landuse practices are generally in better condition than those that are negatively affected by pollution from the surrounding land;

e) Large area of available upstream habitat – the amount of habitat opened up above the barrier to the next barrier or top of catchment if the barrier is repaired must be large, otherwise there is limited benefit to the repair. The more habitat that is opened up by the barrier the better it is for the fish community.

Each of these attributes were categorised by the project team and a score attributed. The score for each attribute is weighted by the importance of that attribute in determining the priority of the barrier.

Stage 3 of the prioritisation process involves undertaking field appraisals of the highest ranked potential barriers after the remote assessment. This will determine if the site is an actual barrier and also define the actual characteristics of the barrier that cannot be determined remotely. Non barriers (ie those determined to have no impact on fish passage at any stage of the hydrograph) are immediately removed from the assessment process as they have no impact on fish communities.

The stage 4 biophysical assessment stage scores the data collected from the field appraisal of the potential barriers and provides further refinement of the priority list created in the remote assessment stage. As the field appraisal discounted all non-barriers from the assessment, the biophysical assessment is now centred on confirmed barriers. This assessment identifies the highest priority barriers in terms of their effect on the biological productivity of a catchment.

Confirmed barriers are assessed against five physical attributes that affect biological productivity, relating to the barrier size, stream condition, water quality, instream habitat and fisheries production. Each barrier is assigned a score (i.e. 1 - 10) for each of the physical criteria.

The biological assessment assigns a score to all barriers based on ‘how well’ they meet the criteria for each of a further five questions:

a) Transparency of the barrier to migrating fish – barriers that are large and have a great impact on the movement of fish (not transparent) are in the greatest need of rehabilitation and will achieve a high score in this criteria. Low barriers that are often easily passed by fish have less impact, are scored lower and are a lower priority for repair;

b) Stream and riparian condition – barriers found in catchments with intact riparian zones are likely to have greater impact as the fish communities in these catchments are usually more productive than those in degraded catchments. To score highly in this criteria the catchment as observed by the assessor must be in good condition;

c) Stream flow – streams with natural, permanent and non-polluted flows have better fish communities than those where flow is restricted or polluted. Barriers on these more natural streams have a greater impact than those on more regulated streams. To score highly in this criteria streams should have good unpolluted flow as determined by the assessing team based on local knowledge;

d) In-stream habitat – streams with diverse and abundant instream habitats support better fish communities and barriers on such streams have a greater impact. To score highly in this criteria streams must have good instream habitats;

e) Importance of site to local fishers – streams with good fish populations are more popular and productive fishing grounds. If a barrier site is within an important fishing ground, it is likely that any barrier in the stream would have a negative impact on fish communities and fisheries. Sites that are highly valued by fishers will score higher for this criteria.

The stage 5 socio-economic assessment introduces a number of social and economic factors to further refine the prioritisation list. This step identifies the most cost-effective barrier for repair with the greatest benefit to the local community. While the previous stages of the prioritisation have identified which barriers have the greatest impact on the biology of the fish communities, this stage identifies non-biological factors and their impact. It is extremely important in determining whether the cost of construction is justified by the social and biological benefits the fishway will generate for both local community and the environment. In this stage the refined list of barriers from the biological assessment is further analysed. Like the other stages, barriers in the socio-economic assessment are assigned a score based on 'how well' they met each of the four selection criteria. A high score for the following attributes means the in-stream barrier scores well in the socio-economic assessment stage of the prioritisation process:

a) Repair cost – the lower the cost to remediate the barrier the more likely it is that the barrier will be rehabilitated. Generally smaller barriers with simple fish passage requirements will be cheaper to remediate than larger barriers with complex fish passage requirements, hence they will score higher than the more complex structures;

b) Fishway Design – a barrier that requires a simple fish passage design with minimal engineering will be easier to fund and complete with local expertise than a barrier requiring highly technical fishway designs to provide passage. As such barriers requiring simpler designs will score higher than more technical fishways;

c) Fish Passage Effectiveness – unless a barrier is completely removed, any repair will only provide partial passage for the fish community. Some fishway designs will provide better results than others, with full-width rock ramp fishways able to pass nearly all fish on all flows, while steep submerged orifice fishways only pass a small proportion of the fish attempting to migrate. If the barrier is suitable for a highly effective fishway design that can pass many fish it will score higher than those barriers where only sub-optimal designs can be implemented;

d) Fisheries Productivity Gains – the improvement in the productivity of fisheries is the primary aim of the rehabilitation of fisheries in the LMB. For repair to be effective it must provide productivity gains where they can be accessed by the local community. As such barriers that provide great productivity gains to many villages will be of a higher priority than those that do not benefit any villages.

Once scoring for all socio-economic attributes has been collated, the scores for each barrier are totalled and added to the score for that barrier from the remote assessment and the biological assessment. The barrier with the highest combined score becomes the highest ranking barrier for repair in this prioritisation process. This final rank will determine the barriers most likely to be rehabilitated. These high priority barriers will provide the largest productive benefit for local communities if they are rehabilitated. The end result of this prioritisation is a report listing the top barriers to fish migration in the target catchment in order of highest priority. The list can be provided to donor bodies who are interested in identifying investment priorities.

5.2 Fishway Optimisation

A large project focus was detailed in-field assessments of fishway effectiveness. Work focused largely on identifying critical design aspects required to pass a maximum number, biomass and size range of fish species. Designs which achieve all three outcomes are most likely to generate the biggest social, economic and environmental returns. Work was subsequently field-based and focused on these main areas.

Fieldwork could only be completed during the rainy season (generally from April until August) which limited the ability of the team to complete all experiments rapidly. Work subsequently followed a logical progression.

Year 1 and Year 2: **Refinement of fishway design criteria** which required a detailed in-situ comparison of different design types to ascertain which were most suited to Lower Mekong species.

Year 3: **Assessment of a permanently constructed fishway**. The team facilitated the construction of a permanent fishway, based on the outcomes of Year 1 and 2. It was important to understand how well the fishway performed.

Year 4: **Optimisation of permanent fishway**. Analysis of Year 3 data revealed potential areas requiring refinement so fieldwork focused largely on ensuring the fishway was optimised to maximise fish movement.

Four discrete experiments were subsequently performed to ensure optimal biological performance to maximise social and economic benefits.

5.2.1 Refinement of fishway design criteria

Fishway design effectiveness was further refined from previous vertical slot and cone experiments by using an experimental in-situ channel. Three different designs were assessed. Firstly, a vertical slot design; which is a commonly applied design worldwide and has been applied with a high degree of success. The vertical slots were 1400 mm high with a slot width of 150 mm. Secondly, two variations of a sub-merged orifice design (150 mm square and 300 mm square orifice opening) were also assessed. The fishway unit comprised four pools which were 1500 mm × 1000 mm in size. Larger pool sizes were considered, but accommodating a larger pool size would require larger amounts of water, which would increase the overall weight of the experimental unit. It was also hypothesized that mostly small-bodied black species, and sub-adult white species, would attempt to access floodplain habitat, so a smaller pool size was selected. The fishway was operated with a 1m depth and standardised to have a headloss of 150 mm between pools.

Experimental replicates were performed in a large open concrete channel which was being prepared for fishway construction. Entrance to the channel was situated at the upstream limit of migration on the Mekong side of the Pak Peung wetland regulator (Figure 4). Discharge through the channel was controlled by a sluice gate installed on the upstream side. Water level in the channel was dependent on Mekong River height (Figure 5). Mekong level varied depending on local rainfall. Prior to the commencement of each experimental replicate, the experimental channel was adjusted so that the fishway entrance aligned with the Mekong tailwater level.

Experiments followed a randomised block design. It took a day to complete each block and work was only undertaken during daylight hours. There were three treatment groups (vertical slot, submerged orifice 15 and submerged orifice 30). Time of day was considered to potentially affect fish migration rates, some potentially preferring different diel activity periods, so treatments were randomly assigned to one of three times of day (8am, 11am or 2pm). Each replicate took three hours to complete.

Prior to commencement all baffles were removed and the upstream control regulator fully opened to flush fish from the channel. Baffles were then reinstated according to the required experimental treatment. Headlosses among cells were measured for consistency and a fish trap (2mm mesh; cone design) was set to capture any upstream migrating fish. Flow was then introduced into the fishway.

Upon completion of each experiment the fish trap was collected and all fish identified, weighed, measured and released upstream into the wetland. The baffles were then removed, the fishway flushed, and the next replicate commenced.

A total of 15 blocks were completed in the rainy season between May and June 2012.

5.2.2 Data Analysis

Univariate Analysis

Analyses focused on identifying differences in fish passage rates among the three treatments to determine which was more effective. A generalised linear model, using a Poisson distribution, was used to compare the number of grey species and number of white species using each of the three fishway treatments. The effect of the blocks was partitioned by using generalised estimating equations in the Genmod procedure (SAS 9.3, SAS Institute 2013).

A randomised block design Analysis of Variance (ANOVA) was used test whether (i) the average number of fish trapped per hour of sampling (Catch Per Unit Effort), (ii) average biomass of fish trapped per hour of sampling (Biomass Per Unit Effort) and (iii) the average number of species of fish trapped per hour of sampling (Species Per Unit Effort) differed among the three fishway treatments. Both CPUE and BPUE were transformed using log(X+1) to meet the assumption of homogenous variances.

To identify if there were any differences in fish length among treatments, a randomised block design ANOVA was used to compare the median, 10^{th} percentile, and 90^{th} of the lengths of fish trapped per hour of sampling between the three fishway treatments. In all ANOVAs, significant effects were followed up using pairwise comparisons and Scheffe's correction for type 1 Error.

Figure 4. The experimental fishway unit established at the upstream limit of migration downstream of the Pak Peung regulator. The entrance is on the downstream side of the unit with the fishway trap on the upstream side (Photo Jim Holmes).

Figure 5. During high Mekong levels the experimental unit was set up within the permanent fishway channel which provided more control over discharge and depth (Photo Jim Holmes).

Multivariate analysis

Considering such a large number of species were collected, multivariate analyses were also performed to ascertain the nature of any complex patterns of fishway use.

The CPUE (average catch per hour) for each species in each fishway treatment and block combination were transformed using $\log^{e}(X+1)$. Similarities between samples were calculated using Bray-Curtis similarity measure and Permutational Analysis of Variance (PERMANOVA; (Anderson and Walsh 2013) was used to test for differences between the treatments sing a randomised block design. Differences in CPUE between species that contributed substantially to any differences between treatments were identified using SIMPER (Clarke and Gorley 2006). The samples were ordinated using Non-Metric Multi-dimensional Scaling (NMDS) (Clarke and Gorley 2006) and species that had rank correlations with the space of 0.6 or more were identified and any relationship in the space plotted using Principal Axis Correlations (PCC) (Clarke and Gorley 2006).

The data were then converted to presence and absence, the Jaccard Similarity measure calculated, and the PERMANOVA and SIMPER procedures performed to identify any species that were present or absent more often in some fishway treatments that others, regardless of abundance. Values on the Jaccard Similarity scale (0 to 1) are interpreted as the proportion of shared species between the two samples.

In each PERMANOVA analysis, if the treatments were deemed to be different ($p < 0.10$) then then a follow up PERMANOVA was performed to compare each treatment in a pairwise manner. In each SIMPER analysis, species were considered most important in separating the treatments if they contributed $\geq$ 5% of total dissimilarity and their standard deviation ratio (Dissimilarity/Std.dev) was $\geq$ 1.

5.2.3 Assessment of a permanently constructed fishway

A concrete cone fishway was retrofitted to the Pak Peung wetland regulator in the dry season of 2012/13. Preliminary research provided design criteria upon which to base the permanent designs (Baumgartner et al. 2012). A cone fishway, based on the fixed crest regulator design and safety considerations, was selected. Both the vertical slot and submerged orifice designs were considered. Each have slots/orifices below minimum wetland water level and there were concerns from local villagers that these design could drain the wetland pool rapidly. The fixed crest level of the cone fishway design ensured that it was not possible for the wetland to be drained below a set water level. Safety considerations were also raised by locals. The fishway would be visited by the local children daily. It was felt that there was some risk of children becoming trapped in vertical slot and submerged orifice designs. The cone fishway design, with substantially better access and egress, and was chosen for the site.

The permanent fishway channel is 245 m long containing 45 baffles. The design consists of multiple baffles made up of 1.0m high concrete cones that have a tapered 100mm to 250mm wide slot between them. The slots in each baffle are offset to aid in turbulence dissipation. Dissipation is achieved by having two alternate baffle arrangements, baffles with three full slots and baffles with two full slots and two half slots (Figure 6). Between each of the baffles was a 2m long and 3m wide pool with sloping sides and a flat bottom that varied in depth between 600mm and 1500mm depending on fishway flow. The fishway was constructed to provide a head differential of 100mm between pools, this was based on previous work which determined this to be optimal for Lower Mekong species (Baumgartner et al. 2012).

To cope with difficult site topography that required extensive excavation works, the fishway was divided into three fishway sections, separated by two long pools (Figure 7; panoramic view; Figure 8; plan view). The lowest section was 70m long and contained 32 baffles and two enlarged resting pools. Upstream from the lower section was a resting pool 45 m long which led to the second fishway section made up of 9 baffles. Upstream again was a second 70m long resting pool and the third fishway section with 5 more baffles. Upstream of the last fishway section and traversing the road was a 12 m long by 1.5 m deep concrete box culvert. A sluice gate regulator was fitted upstream of the culvert to control fishway discharge.

An assessment was performed and experiments designed to determine whether all species and size classes were able to ascend the fishway. A paired top / bottom randomised block design was used. Bottom samples were performed by placing a large fish trap (2mm mesh) at the most downstream point of entry into the fishway. The Mekong River water levels varied substantially during the study, so the downstream point of entry was deemed the point within the fishway where tailwater depth had no influence on hydraulics. Bottom trap location subsequently varied both up and downstream according to tailwater levels. Top samples were taken by placing the same trap at the upstream limit of ascent within the fishway.

Prior to the start of each experimental block, and also at the commencement of each day, the fishway was cleared of all fish by providing a sustained high flow for a period of 30 minutes. The trap was then set in the required location (top or bottom) and the fishway operated for a total of four hours. The trap was then retrieved and all fish transferred to a 60L contained with aerated river water for further processing. The trap was then reset and the remainder of the block completed. A total of 14 blocks were completed.

All trapped fish were identified, weighed and a subset of 20 individuals measured for length.

Figure 6. Alternating concrete cone baffles with three full slots (background) and two full slots and two half slots (foreground).

Figure 7. Panoramic view of the lower fishway channel section of the completed Pak Peung fishway.

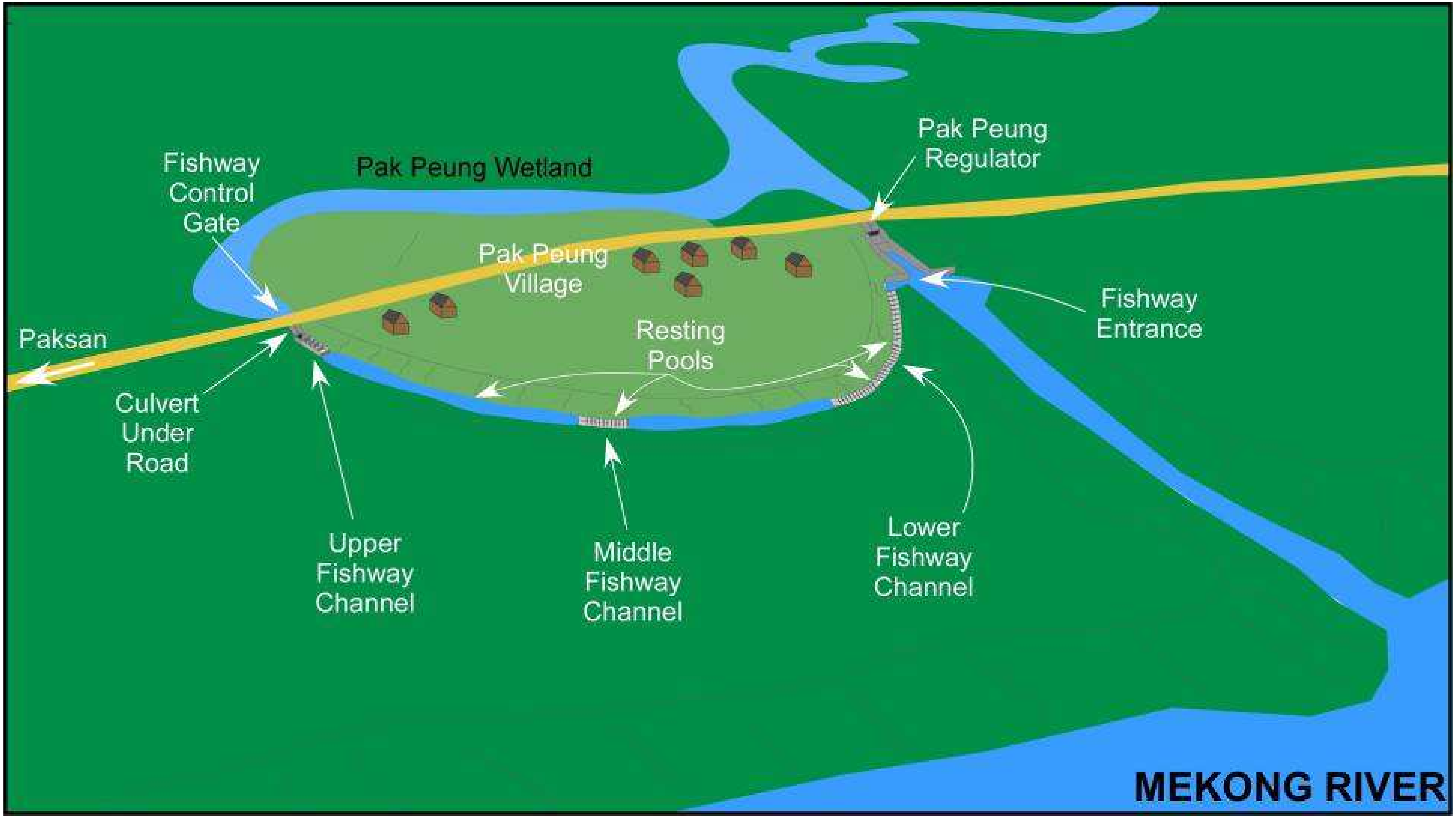
5.2.4 Assessment of a permanently constructed fishway - Data Analysis

Analyses sought to determine differences between catches at the top and bottom of the permanent fishway. Previous work has demonstrated that not all fish species are able to ascend. Analyses subsequently focused on identifying differences in fish community composition and length frequency distribution between the different fishway trapping locations.

Univariate Analysis

A factorial randomised block design ANOVA to test whether the; average number of fish trapped per hour of sampling (CPUE); average biomass of fish trapped per hour of sampling (BPUE); the average number of species of fish (SPUE).

Figure 8. Plan view of the Pak Peung village (courtesy of Google Earth) highlighting (a) Proximity to the Mekong River (b) location of the fishway in relation to Pak Peung village; (c) the three fishway channel sections and (d) The location of the Pak Peung regulator.



The median, 10th percentile, and 90th of the lengths of fish trapped per hour of sampling was different between the location of the fishway trap, day and night sampling, and the interaction of time of day on location. CPUE and BPUE were transformed using log(X+1) to meet the assumption of homogenous variances.

Multivariate Analysis

The CPUE (average catch per hour) for each species in each fishway location, time of sampling and block combination were transformed using $\log_e(X+1)$. Similarities between samples were calculated using Bray-Curtis similarity measure and PERMANOVA (Anderson and Walsh 2013) used to test for differences between the treatments using a factorial randomised block design. Differences in CPUE between species that contributed substantially to any differences between treatments were identified using SIMPER (Clarke and Gorley 2006).

In each PERMANOVA analysis, if the treatments were deemed to be different ($p < 0.10$). A follow up PERMANOVA was then performed to compare each treatment in a pairwise manner. In each SIMPER analysis, species were considered most important in separating the treatments if they contributed ≥ 5% of total dissimilarity and their standard deviation ratio (Dissimilarity/Std.dev) was ≥ 1.

5.2.5 Optimisation of permanent fishway

A further assessment of the permanent fishway (described in 5.2.3; Figure 9) was performed after initial experiments suggested that some species were not ascending the entire lengthy. Given local site characteristics, it was essential that the fishway passed under a major road which required fish to move through a culvert. There has been much global interest regarding fish movement through culverts. Some species are reluctant to enter because of reduced light whilst others are unable to negotiate the sustained laminar flow and high velocities. There was concern that species may be reaching the top of the Pak Peung fishway but then unable to negotiate the culvert into the wetland. Structured experiments were subsequently performed to determine whether culvert passage was a limiting factor for Mekong species.

Experiments sought to determine whether all species and size classes were able to ascend the fishway using a randomised block approach. Three treatments were assessed; bottom, top and culvert. Bottom samples were performed by placing a large fish trap (2mm mesh) at the most downstream point of entry into the fishway. The Mekong River water levels varied substantially during the study, so the downstream point of entry was deemed the point within the fishway where tailwater depth had no influence on hydraulics. Bottom trap location subsequently varied both up and downstream according to tailwater levels. Top samples were taken by placing the same trap at the most upstream limit of ascent within the fishway but downstream of the entrance to the culvert. This treatment allowed an understanding of fish that were negotiating the entire fishway channel and could have entered the culvert. The culvert treatment involved collecting fish from the upstream side of the culvert. Fish trapped from this location must have entered the fishway, negotiated the full length and then passed through the culvert. Thus, any species captured from the culvert treatment are those most likely to recolonise the Pak Peung wetland.

Prior to the start of each block, and also at the commencement of each day, the fishway was cleared by dip netting and then providing a sustained high flow for a period of 30 minutes. The trap was then set in the required location (top, bottom or culvert) and the fishway operated for a total of six hours. The trap was then retrieved and all fish transferred to a 60L contained with aerated river water for further processing. After processing, all fish were released upstream into the wetland. The trap was then reset and the remainder of the block completed. A total of 18 blocks were completed. It took three days to complete a full block.

5.2.6 Data Analysis

Univariate analysis

A randomised block design ANOVA was used to test whether the average number of fish trapped per hour of sampling (CPUE), average biomass of fish trapped per hour of sampling (BPUE), the average number of species of fish trapped per hour of sampling (SPUE), the median, 10th percentile, and 90th percentile of the lengths of fish was different between the three fishway treatments. CPUE and BPUE were transformed using log (X+1) to meet the assumption of homogenous variances. In all ANOVAs, significant effects were followed up using pairwise comparisons and Scheffe's correction for type 1 error.

Multivariate analysis

The CPUE (average catch per hour) for each species in each fishway treatment × block combination were transformed using $\log_e$ (X+1). Similarities between samples were calculated using Bray-Curtis similarity measure and PERMANOVA (Anderson and Walsh 2013) used to test for differences between the treatments using a randomised block design. Differences in CPUE between species that contributed substantially to any differences between treatments were identified using SIMPER (Clarke and Gorley 2006). The data were then converted to presence and absence, the Jaccard Similarity measure calculated, and the PERMANOVA and SIMPER procedures performed to identify any species that were present or absent more often in some fishway treatments that others, regardless of abundance. Values on the Jaccard Similarity scale (0 to 1) are interpreted as the proportion of shared species between the two samples.

In each PERMANOVA analysis where treatments were deemed to be different ($p < 0.10$). A follow up PERMANOVA was performed to compare each treatment in a pairwise manner. In each SIMPER analysis, species were considered most important in separating the treatments if they contributed ≥ 2.5% of total dissimilarity and their standard deviation ratio (Dissimilarity/Std.dev) was ≥ 1.

5.3 Socio Economic

Household surveys were conducted before and after the fishway was developed to measure any socioeconomic benefits. The surveys also sought to determine the overall value of capture fisheries within the wetland, to understand how fish are used on a daily basis and to gauge general community perceptions of changes in wetland condition and fish populations. A mixed quantitative and qualitative methodology was used using a semi-structured interview guide with closed and open questions.

The 'before' survey was conducted in 2011 with 60 households from the six villages that are situated around Pak Peung wetland. An additional 21 women were surveyed in November 2012 using the same questionnaire to increase the proportion of female respondents (Table 1). Interviewees fished on a regular basis (ie. at least once a week). The village leader was asked to select all fisher people willing to be interviewed. A response rate of 90% was achieved. Twenty five elders (16 male, 9 female) from the same villages were also interviewed in November 2012 using a more open interview guide to explore their views on historical changes to the wetland and traditional conservation practices. The 'after' survey was conducted in early 2015 (8 months after the fishway became operational) with 61 people (41 repeat respondents, 20 new respondents) from the same villages (Table 2). The aim was to determine any observed changes in species abundance, quantity of fish caught, used and sold, or changes in fishing locations, times or methods by villagers.

In three surveys, third year fisheries students from the National University of Laos conducted the interviews after formal training. Twelve students worked in pairs (one male, one female), alternating interviewing and note taking roles. Male students interviewed male respondents and female students interviewed female respondents to make participants feel more comfortable. After the first few interviews, the students shared their results with the trainers and discussed how to improve the interview process. Villagers were asked about where they fished (using a map so they could point to locations); how much time they spent fishing in wet and dry seasons (average number of days per week and hours per day); how much they caught on average in a week in both seasons; what species they caught and where; what methods they used; how they used the fish; how they sold the fish and average market prices; fish migration patterns in and out of the wetland and whether fish numbers had increased or decreased since the irrigation weir was built. The data was analysed the using SAS (2011) and graphs were generated using SAS (2012).

Table 2. Number of fishing respondents per village, gender and year.

Village	Total Pop'n	No. of hhs	Men 2011	Women 2011-12	Total 2011-12	Men 2015	Women 2015	Total 2015
Pak Peung	681	121	13	7	20	10	5	15
Paksan Nua	1028	217	8	9	17	7	6	13
Paksan Tai	1026	200	10	1	11	5	0	5
Phonesaat	674	118	4	8	12	0	10	10
Sisaat	669	135	8	5	13	7	3	10
Nasammo	1230	217	5	3	8	6	2	8
Totals	**5308**	**1008**	**48 (60%)**	**33 (40%)**	**81**	**35 (57%)**	**26 (43%)**	**61**

6 Achievements against activities and outputs/milestones

6.1 Objective 1: Analyse and prioritise infrastructure creating migration barriers to lateral fish migrations between the Mekong River and floodplain habitat

no.	activity	outputs/ milestones	What was achieved?	Comments
1.1	Perform satellite mapping of barriers in one key catchment	Generation of preliminary list of fish migration barriers (A)	Completed. Preliminary data was presented at a national workshop.	
1.2	Field-validate locations of barriers using GIS-based surveying	Correlation of preliminary list with actual field information on each barrier (A, PC)	Completed. Data has been presented in a formal report which has been disseminated	
1.3	Create spatial database and generate priority list of fish migration barriers	Generation of GIS-based maps and prioritisation list for fishway construction (A)	Database has been prepared for two major catchments. Priority list is presented in this final report.	
1.4	Distribute list to NGOs and donor bodies to help determine funding opportunities	Meetings with donor bodies and partner agencies in Thailand and other riparian countries to discuss potential funding opportunities (A, PC)	List of sites disseminated to MRC who are developing further prioritisations for the four LMB countries	

no.	activity	outputs/ milestones	What was achieved?	Comments
1.5	Establish an expert panel to provide specialist fish passage advice	A panel which is populated with both local and international experts which can discuss fishway design issues relevant to floodplain regulators in the lower Mekong Basin (A, PC)	Not completed.	This objective was ambitious. The establishment of the panel also proved problematic for two reasons: Firstly, it was determined that the project was the most active group on fishways in the Lower Mekong Basin and there were few others involved in fish passage work. Secondly, there was no budget to support attendance of international experts. At some stage it would be good to establish and resource such a group, either within the Government of Lao PDR or the MRC.

6.2 Objective 2: Research the effectiveness of low-costs fishways for widespread application at floodplain barriers in the lower Mekong basin and the Murray-Darling Basin

no.	activity	outputs/ milestones	What has was achieved?	Comments
2.1	Preliminary trip to Australia for Lao and Thai scientists to inspect existing fishways	Trip report outlining achievements of the study tour (PC)	The meeting took place in Sydney hosted by Fisheries NSW at Cronulla Fisheries Centre. The trip coincided with a project inception meeting. A trip report was produced and submitted.	The trip included a study tour where experts from riparian countries were able to view functional fishways in New South Wales and tropical Queensland.

no.	activity	outputs/ milestones	What has was achieved?	Comments
2.2	Identify two fishway designs for assessment in Lao PDR and one design for assessment in Australia	Brief workshop paper outlining which fishway designs are most appropriate and why (A, PC)	The two fishways designed were selected at the project inception meeting. A Lao engineer participated in the process.	The team would have preferred a traditional vertical-slot fishway, as this design was largely supported by experimental results. However, it was discounted on safety reasons. There was concern that local children would enter the fishway to catch fish and play. The team were worried that high walls and small slot-widths could have been a drowning hazard. The 'cone fishway' which was eventually constructed included as many aspects of vertical-slot fishway design and functionality as possible. Importantly, however, it was safe, and had easier access and egress for children. Experiments then focused on aspects of the cone fishway which maximised passage for local species.

no.	activity	outputs/ milestones	What has was achieved?	Comments
2.3	Identify two sites (Lao PDR) and one site (Australia) for field experiments	Approval gained through relevant authorities to undertake the work (PC)	Two sites were selected; one at Pak Peung wetland in Central Laos which was appropriate based on previous work conducted there. The Lao government set the priority for a second site to be selected in Southern Laos near Savannakhet. A site in Australia was selected at Lock 8 fishway based on previous work. However, partway through the project a new site was selected (at Euston Weir, Lock 15, Murray River) because it was the location of an innovative and novel new fishway design.	

no.	activity	outputs/ milestones	What has was achieved?	Comments
2.4	Construct and install temporary experimental-fishway channels in Lao PDR and Australia	Provide experimental fishway units and deliver to site (A, PC)	An experimental fishway was constructed and assessed in Savannakhet and also used at Pak Peung. Both were funded by the project. Construction of the Euston fishway was funded by the Australian government. Funds from the ACIAR project were used to support the biological assessment.	The experimental fishway at Pak Peung / Savannakhet was constructed out of mild steel using local labour. The project team provided construction specifications and oversaw construction. The process in Australia was far more disconnected. Project management was undertaken by State Water Corporation / Murray-Darling Basin authority. The project team had little input and were subsequently dependent on others for completion.

no.	activity	outputs/ milestones	What has was achieved?	Comments
2.5	Perform field experiments over three consecutive migration seasons in both countries	Successful completion of experiments (A, PC)	Field experiments were conducted in: Pak Peung in 2009, 2011, 2012, 2013. Different experiments were conducted each year. Savannakhet in 2011 only. Work was completed in an experimental fishway channel and also within a temporarily constructed rock ramp fishway. Euston fishway: Did not become operational until 2013. Experiments took place over the 2014/15 migration season.	The team dealt with substantial issues from climatic variability to staff changes, to the entire project changing organisations. Despite these difficulties all fieldwork was completed, reflecting flexibility of the team. The main reason that all work was completed as planned was because of the diverse project team which supported each other, and agreed to complete the project despite substantial pressures. The project would have been unable to complete all deliverables had it not been for the team that was assembled.

6.3 Objective 3: Quantify the biological, ecological and socio-economic benefits of floodplain rehabilitation using fish passage technology to mitigate impacts

no.	activity	outputs/ milestones	What was achieved?	Comments
3.1	Select a site for a detailed research study on fishway effectiveness	Approval gained through relevant authorities to undertake the work (PC)	The project team obtained approval from the Bolikhamsay province and PakSan district officials to construct a permanent fishway at Pak Peung regulator in Central Laos.	The collaborative relationship with Living Aquatic Resources Research Centre and National University of Laos was essential for this relationship with the province and district. The organisations did an outstanding job managing this relationship.
3.2	Perform before construction ecological and socio-economic surveys (at least 1year)	Completion of surveys (A, PC)	A socioeconomic survey was completed in 2011 of 60 household members who fish on a regular basis. An additional 20 people were surveyed in 2012 to increase the number of women and elder respondents. A report was produced.	Socioeconomic results gave baseline information on time spent fishing, locations, methods used, gender differences species caught and opinions of fish catch.

no.	activity	outputs/ milestones	What was achieved?	Comments
3.3	Construct a permanent demonstration fishway at a key site of fish migration	Successful completion of a demonstration fishway (PC)	A fishway was designed by the project team using Lao engineers to design the structure. Working drawings were put to tender and a local company, located in Pak San engaged to undertake the civil works. Work took approximately nine months to complete and was project managed by NUOL and LARReC staff. Considering this was the first-ever fishway constructed in Laos in this manner, there were some commissioning issues with the fishway. These were manually rectified by the project team and local villagers following construction.	This was a very challenging exercise. The team designed the fishway and ran a competitive tender process. Three contractors submitted tenders and a local group from Pak San was awarded the job. The National University of Laos, Living Aquatic Resources Research Centre and Australasian Fish Passage Services oversaw construction and managed the contractor. There were some defects that needed repair during the post-construction commissioning period. Despite this, a functional fishway was delivered on time and budget.

no.	activity	outputs/ milestones	What was achieved?	Comments
3.4	Perform after construction ecological and socio-economic surveys (at least 1year)	Completion of surveys (A, PC)	A post fishway socioeconomic survey was conducted in early 2015 with the same household members. Findings will be presented at the final meeting and a report produced.	Results show no changes in fishing locations and methods used. Villagers from Pak Peung observing new species and catching slightly more fish but other villagers report no change in fish species. Most villagers report catching less fish with some spending more time fishing to compensate, whilst others spend less time. 45% of respondents continue to sell fish, with 25% selling less and 20% selling more.
3.5	Produce guidelines from Objective 2 and 3	Final report, manuscripts and guidelines document (A, PC)	After the project commenced, the MRC commissioned a set of fish passage guidelines that followed on from this work. Project staff contributed to the development of these guidelines.	This was an ambitious objective of the project. The MRC guidelines provided a useful overlap and established a design process. Design criteria for fish passage will be an ongoing development.

7 Key results and discussion

7.1 Barrier mapping

7.1.1 Identification

The barrier prioritisations that were undertaken in the Xe Champhone and Nam Ngum catchments identified 3470 potential barriers to fish migrations. The identification of barriers was successfully undertaken with a combination of satellite imagery, national GIS databases and local knowledge.

7.1.2 Remote Assessment

In the remote assessment all barriers were to be assessed against the set criteria. However, many of these potential barriers were located on small streams which provide very little fish habitat. As a result of this, all barriers located on stream order 1's in low rainfall areas were eliminated during the first step of the automated GIS prioritisation process. This process removed potential barriers on small intermittent streams with minimal fishery value. This process left 555 and 2673 potential barriers to be analysed further in the remote assessment in the Xe Champhone and Nam Ngum respectively. The highest score achieved in the remote assessment stage was 28 in the Xe Champhone (Table 3) and 39 in the Nam Ngum (Table 4). This was achieved by the first potential barrier located upstream from the Mekong mainstream in both catchments.

7.1.3 Field Appraisal

The Field Appraisal of barriers was undertaken by teams from NUOL and LARReC, in conjunction with team leaders provided by Australian project partners. These teams visited each of the highest priority barriers identified in the Remote Assessment and undertook to record data relating to the type and size of each barrier, as well as collecting data to be used in the Biological and Socio-Economic assessments.

A total of 105 (Xe Champhone) and 138 (Nam Ngum) potential barriers were validated in the field during the Field Appraisal stage of the prioritisation. Of the validated potential barriers from both catchments, in the Xe Champhone, 62 (59%) were identified as barriers to fish migration, while 43 potential barriers (41%) were identified as non-barriers, while in the Nam Ngum 96 (70%) were identified as barriers to fish migration, while 42 potential barriers (30%) were identified as non-barriers.

7.1.4 Biological Assessment

Each of the barriers was scored against the five criteria for the biological assessment, based on the information collected during the Field Assessment. This provided barriers that are the highest priority due to the impact that they are having on the fish communities of the waterways studied.

In the Xe Champhone, 61 barriers to fish migration were priority ranked. In accordance with the ecological and physical criteria set out for the Biological Assessment (Table 5). The highest priority barriers were those on the main channel of the Xe Xangxoy tributary, as well as a number of wetland barriers in the lower catchment. In the Nam Ngum, 96 barriers to fish migration were priority ranked in accordance with the ecological and physical criteria set out for the Biological Assessment (Table 6). The highest priority barriers were those on the main channels of the Nam Ngum and Nam Lik tributary, as well as a number of wetland barriers in the lower catchment.

Table 3. Top ten barriers after the remote assessment for the Xe Champhone.

RA Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Medium Weir
2	2343	Xe Xangxoy	Low Weir
3	75	H. Souy	Medium Weir
4	67	H. Makmi	Large Weir
5	77	H Souy (Anabrach)	Bund Wall &
6	76	H Souy (Anabrach)	Bund Wall &
7	215	H Salongkhiang	Dropboard Weir
8	32	H. Sala	Medium Weir
9	68	H. Makmi	Drop Board Weir
10	6005	Xe Champhone	Low weir

Table 4. Top ten barriers after the remote assessment for the Nam Ngum.

RA Rank	Barrier ID	Stream name	Barrier Type
1	S2325	Nam Ngum	Large Dam
2	S918	Nam Ngum	Large Dam
3	S578	Nam Lik	Large Dam
4	S580	Nam Lik	Large Dam
5	77	Nam Xouang	Bridge
6	76	Nam Cheng	Bund Wall &
7	215	Nam Houm	Weir
8	32	Nam Lik	Bridge
9	68	Nam Ngum	Bridge
10	6005	Nam Ngum	Weir

Table 5. The top 25 confirmed barriers and their rank in order of priority after the Biological Assessment stage of the GIS Prioritisation process in the Xe Champhone.

BA Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Medium Weir
2	2343	Xe Xangxoy	Low Weir
3	68	H. Makmi	Drop Board weir
4	6005	Xe Champhone anabranch	Low weir
5	75	H. Souy	Medium Weir
6	67	H. Makmi	High Weir
7	77	H. Souy (Anabrach)	Bund Wall &
8	2471	H. Thouat	High Dam
9	32	H. Sala	Medium Weir
10	6014	H. Payong	High Weir
11	51	Unnamed (near B. Toumgne)	Low Weir
12	79	H. Bak	Regulator
13	114	H. Kalang	Dropboard Weir
14	215	H. Salongkhiang	Dropboard Weir
15	80	H. Lat	Dropboard Weir
16	6112	Unnamed (near B. Bak)	Medium Weir
17	76	H. Souy (Anabrach)	Bund Wall &
18	2274	H. Pakho	Dropboard Weir
19	73	Wetland Sth B. Kengkok-Dong	Wetland Bund
20	43	H. Payong	Medium Weir
21	116	H. Kalang	Medium Weir
22	94	Unnamed (near B. Nongpham)	Wetland Bund
23	104	Unnamed (near B. Nongpham)	Wetland Bund
24	74	Unnamed (near B. Kengkok-	Wetland Bund
25	193	Unnamed (near B. Nongpham)	Wetland Bund

Table 6. The top 23 confirmed barriers and their rank in order of priority after the Biological Assessment stage of the GIS Prioritisation process in the Nam Ngum.

BA Rank	Barrier ID	Stream name	Barrier Type
1	S2325	Nam Ngum	Large Dam
2	S578	Nam Lik	Large Dam
3	S30	Nam Houm	Weir
4	S315	Nam Cheng	Dam
5	S1493	Nam Kho	Weir
6	S480	Nam Khangxang	Culverts
7	S698a	Nam Ken	Weir
8	S639	Nam Kay	Weir
9	S878	Nam Nga	Weir
10	S1335A	Nam Piang	Weir
11	W27	Nam Ngoua - Gnai	Weir
12	S33	Nam Khon	Weir
13	S546	Nam Hai	Pipes
14	S739	Nam Pang	Weir
15	S859	Nam Po	Weir
16	S1330	Nam Piang	Pipe
17	S1330A	Nam Piang	Weir
18	S1827	Nam Kho	Pipe
19	W7	Nam Houm	Weir
20	S29	Nam Kho	Pipe
21	S1548	Nam Thong	Weir
22	S1550	Nam Thong	Weir
23	S2647	Nam Pamom	Weir

7.1.5 Socio-economic Assessment – consideration of four socio-economic factors

To further refine the list of high priority barriers, a socio-economic assessment of each of the confirmed barriers is undertaken. This stage of the assessment process scores each confirmed barrier against the four criteria list in the socio-economic assessment and then adds that score to the overall score from the remote assessment and the biological assessment stages of the prioritisation. This then gives the final scoring for the barriers and provides a list of the highest priority barriers that are affecting fish passage and most cost effective to remediate.

In the Xe Champhone, 61 barriers to fish migration were priority ranked in accordance with the technical and economic criteria set out for the Socio-Economic Assessment. The highest priority barriers were those that affected fish communities greatly, but were relatively simple and cost effective to remediate and had great benefit to the surrounding villages (Table 7). In the Nam Ngum, 96 barriers to fish migration were priority ranked in accordance with the technical and economic criteria set out for the Socio-Economic Assessment. The highest priority barriers were those that affected fish communities greatly, but were relatively simple and cost effective to remediate and had great benefit to the surrounding villages (Table 8).

Table 7. Final ranking for the top 10 priority barriers in the Xe Champhone.

SE Rank	Barrier ID	Stream name	Barrier Type
1	2328	Xe Xangxoy	Med Weir
2	2343	Xe Xangxoy	Low Weir
3	51	Unnamed (near B. Toumgne)	Low Weir
4	68	H. Makmi	Drop Board Weir
5	6005	Xe Champhone anabranch	Low weir
6	75	H. Souy	Med Weir
7	114	H. Kalang	Dropboard Weir
8	80	H. Lat	Dropboard Weir
9	215	H. Salongkhiang	Dropboard Weir
10	32	H. Sala	Med Weir

Table 8. Final ranking for the top 10 priority barriers in the Nam Ngum.

SE Rank	Barrier ID	Stream name	Barrier Type
1	S2325	Nam Ngum	Large Dam
2	S578	Nam Lik	Large Dam
3	S30	Nam Houm	Weir
4	S315	Nam Cheng	Dam
5	S480	Nam Khangxang	Culverts
6	W27	Nam Ngoua - Gnai	Weir
7	S1335A	Nam Piang	Weir
8	S859	Nam Po	Weir
9	S1330	Nam Piang	Pipe
10	S1493	Nam Kho	Weir

7.1.6 Barrier mapping - Discussion

The study identified a total of 3470 potential barriers to upstream fish passage in two catchments in southern and central Laos. Through desktop mapping, field assessments and refined GIS analysis processes, this objective was successfully able to distil these many barriers into refined lists of high priority barriers for both the Xe Champhone and the Nam Ngum catchments.

The study has highlighted that numerous existing barriers are impacting on fish and fisheries in the Xe Champhone and Nam Ngum catchments. The majority of the 220 species of fish in the Xe Champhone require free access along waterways and out onto wetlands and floodplains in order to complete their life-cycle. Fish are moving at all flows and at all times of the year when there are flows, in both upstream and downstream directions but this peaks during the wet season. Barriers to these fish movements have the potential to impact on fish populations both in terms of productivity and of genetic health. These fish are an important food resource to the people living within the Xe Champhone catchment.

Several different types of instream infrastructure were identified including structures servicing agriculture in the catchments. There are hundreds of these structures and the majority of these have been located and mapped for this project. A barrier prioritisation methodology developed for catchments in Australia has been successfully translated to Laos. The prioritisation process identifies where restoration of fish passage (ie. at which barriers) will have the most benefit. Criteria specific to the region have been devised so that the outcome gives best value for the people and biota of the Xe Champhone and Nam Ngum catchments.

Through the prioritisation process the barriers were ranked according to the impact that they are having on the fish communities of the Xe Champhone and Nam Ngum catchments and the cost and technical feasibility of rehabilitation of fish passage at each of the sites. This ranked list provides a guide to the places where targeted rehabilitation of fish passage will have the greatest benefit to the fisheries and local communities of the region. The list contains many significant barriers in the region, as well as a number of smaller barriers that while having less impact are cheaper and simpler to fix.

The prioritisation of barriers to migration that was undertaken in the Xe Champhone and Nam Ngum was adapted from a process that has been undertaken in a number of catchments in Tropical northern Australia (Moore and Marsden 2008, O'Brien et. al. 2010). The transfer of this process into the Lower Mekong Basin had a number of potential risks. The main issue was the limited access to suitable data and imagery. Currently much of the satellite imagery available in Lao P.D.R. is of a poor standard for the identification of barriers, however this situation is improving all the time, with future prioritisations likely to be significantly easier due to the availability of new imagery, including free imagery. It may be that in this prioritisation there are other high priority barriers that have not been identified, mainly due to the rapid pace of development and the delay in the availability of imagery meaning that often there are new barriers built that are just not present on any imagery. However by combining the imagery with new datasets and the knowledge of the local irrigation officials this risk has been minimised. The availability of datasets that have existing information on barriers is also limited in this region, but this is less problematic than for the imagery as this information only makes the processing of barriers easier and is not as critical as locating the barrier in the first place. Even with these limitations, the process was successfully implemented in the Lao P.D.R., providing the first barrier prioritisations in the Lower Mekong Basin. Through this we have demonstrated the potential for further application of the technique to other catchments throughout the region.

With the Xe Champhone and Nam Ngum prioritisations completed and a list of recommended sites for rehabilitation of fish passage available, Government Departments and NGOs can now move forward with an investment program that looks to source funds to implement options outlined for each structure in the priority list. It should be recognised that the list is a guide only and on-ground conditions may make some sites more or less achievable. For example some of the structures have funding for fish passage infrastructure already in progress and as such will be completed first, regardless of their ranking in this prioritisation. In all cases the feasibility of rehabilitation of a site should be investigated thoroughly prior to any design or construction investment being undertaken, to ensure that providing passage at the barrier maximises improvements for the fish community and also provides the most cost effective remediation for investors.

While the standard of the input imagery was sub-optimal in some areas, efforts were made to address this using local knowledge and input, which has been key to the success of this project and for any future on-ground works. Existing fishway technology used at barriers in Australian waterways is considered applicable to barriers on the Xe Champhone.

A data set now exists for all the barriers assessed in the project and a working list of the top priority barriers is available for future investment. Restoration of fish passage at these priority barriers will have the best outcome for fish populations and fisheries productivity, while being technically and financially feasible. The list should be used as a guide, depending on the resources and imperatives of the investor and further feasibility assessments are recommended before expenditure on design or construction for a particular site.

The prioritisation demonstrated what while there are hundreds of barriers within the Xe Champhone and Nam Ngum catchments, remediation of a small number of the highest priority barriers will significantly increase the habitat available to fish. By restoring fish passage to these priority sites, free passage between the Mekong River and the catchments, wetlands and floodplains of the Xe Champhone and Nam Ngum will be greatly enhanced, maximizing the fish habitat value of these systems and ensuring that the local communities of the Xe Champhone and Nam Ngum have access to healthy and productive fisheries.

7.2 Fishway design, construction and assessment

7.2.1 Refinement of fishway design criteria

Total catches

A total of 177 species were captured within the fishway over the four year assessment period (Appendix 1). Of these, 108 species were captured from these experiments from 7,525 individuals (Table 9). The most fish and species were captured from vertical slot fishway above any other experimental treatment. However, even when corrected for effort, fishermen caught more fish and species overall. Fishermen also caught the most unique species (those not seen in other treatments). The most abundant species were Cyprinids, *Crossocheilus atrilimes* (Siamese algae eater), *Thynnichthys thynnoides* (small scale barb) and *Rasbora autotaenia* (Pale rasbora). A red listed species, *Probarbus jullieni* (Julien's golden barb), was also collected. 34 species were represented by 10 individuals or less.

Fishway use by grey and white species

There were significantly more grey (mean = 5.9 grey species per block) than white (mean = 1.3) species using the fishways (χ^2= 10.77, df = 1, p = 0.001) and this difference was independent of whether the fishway was a vertical slot or a submerged orifice ($\chi^2_{ecology \times treatment}$ = 1.53, df = 2, p = 0.46). During the rainy season the Pak Peung regulator is largely operated to maximise runoff from the floodplain. Many floodplain species captured in fishway samples may have been displaced through the regulator during the course of gate operation.

Biomass, species richness, length

There was no difference in the catch, biomass, species richness per hour of effort (Table 10) between the treatments. Total abundances were largely similar among treatments (Table 10). The average number of species caught in the V-slot treatment was higher than the two submerged orifice (Table 10) treatments but the difference was not significantly different (p=0.069). Fewer species were captured from Submerged Orifice 15cm treatment, and none were unique. Many more species were captured from submerged orifice 30cm and vertical slot treatments and nine species were unique to those treatments. There was no significant differences in the median, 10th percentile or 90th percentile of lengths of fish using the three experimental fishway treatments. In general, larger fish were favoured by fishermen from day samples (Figure 9a) and smaller fish were collected from the vertical slot fishway at night (Figure 9b).

There was a significant difference in the relative abundance of fish communities between the three fishway treatments and the catch by fishermen in the same channel (Pseudo-F = 5.05, df = 3, 34, p < 0.0001). The fisherman caught a significantly different species assemblage to all of the fishway treatments (Pseudo-F $_{Vs\ V\text{-}S}$ = 7.53, df = 1, 9, p < 0.0001; Pseudo-F $_{Vs\ V\text{-}SO\ 15cm}$ = 6.54, df = 1, 9, p < 0.0002; Pseudo-F $_{Vs\ V\text{-}SO\ 30\ cm}$ = 8.13, df = 1,10, p < 0.0001).

Table 9. Total species caught from fishway optimisation experiments at Pak Peung regulator. For brevity, species will less than 10 individuals were omitted from the table. * indicates an IUCN red listing.

Species name	Fisherman	sub15	sub30	V-Slot	Grand Total
Crossocheilus atrilimes	25	437	621	548	1648
Thynnichthys thynnoides	341	572	118	260	1303
Rasbora aurotaenia	444	57	166	96	813
Parambassis siamensis	81	78	173	196	623
Hypsibarbus lagleri	372	34	34	31	471
Osteochilus lini	75	157	37	109	388
Clupeicthys aesiamnesis	0	0	1	0	366
Cyclocheilicthys repasson	329	16	4	0	349
Xenentodon cancilla	251	1	5	24	294
Puntius brevis	43	38	51	73	208
Parachela spp	9	14	43	56	163
Labiobarbus leptocheilus	109	25	21	3	158
Labiobarbus siamensis	78	6	14	3	101
Sikukia gudgeri	69	7	14	3	95
Puntoplites falcifer	46	3	8	3	60
Barbonymus schwanenfeldii	46	2	4	3	56
Raiamas guttatus	6	3	8	36	56
Osteochilus hasselti	29	13	0	1	43
Unknown 1	19	7	4	6	36
Rasbora steineri	1	2	16	12	34
Hampala dispar	11	4	7	1	23
Nemachellus spp	0	0	7	4	19
Rasbora daniconius	0	1	3	9	17
Henicorhynchus siamensis	9	3	0	4	16
Hypsibarbus wetmorei	13	0	0	0	13
Rasbora trileneata	0	0	5	3	12
Parachela oxygastroides	11	0	1	0	12
Homaloptera smithi	0	3	4	4	12
*Probarbus jullieni**	4	2	3	1	10
Grand Total	**2453**	**1496**	**1408**	**1515**	**7525**
No. Species	**37**	**34**	**42**	**42**	
No. Unique species	**5**	**0**	**5**	**4**	

The two main species contributing to the differences were *Crossocheilus atrilimes* (unnamed), which made up half of fishway abundances but less than 2% of fishermen's catch (Table 4). Contrarily, *Rasbora aurotaenia* (Pale Rasbora) was more abundant in fishermen's catch than the fishway treatments (Table 11).

The fisherman caught a significantly different species lists to each of the fishway treatments (Pseudo-F $_{\text{Vs V-S}}$ = 5.95, df = 1, 9, $p < 0.0001$; Pseudo-F $_{\text{Vs V-SO 15cm}}$ = 3.83, df = 1, 9, $p < 0.002$; Pseudo-F $_{\text{Vs V-SO 30 cm}}$ = 4.91, df = 1,10, $p < 0.0001$). The two most important species contributing to the differences were *Cyclocheilichthys repasson* (unnamed Silver Cyprinid) and *Thynnichthys thynnoides* (Tiny scale barb), which were collected much more frequently by fishermen than caught within the fishway (Table 12).

Fish community comparisons among fishways

Overall, there was a significant difference in the CPUE assemblages of species collected by the three treatments (Pseudo-F = 1.54, df = 2, 28, $p = 0.045$). When comparing the CPUE in the three treatments pair by pair, it was clear that the V-slot treatment collected different species and abundances to the submerged orifice 15cm treatment, (Pseudo-$F_{V\text{-}slot\ Vs\ submerged30}$ = 2.30, df = 1,14, p <0.02) whilst the submerged orifice 30cm Fishway collected species assemblages and abundances that were not different to either the submerged orifice 15 cm or V-Slot treatments (p > 0.19). Four key species were identified as contributing to the difference between the 15 cm SO and the VS fishway catch (Table 13).

There was a highly significant difference in the species assemblages present in the three Fishway treatments overall (Pseudo=F = 1.92, df = 2, 28, p < 0.002). The Submerged orifice 15 cm and Submerged orifice 30 cm treatments did not pass significantly different assemblages to each other (Pseudo-F = 1.02, df = 1, 14, p = 0.375), but passed significantly different species assemblages than the V-Slot treatment (Pseudo-$F_{V\text{-}Slot\ Vs\ Submerged\ 15}$ = 2.96, df = 1, 14, p < 0.0001; Pseudo-$F_{V\text{-}Slot\ Vs\ Submerged\ 30}$ = 1.90, df = 1, 14, p < 0.01). Major species identified as contributing to the overall differences in shared species list between the treatments include *Raiamas guttatus* (Pale Rasbora), and *Puntius brevis* (Swamp barb). These both occurred in more samples in the V-Slot treatment than either of the submerged orifice treatments (Table 14).

7.2.2 Preliminary Discussion

Comparing three different fishway designs simultaneously, using actively migrating species, provided a rapid assessment of potential for wider rollout in the Lower Mekong Basin. Each design successfully passed a diverse range of fish species and size classes providing confidence that fishways will be an effective solution to help restore passage at floodplain regulators. Importantly, assessing several different designs simultaneously provided information that is applicable to a range of situations. Thus, the study has now led to the understanding that several feasible fishway options could be applied, depending on the site characteristics and local species.

In general, more fish and species ascended the vertical slot fishway. Vertical slot fishways are generally more successful at passing a larger diversity of fish species than pool and weir type fishways (Schwalme and Mackay 1985). Vertical slot fishways have several advantages over other designs. Firstly, is increased operational range (Stuart et al. 2008). Providing a vertical slot, rather than an orifice enables headwater levels to fluctuate more widely without greatly influencing internal hydraulics. Vertical-slot fishways can therefore be constructed at sites which have more variable headwater and tailwater ranges (Barrett and Mallen-Cooper 2006). Such hydrological flexibility is a critical consideration for providing fish passage in the Lower Mekong Basin, which has water levels which can vary by over ten vertical meters between the rainy and dry seasons (Kite 2001). Secondly, vertical slot fishways can provide passage for higher fish biomass because there is a greater slot area for fish to navigate (Clay 1995). Passing high fish biomass is an extremely important consideration for the Lower Mekong Basin considering the highly diverse range of species observed attempting to gain passage. Thirdly, vertical slot fishways can pass much larger fish, as there is no restriction based on the physical orifice size if an appropriate slot width is selected. Having capacity to provide passage for larger species is of extreme importance especially from an economic and social point of view. Many larger species have higher potential to both generate income and also provide nutrition outcomes (Jensen 2001).

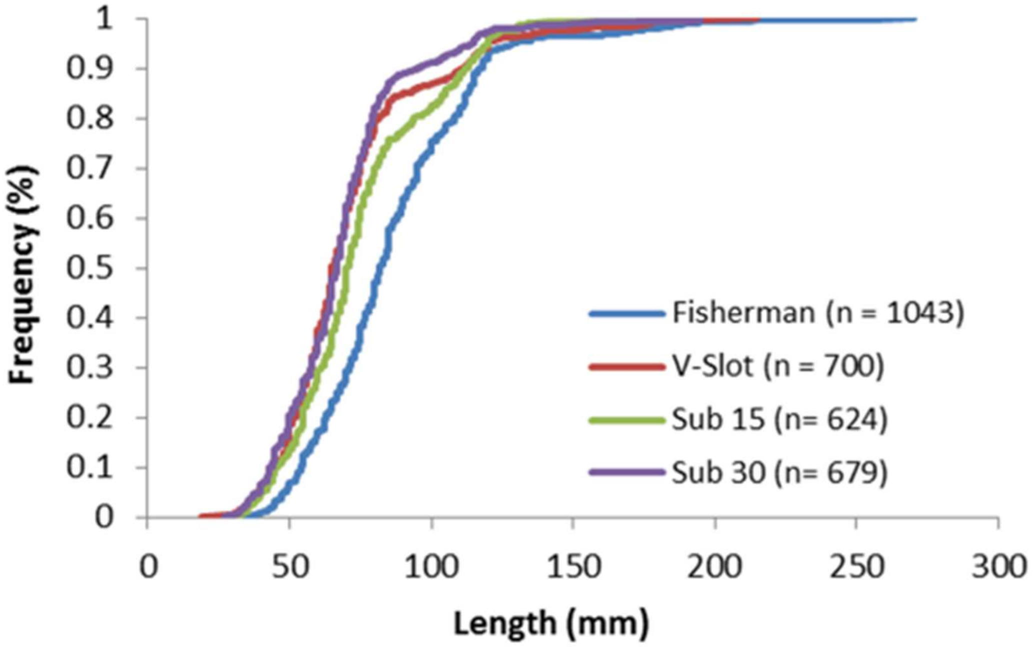
When selecting a fishway that is seeking to rehabilitate a depleted fishery, it is important to understand local fisher behaviour, expectations and species preference. Essentially, fish passage rehabilitation is as much about generating social outcomes as it is rehabilitating depleted fisheries. Involving fishers in the design, construction and assessment process is therefore an important consideration to ensure local knowledge is captured (Valbo-Jørgensen and Poulsen 2000). Our study revealed that fishers have a preference for targeting larger fish. Fishermen deploy specific gear types aimed at maximising catches of migrating fish downstream of regulator sites (Bouakhamvongsa et al. 2006). Larger fish have an economic value and provide more food and are hence targeted by fishers. The fishway was designed to pass a range of species and size classes irrespective of large or small. So whilst the size range was within expected design limits, local fishers expressed a preference to see much larger species gaining passage.

Vertical slot and submerged orifice fishways also have different discharge and turbulence profiles (Tarrade et al. 2008). Although all fishways were assessed on the same physical gradient, subtle changes in the orifice and slot areas will have influenced both discharge and hence cell turbulence. All designs contained an average slot or orifice velocity of 1.4 $m.s^2$. But turbulence profiles greatly differed between vertical slot (14 $watts.m^3$), submerged orifice 15 (45 $watts.m^3$) and submerged orifice 30 (178 $watts.m^3$) because discharge varied. Essentially this determined that both the vertical slot and submerged orifice 15 replicates had lower turbulence, but submerged orifice 30 had higher attraction flows.

The relationship between discharge, turbulence and attraction is difficult to resolve. High attraction is desirable to attract more fish to the fishway, but low turbulence is required to maximise passage, especially for small fish (Liu et al. 2006). It is a fundamental principle that if fish cannot find the entrance, then passage will not be possible (Clay 1995). The issue of reduced attraction efficiency can therefore be largely resolved by improved entrance location placement. Optimal design becomes an issue of trade off's. If entrance location is optimised, then slot or orifice selections can be based on local ecology. If many large fish are expected to migrate, or if the site has a wide operational headwater range, then a vertical slot may be an optimal solution as it will provide greater flexibility with respect to fish size. If the migratory population is focused towards small benthic species, then a submerged orifice fishway may suffice. In our study, there was no single fishway which generally performed better than another. So this provides flexibility when selecting suitable fishway options at a site. The physical site characteristics can be considered along with a knowledge of local species and hydrology. An optimal design can then be selected in consultation with biologists, engineers and developers.

Figure 9. Cumulative length distribution plots (pooled across all species) for each treatment for (a) day and (b) night samples. The total number of fish measured is provided in parentheses.

(a)



(b)

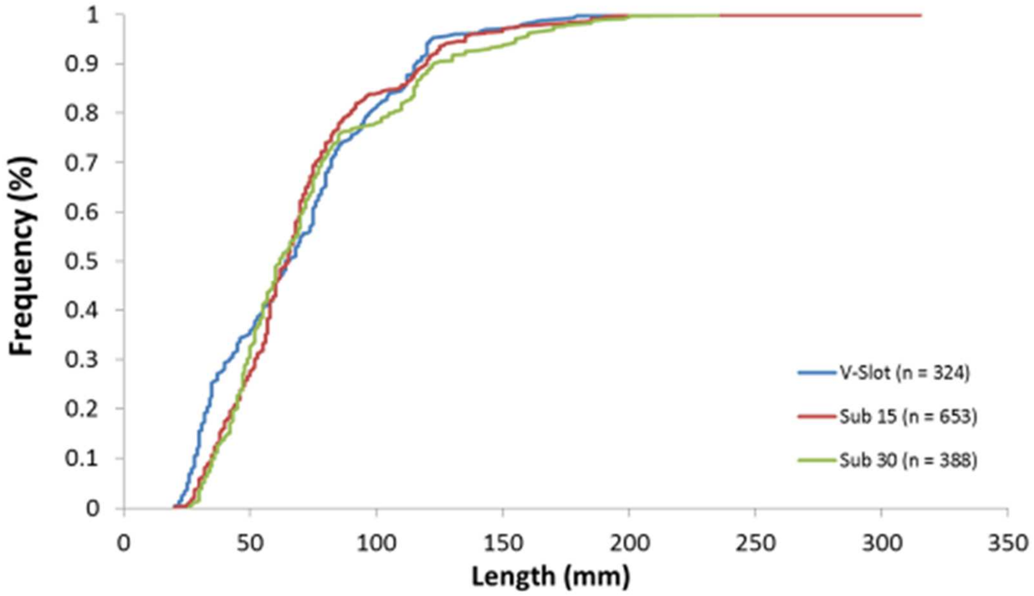


Table 10. Comparison of univariate fish statistics between a vertical slot and two submerged orifice fishways at Pak Peung experimental Fishway in 2012.

Fish response	Treatment mean			ANOVA		
	V-Slot	sub15	sub30	F	df	P>F
Loge Biomass/Hour	0.57	0.56	0.47	0.97	2,28	0.3901
Loge Catch/Hour	4.36	4.03	4.32	0.18	2,28	0.8325
Species Richness/Hour	4.91	4.28	3.67	2.16	2,28	0.1388
10th percentile of fish length (mm)	46.3	54.9	50.3	1.23	2,28	0.3069
Median fish length (mm)	66.8	71.6	66.9	1.08	2,28	0.3549
90th percentile of fish length (mm)	99.3	94.4	90.8	0.51	2,28	0.6079

Table 11. Fish species whose differences in abundances contributed substantially to overall similarity differences (using SIMPER procedure) between the Vertical Slot and submerged 15cm orifice fishway cm in Pak Peung Experimental fishway in 2012. Values are the average log(X+1) abundance recorded in that treatment type.

Species	V-Slot	Submerged 15
Crossocheilus atrilimes	2.29	1.97
Rasbora aurotaenia	1	0.55
Parachela spp.	0.73	0.18
Raiamas guttatus	0.65	0.07

Table 12. Fish species that occurred disproportionately (using SIMPER procedure) between the three Vertical Slot Fish way treatments in Pak Peung Experimental fishway in 2012. Values are the proportion of samples that the species was collected in. Values in brackets are when the proportion of occurrence was not a substantial contributor to differences between the other treatments.

Species	V-Slot	Submerged 30	Submerged 15
Raiamas guttatus	0.8	0.25	0.13
Puntius brevis	0.67	(0.56)	0.47

Table 13. Average relative abundance (% of all catch) of species whose relative abundance made a substantial contribution (using SIMPER procedure) to differences in composition between fishermen's catch and the experimental fishway at Pak Peung in 2012.

Species	Fishermen	V-Slot	Submerged 15	Submerged 30
Crossocheilus atrilimes	2.0	48.3	49.7	51.9
Rasbora aurotaenia	14.8	7.0	6.5	9.3

Table 14. Proportion of samples occurred in by species whose presence made a substantial contribution (using SIMPER procedure) to differences in composition between fishermen's catch and the experimental fishway at Pak Peung in 2012. Values in brackets are when the proportion of occurrence was not a substantial contributor to differences between the other treatments.

Species	Fishermen	V-Slot	Submerged 15	Submerged 30
Cyclocheilichthys repasson	1.00	0.00	(0.46)	0.29
Thynnichthys thynnoides	0.77	(0.31)	0.15	0.14

7.2.3 Assessment of a permanently constructed fishway

A total of 36,240 fish from 99 species were collected over the 18 block sampling period. More fish were collected during the day (n = 19,119) than at night (n = 17,121). More individual fish and species were captured from bottom samples during the day than at the top at night. Twenty five species were only collected from night samples, whilst only four were uniquely collected during the day. Of the exclusive night migrators were key catfish species *Wallago attu*, *Hemibagrus wyckoides, Pangasius macronema Mystus albolineatus, Mystus atrifasciatus, Mystus mysticetus, Mystus singarian* and *Ompok bimaculaus.* None of these were collected during the day. Twenty one species were only collected from the bottom, whilst only three species were uniquely collected at the top.

The number of species collected was significantly higher during the day (average 23.7 species per set) than the night samples (average = 19.8; F = 8.53, df = 1, 49, p <0.001) and significantly higher at the top (24.7) than the bottom (18.8) (F = 18.9, df = 1, 49, p < 0.0001) of the fishway (Figure 10). Time of sampling and location effects were independent of each other ($P_{location \times time}$ = 0.595).

The biomass per unit effort was significantly higher during the day (mean Loge(X+1) biomass = 4.8 kg/hour) than night sampling (2.35 kg/hour) (F = 30.8, df = 1, 49, p <0.0001), but not affected by location of the trap (P > 0.23).

There was a significant interaction of time of sampling and location of the fishway trap on the CPUE ($F_{location \times time}$ = 4.3, df = 1, 49, p <0.04). More fish were collected from the fishway bottom than the top. More fish were also collected from day samples than at night (Figure 1). However, the average of the log (X+1) transformed number of fish per hour of operations at the fishway bottom during the day (mean = 3.42) was significantly greater than all of the other treatment combinations, which were not different from each other (means; Top_{day} = 1.81; $Bottom_{night}$ = 1.32; Top_{night} = 0.86).

Fish at the top of the fishway were significantly longer than at the bottom (Average difference after partitioning the effect of random blocks = 13.8 mm; Table 15). 10% of fish collected in the bottom location were 43.9 mm or less, but at the top the smallest 10% of fish were 52.8 mm or less, whilst 10% of fish at the top of the fishway were 141.5 mm or more, compared to 125.1 mm or more at the bottom (Table 15). These observations suggest that there are some smaller individuals which were unable to ascend the fishway.

Community assemblage differences

The differences in the assemblage of fish CPUE between the top and bottom samples was dependent on whether the samples were taken during the day or night (Pseudo-$F_{Location \times Time}$ = 2.08, df = 1, 15, $p < 0.05$) (Figure 11). Follow up pairwise comparisons found that all four combinations of top and bottom and day and night samples had significantly different CPUE assemblages to each other (all comparisons, $p < 0.01$). The highly abundant *Parambassis siamensis* was always more abundant at night than during the day and at the bottom compared to the top, whereas *Rasbora aurotaenia* was always more abundant during the day, and at the top rather than the bottom (Table 16).

Figure 10. Average log_e(CPUE+1) of fish in the Pak Peung Fishway. Averages with the same letter are not different after Scheffe' correction for multiple comparisons.

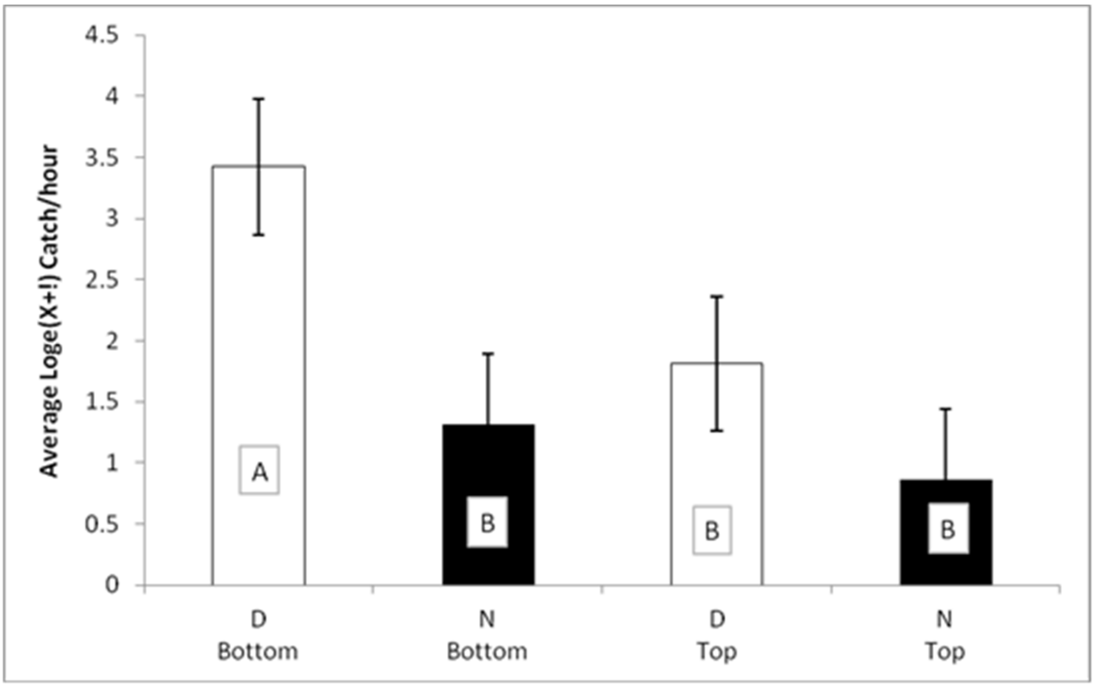


Figure 11. Multi-dimensional scaling ordination of fish communities captured during top (blue), bottom (green), day (hollow), night (solid) sampling within the Pak peung fishway.

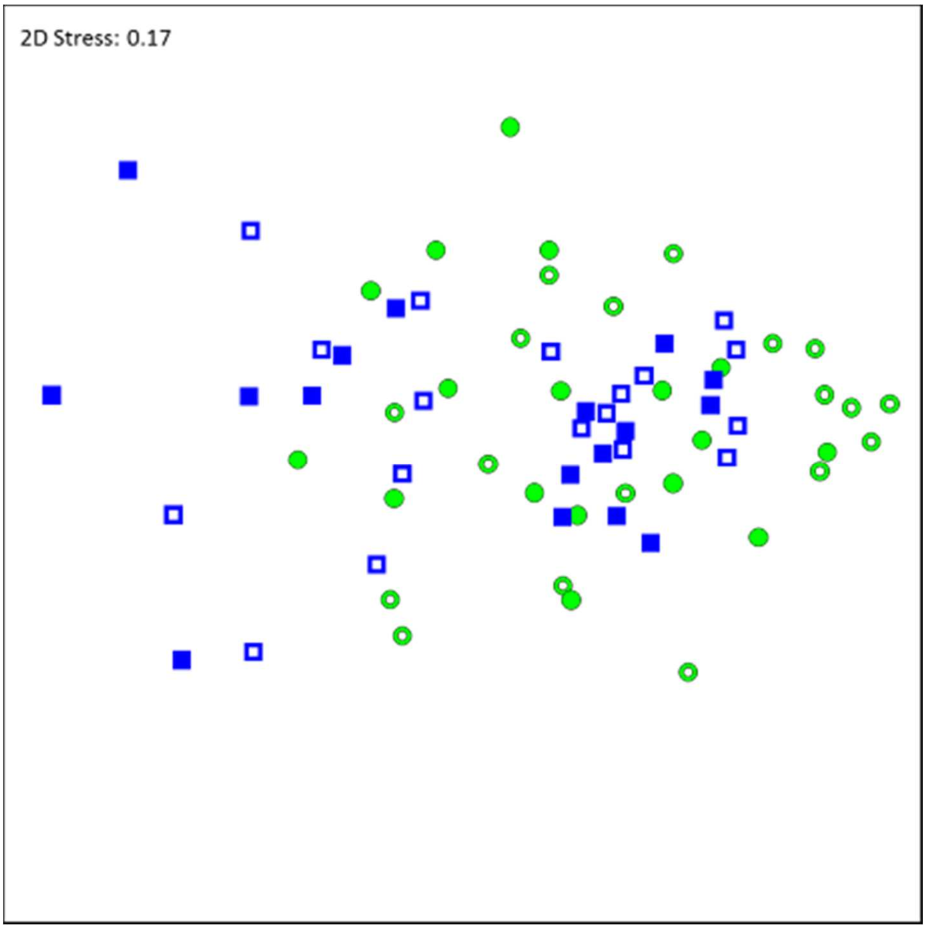


Table 15. Comparison of length statistics of fish collected at the top and bottom of the fishway at Pak Peung in 2012.

	ANOVA			Size (mm)	
Length statistic	F	df	p-value	Bottom	Top
10th percentile	27.2	1,49	<0.0001	43.9	52.8
Median	27.77	1,49	<0.0001	66.8	80.0
90th Percentile	7.66	1,49	<0.01	125.1	141.5

Table 16. Average CPUE for fish species identified (SIMPER) as contributing substantially to differences in fish CPUE between day and night and top and bottom samples at Pak Peung in 2013. Values in brackets are when the CPUE was not a substantial contributor to differences with the other treatments.

Species	Day Top	Night Top	Day Bottom	Night Bottom
Parambassis siamensis	1.92	1.48	2.92	2.19
Rasbora aurotaenia	1.03	0.83	0.82	0.3
Labiobarbus leptocheilus	0.84	0.49	(0.35)	0.21
Puntius brevis	0.61	0.66	1.01	(0.51)
Xenentodon sp.	0.75	0.47	(0.89)	(0.57)

7.2.4 Preliminary Discussion

A wide range of species and size classes were able to ascend the fishway. There were clear diel differences in movement rates and more species and individuals were collected from the bottom compared to the top. But overall the work demonstrated that construction of a fishway, based on a prior knowledge of swimming abilities of local species, provided successful passage for the majority of a very diverse riverine Mekong fish community. But the migratory behaviour of individual species was complex, comprising a mix of fish with exclusive day and night preferences across a range of difference swimming abilities.

These observations suggest that whilst the fishway was successful, it could not provide passage for all species and size classes attempting to migrate. An important realisation was that fishways cannot be expected to fully mitigate the impacts of the regulator. The decision to retrofit a fishway (a) recognises the need to provide fish passage because the barrier is having some impact and (b) accepts that return to unmodified conditions is unfeasible. The challenge is then to develop the best solution possible given the site characteristics and the available budget for the known migratory population (Noonan et al. 2012). The only way to fully restore fish passage is to remove the barrier altogether, but in some instances this is simply not feasible (Kemp and O'Hanley 2010). Where barrier removal is sub-optimal, then fishway operation will need to be customised to maximise passage of local species. For instance, the observation that most species were migrating during daylight hours suggests that any operational considerations should maximise fish passage during this time. But there were also twenty five species which were only collected at night which suggests two important points.

Firstly, that sampling activities confined to daylight hours alone would have failed to adequately capture all fish attempting to ascend the fishway. It further indicates that unless fish are able to ascend the entire fishway during daylight hours then successful passage may not be possible. Fishway design can be altered to deal with this issue. Many fishways now contain resting pools (Barrett and Mallen-Cooper 2006). These are areas where velocity and turbulence are substantially reduced and require less energy expenditure to ascend. Although the existing fishway contained resting pools, there was no sampling conducted to determine overall effectiveness. Further, flushing the fishway early in the morning would have prevented these species from ascending. Understanding whether these species, were present in resting pools, and would have continued migrations during daylight hours is a strong priority for further work.

Secondly, it suggests that there are a number of species which exclusively move at night. Diel changes in fish migration rates are common (Nunn et al. 2010), but are not widely reported from the Lower Mekong Basin. Understanding diel variations in movement rates are important to ensure all migratory species are able to successfully pass. Of particular interest are catfish species, which were exclusively captured at night. Catfish species are important from both a social and economic perspective (Baird et al. 2004). The exclusive observations of catfish species at night suggest that fishway operations could be optimised to facilitate passage. For instance, increased night-time discharges could facilitate attraction and would be a worthwhile focus of future research.

Length data indicated that not all very small species could ascend. In fact, the mean length of fish successfully reaching the exit were much larger than bottom samples. Passing very small fish is a design characteristic that can be managed with construction principles. Small fish require lower velocities and turbulence to ascend (Mallen-Cooper et al. 2008). Providing larger cells, reducing overall discharge or retrofitting dissipators are all effective means of reducing turbulence. Such solutions are known to substantially pass greater numbers of small fish (Mallen-Cooper et al. 2008). There are ecological trade-offs however. Many of these solutions can have adverse effects on attraction and this reduce passage rates of large species. The challenge in fishway design is to identify an ecological target for the final structure and ensure that construction principles or operations protocols are sufficient to achieve overall objectives.

There are several operational guidelines that can serve to maximise operation of the existing fishway. Firstly, the fishway should be operated at highest possible discharge at night during periods of peak catfish migration. That would decrease small fish passage but would maximise the passage of economically important species into the wetland thus maximising social outcomes given the preference of locals to catch and consume catfish species. Secondly, during periods of decreased large fish passage, addition of dissipators or volitional decreases in discharge would maximise small fish migration. These operational issues would be best discussed in a community co-management context where the local villagers take ownership of the fishway and local fisheries assets.

7.2.5 Fishway optimisation

A total of 25,275 fish from 88 species were captured during the study. More individuals were collected from the bottom (n = 14,995) than at the top (n = 7,852) or the culvert (n = 2,428) (Table 17). Species composition differed among treatments (bottom = 64; top = 66; culvert = 59) and some were unique to each. For example, nine species were captured from the bottom and not the top or culvert; eight were captured at the top, and not the bottom or culvert; and six were captured at the culvert but not the bottom or top.

The number, biomass and species richness of fish collected per hour showed a gradual decline from the bottom of the fishway to the top and then the culvert (Figure 4). Statistical tests found that there were more fish and more species of fish collected per hour in the Bottom than either the Top or Culvert locations (F_{CPUE} = 12.6, df = 2, 44, p < 0.0001; F_{SPUE} = 19.2, df = 2, 45, p < 0.0001). The biomass per hour of fish collected at the Top, Bottom or Culvert treatments were not statistically significantly different to each other (F_{BPUE} = 1.9, df = 2, 44, p = 0.161).

There was a difference in the 10th percentile and median lengths of fish between the three fishway trap locations (Table 8). Fish getting up the fishway tended to be larger than at the bottom of the fishway (Figure 12). The smallest 10% of fish at the bottom were significantly shorter than at the top of the culvert (Table 17). The Median length of fish at the bottom was also shorter than at the Top or in the Culvert (Table 18). The largest 10% of fish was not statistically significantly different between the three locations.

Table 17. Total abundances of each species captures within the fishway from bottom, top and culvert locations. Species are sorted in descending order.

Species name	Bottom	Top	Culvert	Grand Total
Parambassis siamensis	5188	3832	466	9486
Clupeichthys aesarnensis	4300	130	0	4430
Sikukia gudgeri	791	910	355	2056
Rasbora borapetensis	785	486	49	1320
Xenentodon sp.	677	482	135	1294
Parachela spp	452	282	139	873
Rasbora aurotaenia	166	185	282	633
Puntius brevis	289	79	61	429
Puntioplites falcifer	240	81	68	389
Amblyrhynchichthys micracanthus	91	219	45	355
Hampala dispar	202	54	61	317
Rasbora trilineata	235	51	1	287
Barbonymus altus	74	142	43	259
Yasuhikotakia lecontei	81	160	6	247
Tenualosa thibaudeaui	29	210		239
Rasbora daniconius	177	37	20	234
Labiobarbus leptocheilus	17	25	189	231
Osteochilus hasselti	175	34	5	214
Mystacoleucus marginatus	103	74	7	184
Cyclocheilichthys lagleri	36	16	131	183
Parachela siamensis	37	23	81	141
Probarbus jullieni	101	20	17	138
Puntius partipentazona	103	20	2	125
Puntius orphoides	85	30	0	115
Macrognathus semiocellatus	108	1	3	112

Species name	Bottom	Top	Culvert	Grand Total
Crossocheilus atrilimes	35	37	30	102
Hypsibarbus lagleri	18	5	48	71
Acanthopsoides hapalias	30	15	12	57
Oreochromis niloticus	36	7	12	55
Raiamas guttatus	36	11	2	49
Hampala macrolepidota	30	9	9	48
Scaphognathops stejnegeri	20	22	5	47
Paralaubuca typus	6	40	0	46
Macrognathus siamensis	38	3	3	44
Poropuntius normani	35	3	3	41
Henicorhynchus ornatipinnis	7	27	6	40
Thynnichthys thynnoides	14	15	10	39
Esomus metallicus	16	1	19	36
Trichopsis vittata	1	0	32	33
Hypsibarbus malcolmi	14	6	7	27
Osteochilus lini	0	3	18	21
Henicorhynchus siamensis	10	1	4	15
Pseudolais pleurotaenia	3	11	1	15
Parasikukia maculata	15	0	0	15
Puntius proctozystron	9	6	0	15
Nandus oxyrhynchus	12	3	0	15
Acanthopsis spp	3	7	4	14
Mastacembelus armatus	12	1	1	14
Amblypharyngodon chulabhornae	2	5	6	13
Auriglobus nefastus	10	0	0	10
Lepidocephalichthys hasselti	9	1	0	10
Pristolepis fasciata	1	1	7	9
Chitala ornata	8	0	0	8
Homaloptera smithi	0	8	0	8
Mastacembelus favus	5	1	1	7
Notopterus notopterus	0	2	3	5
Mystus singaringan	0	3	1	4
Puntius aurotaeniatus	2	1	1	4
Cyclocheilichthys siaja	0	0	4	4
Mystus mysticetus	0	1	3	4
Trichopodus microlepis	2	0	1	3
Badis ruber	3	0	0	3
Henicorhynchus lobatus	0	2	1	3
Channa striata	2	1	0	3
Oxyeleotris marmorata	1	1	1	3
Rhinogobius mekongianus	2	0	0	2
Osteochilus waandersii	1	0	1	2
Trichopodus trichopterus	0	2	0	2
Hypsibarbus wetmorei	2	0	0	2
Clarias sp. (cf.batrachus)	2	0	0	2

Species name	Bottom	Top	Culvert	Grand Total
Hemibagrus spp	0	0	1	1
Cyprinus carpio	0	1	0	1
Trichopodus pectoralis	1	0	0	1
Mystus multiradiatus	0	0	1	1
Channa micropeltes	0	1	0	1
Oxygaster pointoni	0	0	1	1
Cyclocheilichthys enoplos	0	1	0	1
Labeo chrysophekadion	0	0	1	1
Clarias gariepinus	0	1	0	1
Ompok bimaculatus	0	0	1	1
Mystacoleucus ectypus	0	1	0	1
Channa gachua	0	1	0	1
Opsarius koratensis	0	1	0	1
Hemibagrus spilopterus	0	0	1	1
Grand Total	**14995**	**7852**	**2428**	**25275**

Figure 12. Cumulative distribution functions for fish lengths comparing culvert (red), top (green) and bottom (blue) treatments.

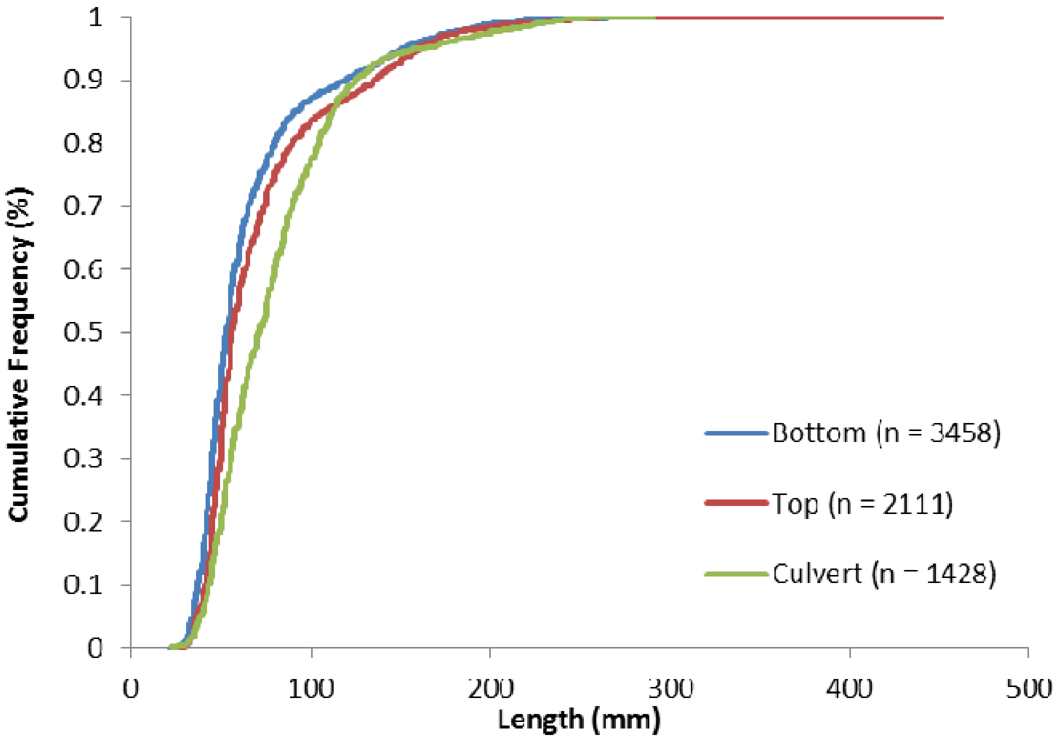


Table 18. Comparison of length statistics of fish collected at the bottom, top, and culvert of the fishway at Pak Peung in 2014. Shaded cells indicate lengths that are not statistically significantly different to each other.

Length statistic	ANOVA			Size (mm)		
	F	df	p-value	Bottom	Top	Culvert
10th percentile	8.5	2,44	<0.001	37.7	41.6	54.6
Median	2.35	2,44	<0.01	57	64.6	77.4
90th Percentile	0.7	2,44	0.51	121.9	130.4	131.8

There was a significant difference in the CPUE species assemblage between the three fishway trap locations in 2014 (Pseudo-F = 5.2, df = 2, 44, p < 0.0001) (Figure 13). Species assemblages in all three locations were different to each other (Pseudo-$F_{\text{Culvert V Bottom}}$ = 6.5, df = 1, 21, p < 0.0001; Pseudo-$F_{\text{Bottom V Top}}$ = 3.3, df = 1, 22, p < 0.0001; Pseudo-$F_{\text{Culvert V Top}}$ = 5.1, df = 2, 22, p < 0.0001). Not all species contributing to difference were collected in higher abundance from bottom samples. *Xenentodon* spp were actually sampled in higher relative abundances from top samples (Table 19).

There was a significant difference in the list of species between the three fishway trap locations in 2014 (Pseudo-F = 4.4, df = 2, 44, p < 0.0001). Species assemblages in all three locations were different to each other (Pseudo-$F_{\text{Culvert V Bottom}}$ 5.8, df = 1, 21, p < 0.0001; Pseudo-$F_{\text{Bottom V Top}}$ = 2.9, df = 1, 22, p < 0.0001; Pseudo-$F_{\text{Culvert V Top}}$ = 4.2, df = 2, 22, p < 0.0001).). SIMPER revealed that all species contributing to significant differences among treatments were all more abundant from bottom treatments than all others (Table 20).

There was a significant block effect (Pseudo-F = 4.27, df = 24, 44, p < 0.001), which was also dependent on treatment (Pseudo-F = 2.53, df = 2, 44). Successful ascents throughout the entire fishway, and through the culvert, were strongly associated with head differential. There was sufficient airspace between the water surface and culvert ceiling up until the completion of Block 7 (Figure 14). Successful passage through the culvert was highest during this period (Figure 15). The culvert became inundated after block 8 and culvert fish catches dropped substantially (Figure 15). Beyond block 8, higher catches were still evident in both top and bottom samples suggesting that fish continued to migrate throughout the experimental period, but were unable to negotiate the culvert.

Figure 13. Differences in abundance, biomass and species richness of fish collected at the top, bottom and culvert of the fishway at Pak Peung in 2013. For each response, columns with the same letters are not significantly different.

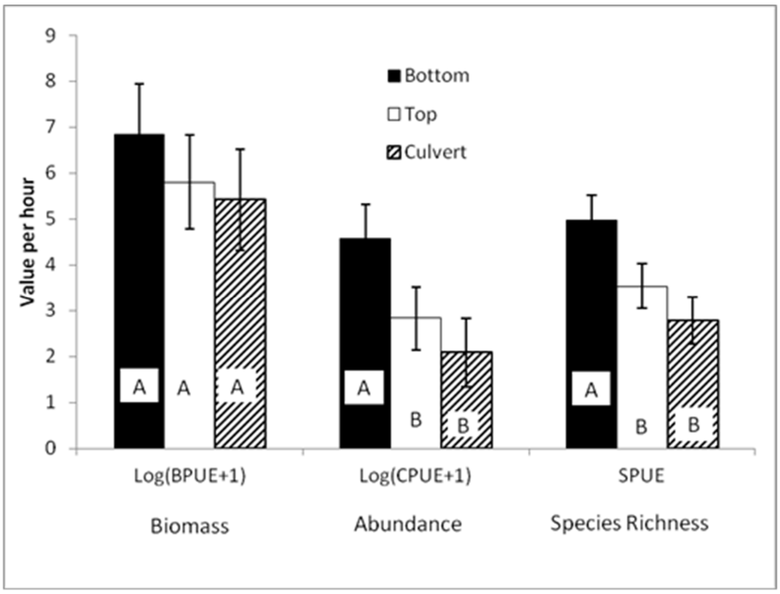


Table 19. Average CPUE for fish species identified (SIMPER) as contributing substantially to differences in fish CPUE between bottom, top and culvert samples at Pak Peung in 2014. Values in brackets are when the CPUE was not a substantial contributor to differences with the other treatments.

Species	Bottom	Top	Culvert
Parambassis siamensis	2.89	2.4	0.9
Sikukia gudgeri	1.35	1.06	0.49
Xenentodon sp.	1.14	1.2	0.45
Parachela spp.	1.15	0.71	(0.41)

Table 20. Proportion of samples occurred in by species whose presence made a substantial contribution (using SIMPER procedure) to differences in composition between the Bottom, Top and Culvert samples in the experimental fishway at Pak Peung in 2014. Values in brackets are when the proportion of occurrence was not a substantial contributor to differences between the other treatments.

Species	Bottom	Top	Culvert
Macrognathus semiocellatus	0.65	0.04	0.13
Probarbus jullieni	0.83	0.37	0.35
Raiamas guttatus	0.65	0.30	0.04
Rasbora daniconius	0.70	0.37	0.22
Rasbora borapetensis	0.65	0.30	0.26
Puntius partipentazona	0.61	0.15	0.09
Parachela spp	0.78	(0.52)	0.39
Mystacoleucus marginatus	0.65	(0.63)	0.13
Rasbora trilineata	0.74	0.56	0.04
Sikukia gudgeri	0.87	(0.78)	0.39
Yasuhikotakia lecontei	0.63	0.04	(0.04)

Figure 14. Headwater and tailwater levels measured at the completion of each block for the duration of the study.

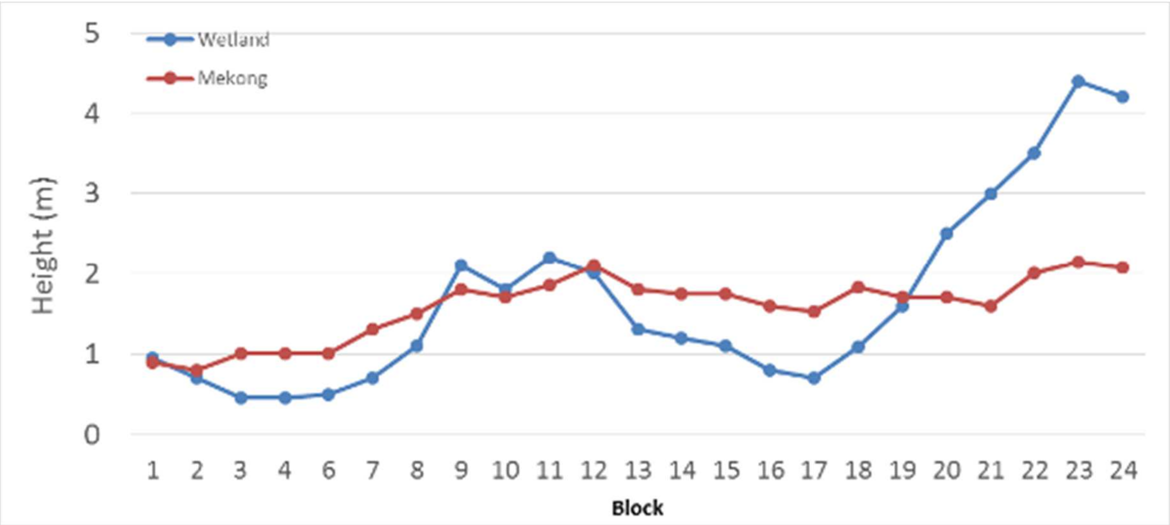
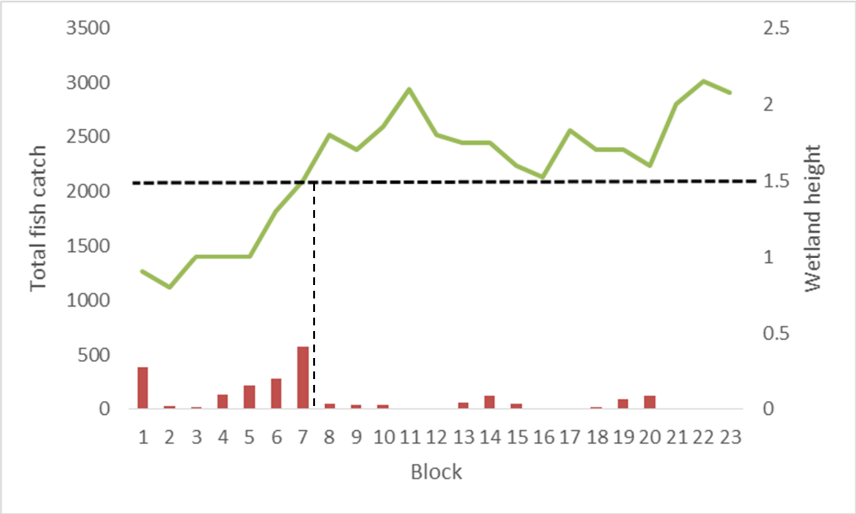
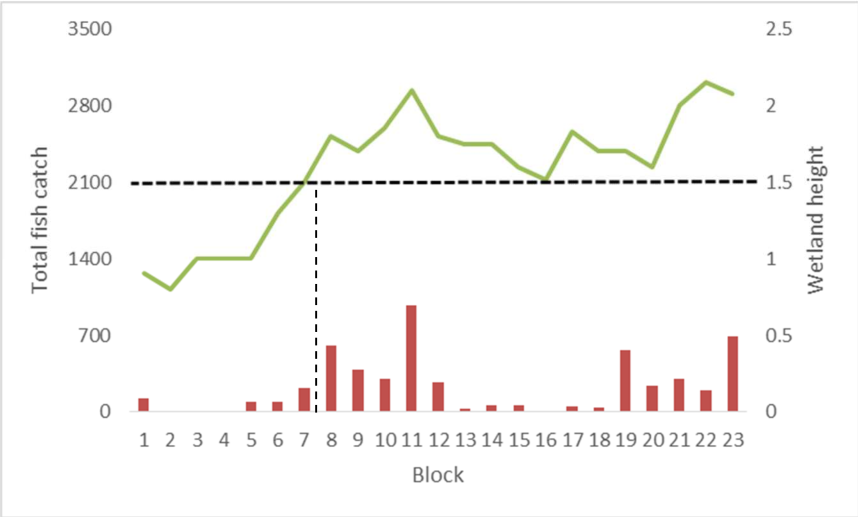


Figure 15. Total abundance of fish caught within each treatment (a = top, b= bottom and c = culvert) with respect to head differential across the fishway exit. The horizontal dotted line refers to the point where the road culvert became inundated by headwater. The vertical dotted line depicts the block where inundation occurred. Wetland height is depicted by the solid green line.

a) Culvert



b) Top



c) Bottom

7.2.6 Preliminary Discussion

Several aspects of fishway design which will greatly advance the ability to pass Lower Mekong species were determined by this study. It validated previous claims that fishways can provide opportunities for fish to move between the Mekong River and regulated floodplains. It further demonstrated that not all species which entered a permanent demonstration fishway were able to ascend. Strong evidence was also gathered which suggests Mekong species are reluctant to migrate through a culvert, especially when exposed to a high operating head.

High species diversity through the fishway provided further confidence that connectivity between the Mekong River and its floodplain is possible with well-designed engineering solutions. Preliminary investigations provided the preliminary design criteria needed to increase confidence in fishway technology (Baumgartner et al. 2012). So the permanent fishway at Pak Peung provided the first opportunity to scale in-situ fish passage experiments up to a fully functioning fishway. Large numbers of fish reached the exit which suggested that the process was successful. But bottom catches were high and comprised many small fish.

Observations that not all fish could ascend are consistent with the assertion that fishways are not a perfect solution (Bunt et al. 2012). The best mechanism to reinstate fish passage at a given site is weir removal, which is not always feasible. Providing effective fish passage is then dependent on the available budget, site topography and knowledge of migratory species. Many small individuals were collected from bottom samples suggesting that hydraulics may have been unsuitable. But such observations are a key component of adaptive management. The current study has provided important insights which can be applied to future works such as identifying solutions suitable for small-bodied species. These could occur through more conservative design criteria such as reducing slope, decreasing discharge or increasing pool size. All are key criteria which can improve small bodied species passage.

A further knowledge advance was understanding fish interactions with culverts. The drop in culvert fishway catches upon inundation suggests that many species are sensitive to changes in internal hydraulics. Through the same time period, high species diversity and abundance was observed at the fishway top and bottom, suggesting that fish continued to migrate. Furthermore, more species and higher abundances were captured at the culvert exit prior to inundation, indicating that head differential has a substantial influence on passage success, rather than other factors associated with culverts. Culvert inundation fundamentally changes the flow regime. Best practice guidelines for culvert passage suggest that culverts must (a) flow at depths less than full flow and (b) have entrance and exit conditions that are relatively constant to maximise fish passage opportunities (Evans and Johnston 1980). The implications of this for the Pak Peung fishway are that it will provide sub-optimal passage into the wetland during particularly high headwater events.

Culvert-related fish passage issues could be resolved by replacement with a larger unit that can cope with an increased head differential. There is a limited window for this to occur. There are currently plans underway to seal the entire road above the culvert which will require substantial earthworks. A proposal could be put to the road constructing authority to upgrade the existing culvert during the works process. Fish passage could also be optimised through operational means. Headloss across the culvert could be managed by manipulating water levels within the wetland. The Pak Peung regulator serves to keep water levels low early in rainy season to prevent rice crop inundation. Such operational measures will serve to maximise fish passage opportunities because a low wetland level will ultimately result in acceptable culvert conditions provided inundation does not occur. Ensuring that culvert inundation is included in the development of any community co-management strategy will be important to optimise fishway operations over the long term.

7.3 Socio Economic Results and Discussion

Detailed results have been prepared for publication and the draft manuscript has been submitted. A short synopsis of key results are presented here.

The pre-fishway study confirmed that fishing is a major livelihood activity for villages around Pak Peung wetland with a wide range of fish species harvested. People fish for at least 10 hours or more per week and up to 60 hours/week or longer during the dry season. Villagers fish at 14 locations in the wetland but mostly at five locations. Women fish closer to the villages and less often than men. The estimated total catch per day from the 14 locations and 81 households was 3,117kg. Individual catches per day varied from 0.5kg to 12kg (average 3kg) depending on fish species and sizes. Most fish are consumed by the household or given to relatives and friends but about 15 kg are sold per week (range 5kg to 28kg). Given the average price of 30,000kip per kg, the average weekly income was estimated to be approximately 450,000kip. However, there is a large variation in household fishing practices and income (range 150,000 to 840,000 kip/week).

The only change that can be potentially related to the fishway becoming partially operational in 2014 was observations of more species in the wetland. However given this was mostly voiced by people from Pak Peung village near the fishway, it indicates that fish may not have migrated into other parts of the wetland yet. In the 2014 wet season most fish were captured for monitoring purposes as they moved up the fishway. At least two more wet seasons are needed with the fishway fully operational to see if there is a significant increase in fish catches, species and subsequent socioeconomic benefits to people.

Although not related to the fishway, ongoing reports of fish decline in the wetland and illegal fishing practices need to be addressed in combination with increased population and the need for income in local villages. Other factors that can influence fishing practices need further investigation such as alternative employment options and increasing income from other sources enabling families to buy fish from the local market. It will be important to monitor these broader socioeconomic changes as well as changes in fishing behaviour, use, sales and income over the next few years. Given the level of community concern about declining fish populations and loss of habitat, village leaders, elders and senior monks need to be involved in setting regulations and engaging the community to take care of the wetland environment.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Scientific outputs

The project will eventually result in five journal publications. One has been submitted and four are currently in preparation.

Scientific Advances

Over 7,500 barriers to fish migration were mapped across two catchments; the Xe Bang Fai and Xe Champone. Detailed characteristics of each barrier were documented and used to populate detailed graphics information systems databases. A prioritised list was generated and has been used to guide further investment opportunities in these catchments. The project team obtained the first design criteria, and fishway, developed for Lower Mekong species. The team demonstrated that an experimental *in-situ* approach was entirely appropriate for refining design criteria. Working with actual migrating fish in the field provided data that was unbiased from handling or laboratory effects. Fish were motivated to migrate which provided results that were directly applicable to effective construction.

Constructing the first fishway designed for Lower Mekong species was also a substantial achievement. Designed and built by the project team, with assistance from local labourers and contractors, the structure has provided passage for over 150 fish species. Species passing through the fishway included three IUCN red-listed species, In addition, a range of larger catfish species were captured, mainly at night, providing hard information on the migratory habits of these species for the first time. Detailed information was also collected on small-bodied species, and also juveniles of large-bodied species entering nursery habitat. These are all new information that will help to advance the knowledge and management of Mekong species into the future.

The work also highlighted to vulnerability of Lao fish species to regulator construction. For instance, despite much preliminary experimentation, construction of a permanent fishway still had some operations issues to resolve. These included:

(i) Recognising that not all small fish will be able to ascend a fishway even when very conservative design parameters were provided.

(ii) Understanding that some species only migrate at night

(iii) Understanding that some species have difficulty negotiating culverts

(iv) Demonstrating that turbulence can be a substantial factor influencing fishway success

(v) Learning that fisheries recovery will take some time and not be immediate

(vi) Appreciating that local knowledge is paramount to effective fishway construction and operation

8.2 Capacity impacts – now and in 5 years

The project positively influenced capacity in both Australia and Lao PDR.

8.2.1 Lao Capacity Impacts

Village Level

Village level impacts were substantial. The team strongly engaged at the village level for the entire project duration. The purpose of these interactions were twofold. Firstly, to help gain broader understanding for the approach and intended outcomes. Secondly, to build trust and provide an additional avenue for local employment and engagement. Both were largely seen as essential for broader project success.

The project provided a large degree of community cohesion, which was strongly supported by qualitative socio-economic surveys. There are six villages surrounding Pak Peung Wetland. Fishway construction was an activity that unified all villages into a common activity which will provide community-level benefits. The communities are presently working with the Pak San district, World Wide Fund for nature and provincial offices to develop a community co-management strategy to ensure all equally benefit.

Villagers also played an important role in fishway construction. A key requisite was the need to demonstrate that fishways could be constructed by using local staff. A local contractor was engaged via a competitive selection process; and local staff were employed to carry out construction activities. All works were performed under the guidance of team members who ensured that contractors closely followed the design and guided minor modifications to improve performance post-construction. To increase the chance of large-scale uptake, building local capacity for fishway construction was deemed more important than outsourcing to a larger construction company. Demonstrating that local communities could work with the project team to implement and construct fish passage solutions was a remarkable demonstration of capacity.

Local Government Level

There was strong engagement from district and provincial officers throughout the project. Considering this was the first fishway to be constructed, and that the site was to act as a national demonstration, there was considerable interest in ensuring project success.

National and International level

The greatest capacity impacts of this project are:

- The transfer of fish passage technology principles from Australia to Lao PDR
- An understanding of fishway design and assessment principles by Lao researchers
- The transfer of new knowledge from the Lower Mekong Basin to Australia

The transfer of technology principles is an ongoing task. Fish passage development in Australia has taken over 25 years to achieve a program that is now being applied on a large scale in the eastern states. The program has been built on the foundations of solid scientific inquiry that enabled the development strategic plans to facilitate the construction of suitable fishway designs. Australian scientists have benefitted from working in a river system that is largely unaffected by river development. To work at a site which yields over 150 species is something many scientists are unable to gain direct experience with in Australia. Developing skills in multispecies analytical methods, fish identification, working in remote areas and also new cultural experiences have provided substantial personal development opportunities for staff. In addition, many junior staff who entered the project through the Australian Youth Ambassador volunteer program have now secured longer term employment in the scientific field upon return.

The main in-country capacity impacts from our project has been to facilitate a cultural change among NRM groups in Lao by demonstrating that the effects of migration barriers can be adequately mitigated. Once an appreciation for technology is achieved, the next step is to demonstrate its effectiveness. The second major capacity impact was therefore training Lao researchers to understand the importance of experimental design when attempting to determine fishway success. To assist with this objective, Lao researchers from both LARReC and NUOL have been involved in helping to develop a curriculum on fish passage and also involving government officials in project achievements.

Learning has been multi-lateral. For instance, the project team invited involved researchers seeking to implement a similar fishway program in North Eastern Thailand. A Thai delegation from Wetlands Alliance from Udon thani visited our site in Savannakhet in 2011. Based on a positive impression of our work, with some design assistance, they constructed and built their first rock-ramp fishway in Northeast Thailand. The construction program was an excellent example of uptake beyond the immediate project team and in another country.

Similarly, the World Bank has funded extensions (through external consultants) of barrier mapping methods to other catchments within Lao PDR including the Xe Bang Fei. In addition it funded the construction of 10 new fishway structures in Kammouane and Savannakhet provinces based on Pak Peung designs (Figure 16).

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

The project has demonstrated that fishways have the potential to generate economic impacts in Lao PDR. In many areas of the LMB, fisheries have changed dramatically. Some fisheries are beginning to collapse and subsistence fisheries are becoming adversely affected. The construction of suitable fishways will be a useful management tool to help offset the effects of river development projects, and prevent further declines of fish communities as areas of the LMB experience increasing river management works. In reaches where dramatic declines in fish abundance have occurred, the economic benefits of fish passage construction will be obvious. Immediate economic benefits could not be quantified as the existing project focused largely on scientific and research outputs. Consequently, fish passage into the wetland was limited. Most fish were trapped within the fishway for research purposes to determine the overall success of the demonstration site. It will be a focus for future research.

The financial status of families upstream of migration barriers will improve substantially as fisheries are restored (Category one). Wetland fisheries are expected to rehabilitate and provide a source of food and income for many river communities. The existing project directly dealt with fisheries rehabilitation at one site (Pak Pueng). It is expected that these fishways will facilitate the upstream migration of thousands of migratory fish. Fishermen upstream of the regulator are expected to realise increases in fish catches which will provide economic benefits by (1) Reducing a need to travel to market, or new fishing locations to source fish and (2) By providing access to a tangible commodity which could be traded or sold.

The construction of ten additional fishways in the Kammouane and Savannakhet provinces is a substantial economic impact. In effect, the World Bank investment in new structures matched the ACIAR research project contribution. Thus the research investment from ACIAR, and the subsequent outcomes, provided sufficient justification for the World Bank to immediately apply the results to many irrigation structure upgrades. These have provided direct economic benefits, in the form of employment and salaries, to villagers, contractors and engineers in the Savannakhet and Khammuane provinces.

Figure 16. Before and after pictures of a fishway constructed in Savannakhet province. Fishway designs were directly applied from results obtained at Pak Peung and funded by the World Bank.

8.3.2 Social impacts

There were four major social impacts arising from the project:

- **Community cohesion:** locals became united in their desire to see the project succeed, and this was particularly evident when local staff are keen to work on the fishway project. We actively employed local staff to assist with fieldwork, attend project workshops, coordinate community co-management meetings and disseminate information which built substantial goodwill within the community. Consideration of children was also a major factor. Consultation village and district officials suggested that children will both play and fish within the fishway upon completion. So we needed to arrive at a design that allowed this to continue safely. Traditional fishway designs would have had high falls or rocks which would have created fall and entrapment hazards. The final design had low sloping walls, shallow water and easy access/egress. All of these considerations had the safety and welfare of children in the forefront of planning and worked well when put into practice.

- **Improved community knowledge of floodplain fisheries:** capture fisheries ecology and productivity are difficult concepts to understand. Many fishers have a rudimentary understanding, based largely on fish they encounter frequently during the course of artisanal fishing activities. Social surveys revealed that 85 per cent of citizens engaged in fishing activities had not completed secondary school. The opportunity for people to work directly on the project provided hands-on education about capture fisheries ecology and productivity. At the commencement of the project staff had little or no grasp of concepts regarding the collection of ecological data and scientific method. Upon project completion, local staff were actively engaged in data collection, fish identification and experimental setup. It was a substantial achievement.

- **Improved community co-management frameworks:** the floodplain capture fishery is largely regarded as a shared resource in the Pak San District. Seven villages are located at varying distances from the fishway site; however, there was broad recognition within the community that the villages should benefit equally. Local provincial and district officers commenced discussions with local nibans (village chiefs), in collaboration with the World Wide Fund for nature to ensure that appropriate mechanisms were put in place to provide equal benefits.

- Achievements during the project included:
  A) Introduction of a fish conservation zone upstream of the fishway to prevent exploitation of migratory fish
  B) Implementing a fishing ban within the fishway
  C) Establishing interpretative signage explaining the fishway and how it works
  D) Running a range of community workshops and information sessions
  E) Organising a community tree planting day to stabilise banks and prevent slumping

- **Regional leadership on fishway issues:** fishway construction and capture fisheries restoration are developing issues in Laos. Staff involved in the project have shared their knowledge and experience by contributing to extension activities in other districts and provinces. For instance, villagers and district officers participated in project planning meetings with irrigation officials in Savannakhet (southern Laos) to provide a village-level perspective on expected benefits. The team also travelled to North East Thailand to discuss options for fishway construction, and to share experiences, with locals interested in fisheries rehabilitation. It led to the full construction of a fishway funded by local investors.

8.3.3 Environmental impacts

Substantial positive environmental impacts emanated from this project. Fishway construction was completed in May 2014. Unfortunately there was no monitoring conducted in the 2015 migration season so determining immediate positive outcomes was not possible. Measurable differences for short-lived species are expected to be occurring now (Category 1), and for longer lived species will occur within 5 years (Category 2). Some key outcomes from the project provided multiple lines of evidence suggesting the types of environmental outcomes that can be expected. These include:

1. That over 150 fish species were recorded within the fishway over the course of research activities. These preliminary data suggest that measurable impacts within the wetland could be expected within five years. Social surveys indicated that many species have become locally extinct since regulator construction.
2. Initial monitoring suggested that, during peak migration rates, up to 100 kg of fish were entering the wetland over a 24 hour period. These could equate to over 18,000kg fish entering the wetland over the entire migration season (April to September).
3. Several juveniles threatened species were also collected, some of which are IUCN red-listed. These would not have been able to access wetland habitat if the fishway was not constructed. That these species were entering at a juvenile life history stage suggests they were accessing important nursery habitat required for early growth.
4. Most species entering the wetland were juveniles of river species which grow to several kilograms. These species require access to nursey habitat in order to access feeding and refuge during critical developmental stages. Prior to fishway construction these important lateral movements were not possible.

8.4 Communication and dissemination activities

8.4.1 Summary of dissemination activities

1. Formal presentations given in Thailand (Khon Kaen – Regional Fish Passage workshop convened by FAO) regarding fish passage research and development currently being undertaken in Laos. These presentations were attended by many delegates from Thailand, Vietnam, Myanmar, Cambodia and European experts in March 2013
2. Pak Peung wetland fish passage site was visited by the Australian Ambassador in April 2013. This was followed with a front page newspaper article of the visit being published in the Vientiane Times on Friday 26th April 2013.

   http://www.vientianetimes.org.la/FreeContent/FreeConten_Laos_leads.htm
3. Published a brochure improving fish passage in the Mekong and Murray Darling - Basins in both Lao and English languages. These brochures are now being disseminated within district provinces of Laos and various workshops held in both Lao and Australia.
4. Provided footage to be used on Bolikhamsay and Vientiane Province television news stations. This footage is from the Australian Ambassadors visit to Pak Peung wetland fish passage site. This will assist in demonstrating the importance of fish passage within the Lower Mekong Basin
5. Media opportunities arising from the placement of Australian Youth Ambassadors for Development (AYAD).
6. Media opportunity from the Crawford Fund fellowship with an article being written in the Vientiane Times about the recent opportunities being given to Lao counterparts

7. An article was published on the 2 AYAD volunteers working together as part of this project. This was released in the AYAD magazine.
8. Dr Oudom Phonekhhampeng (National University of Laos) and Mr Douangkham Singhanouvong, (Living Aquatic Resources Research Centre) presented project findings at the American Fisheries Society Symposium in August 2012 and 2015.
9. Dr Martin Mallen-Cooper attended an Oxfam roundtable meeting in Canberra which focused on Water and Resource Governance in the Mekong Region, April 2013. Martin participated by sharing perspectives and experiences about this project on behalf of the project team.
10. Installation of interpretive signage at Pak Peung wetland fish passage site. This signage will be installed within the next few months and display information to the general public in both Lao and English languages. The signage will include information and pictures focusing on this project, the fishway design, various migrating fish species and the importance of fishways.
11. Various Rotary Club presentations by Jarrod McPherson a returned Australian Volunteer for International Development (AVID). Jarrod gave presentations focusing on the work being conducted by this project, the importance of fishways within both the Lower Mekong and Murray Darling Basins and his experience as an AVID volunteer. http://club.coolamonrotary.com/?p=3395
12. Dr Lee Baumgartner attended a hydropower workshop in Hobart, Tasmania April 2013. The workshop was held primarily for various Lao delegates including the vice minister for energy and mines and over 20 senior government officials. Dr Baumgartner gave a presentation to the delegates focusing on the findings and works of the project.
13. Dr Oudom Phonekhampheng and Douangkham Singhanouvong presented at the 4th Australian Technical workshop on fishways in Townsville, 2011
14. Dr Oudom Phonekhampeng and Garry Thorncraft from the National University of Lao presented research findings at the Global Conference on Inland Fisheries, Rome, FAO, January 2015.
15. An FAO funded SEAFDeC Fish Passage Workshop in 2013 showcased the project. Lead regional researchers recognised Laos as being clear leaders in the field of fish passage research in the region and held them up as examples for other ASEAN countries to follow (Khon Kaen, Thailand, 17-20 March 2013)
16. Dr Lee Baumgartner and Garry Thorncraft presented on the project at the ’15 years of success in the Lower Mekong Basin’ conference hosted by SEAFDEC in Phnom Penh, November 2014.
17. The project team have been successful in agreeing to have the American Fisheries Society Host a “Maintaining sustainable Fisheries in the Lower Mekong” symposium. Twenty one abstracts were accepted and researchers from all over the globe attended and shared experiences. A follow up meeting is scheduled for the 2017 American Fisheries Society meeting in Tampa, Florida.
18. The final project meeting and project review was held in Vientiane, Lao PDR, April 2015. Project outcomes were provided to the review team and guidance was given to the project team regarding finalisation of project outputs.
19. Commencing planning for a major regional fish passage conference to be held in Vientiane in September 2016.

9 Conclusions and recommendations

9.1 Conclusions

The project successfully achieved all objectives; many which were achieved for the first time in the lower Mekong Basin. These included:

1. Completing the first ever fish passage barrier mapping exercise in the Lower Mekong Basin.
2. Constructing and assessing the first ever fishway constructed specifically for Lower Mekong species
3. Quantifying community perceptions of improved fish passage and value of a wetland fishery

9.1.1 Barrier mapping

Riverine development in tributary streams is much more extensive, from a fish passage barrier perspective, than previously recognised. Relying on existing databases alone would have resulted in a gross underestimation of catchment development, especially considering many structures were unlicensed and therefore unrecognised. Almost 3,500 migration barriers were identified from two sub-catchments and highlighted the overall degree that fish passage could be impacted. Prioritising fish passage barriers was an extremely useful process. Areas for potential investment have been identified in two key catchments. The next phase of this work will require working closely with funding agencies and donor bodies to try and coordinate investment opportunities throughout the Lower Mekong Basin.

9.1.2 Fishway design, construction and assessment

The project led to many findings relevant to restoring fisheries productivity in the Lower Mekong Basin. Firstly, it conclusively demonstrated that fishways are capable of passing high biomasses and abundances of endemic species over a broad size range. It also provided observations that there are important aspects of fish biology that require further understanding to be effective for all Lower Mekong species. Aspects of culvert design, internal hydraulics, entrance location and species ecology need to be fully understood to ensure solutions are sustainable. Results indicated that fishway design, and ongoing management, are complex. Fishway design needs to account for all possible species and hydrological situations to provide effective passage. However in Laos, consideration must be given to social factors to ensure that construction practices provide community safety.

9.1.3 Socio-economic surveys

Socio economic surveys validated previous assertions that fish are an important commodity in Lao PDR. Local fishers valued their resource but also felt that there were important management solutions which could be implemented to ensure sustainability. There was broad agreement that improving fish passage at the regulator was a welcome and sustainable solution. Locals felt that the fishway will be a good outcome but would have more positive benefits if also implemented along with improved fishing regulations, improved water quality in the wetland and enforced fishing closures. Despite these conclusions, fishers still reported new species appearing within the wetland near the fishway. But these species were yet to colonise far reaching areas of the wetland. It suggested that recolonization is likely to take several years, but that benefits could be measurable, especially if a multiple-lines-of-evidence approach was taken.

9.2 Recommendations

9.2.1 Barrier mapping

1. Work was only carried out in two catchments. Applying similar results in other catchments, with a view to the eventual mapping of the entire Lower Mekong Basin, is essential to understand the overall area impacted by migration barriers.
2. Performing targeted dissemination activities to ensure the prioritisation lists are considered for further investment is essential.
3. Ensuring that a standard method for barrier mapping is used across the Lower Mekong Basin will be critical to ensure prioritisation lists are applicable to other sites and locations.

9.2.2 Fishway design, construction and assessment

1. It is recommended that the assessment surveys be continued for a further five years to ensure fishery recovery into the wetland is quantified over a longer time period.
2. Fishway design criteria requires further refinement in light of observations that smaller bodied species have difficulty ascending the fishway, and that some species cannot ascend the culvert. These need to be resolved at both the Pak Peung site and also applied at new fishway installations.
3. Understanding the migration ecology of larger bodied species is worthy of further exploration. In particular, the observation that most catfish species were migrating mainly at night is important for future fishway design considerations.
4. The project focused solely on upstream migration. It is equally important to ensure that fish are able to move from the wetland downstream to the Mekong, especially when water recedes during the dry season. Quantifying the success of return migrations is essential for longer term fisheries sustainability.
5. Ensuring that lessons learned at the Pak Peung site, in terms of design, fish ecology and construction are communicated to influencers within government and applied more widely throughout the Lower Mekong Basin.
6. It was challenging using a construction contractor who had not completed a fishway in the past. There were considerable construction repairs which were required, but is a normal part of the contractor education and familiarisation process. We recommend that construction training, and access to high quality construction materials would be important for future fishway construction.

9.2.3 Socio-economic surveys

1. Conducting robust and detailed socioeconomic surveys requires a substantial investment over a longer timeframe to be able to understand benefits arising from fishway construction. It is recommended that the annual surveys continue in order to track any change trajectories arising from improve fish passage into the wetland.
2. Villagers recommend that other management strategies, in addition to fish passage restoration, be implemented at Pak Peung. Approaches to improve water quality and reduce overfishing were deemed important.
3. Understanding economic benefits arising from fishway construction are particularly important. It is anticipated that many thousands of kilograms of fish could colonise the wetland over a migration season. Ensuring that these are translated into tangible and quantifiable economic benefits are important.
4. The villagers played an enormous role in the project. Future projects will need to ensure that villager and district engagement is paramount to increase the likelihood of success.

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11 Appendix: Species list

Table 12.1. Full list of species captured either ascending, or attempting to ascend, the fishway; and by local fishers, throughout the study period at the Pak Peung wetland site

Number	Species Code	Ecology	IUCN Red List Category	Species Name	Family
1	ACADEL	white	Least Concern	*Acanthopsoides delphax*	Cobitinae
2	ACAHAP	white	Least Concern	*Acanthopsoides hapalias*	Cobitidae
3	ACASPP			*Acanthopsis spp*	Cobitidae
4	ACRIRI	white	Data Deficient	*Acrossocheilus iridescens*	Cyprinidae
5	AKYEPH	white	Data Deficient	*Akysis ephippifer*	Akysidae
6	AKYVAR	white	Data Deficient	*Akysis varius*	Akysidae
7	AMBCHU	black	Least Concern	*Amblypharyngodon chulabhornae*	Cyprinidae
8	AMBMIC	grey	Least Concern	*Amblyrhynchichthys micracanthus*	Cyprinidae
9	AMBTRU	grey		*Amblyrhynchichthys truncatus*	Cyprinidae
10	ANATES	grey		*Anabas testudineus*	Anabantidae
11	AURNEF	grey	Least Concern	*Auriglobus nefastus*	Tetraodontidae
12	BADRUB	grey	Least Concern	*Badis ruber*	Badidae
13	BAGSPP			*Bargarias spp*	Bagridae
14	BARALT	grey	Least Concern	*Barbonymus altus*	Cyprinidae
15	BARGON	grey	Least Concern	*Barbonymus gonionotus*	Cyprinidae
16	BARLAE	white		*Barbicthys laevis*	Cyprinidae
17	BARSCH	grey	Least Concern	*Barbonymus schwanenfeldii*	Cyprinidae
18	BETPRI	grey	Least Concern	*Betta prima*	Osphronemidae
19	BOTLEC	white	Least Concern	*Botia lecontei*	Cobitidae
20	BOTMOD	grey	Least Concern	*Botia modesta*	Cobitidae
21	BRAMEK	black	Least Concern	*Brachygobius mekongensis*	Gobionellinae
22	CEPBOR	white		*Cephalocassis borneensis*	Ariidae
23	CHAGAC	grey	Least Concern	*Channa gachua*	Channidae
24	CHAMIC	grey	Least Concern	*Channa micropeltes*	Channidae
25	CHASTR	grey	Least Concern	*Channa striata*	Channidae
26	CHELAU	grey	Not Evaluated	*Chela laubuca*	Cyprinidae
27	CHIBLA	white	Near Threatened	*Chitala blanci*	Notopteridae
28	CHIORN	grey	Least Concern	*Chitala ornata*	Notopteridae
29	CIRCIR	white	Vulnerable	*Cirrhinus cirrhosus*	Cyprinidae

Number	Species Code	Ecology	IUCN Red List Category	Species Name	Family
30	CIRJUL	grey	Data Deficient	*Cirrhinus jullieni*	Cyprinidae
31	CIRMOL	grey	Near Threatened	*Cirrhinus molitorella*	Cyprinidae
32	CLAGAR	grey	Not Evaluated	*Clarias gariepinus*	Clariidae
33	CLAMAC	grey	Near Threatened	*Clarias macrocephalus*	Clariidae
34	CLASPP	grey		*Clarias sp. (cf.batrachus)*	Clariidae
35	CLUAES	grey	Least Concern	*Clupeichthys aesarnensis*	Clupeidae
36	CLUBOR	grey	Least Concern	*Clupeoides borneensis*	Clupeidae
37	CROATR	white	Least Concern	*Crossocheilus atrilimes*	Cyprinidae
38	CROOBL	white	Least Concern	*Crossocheilus oblongus*	Cyprinidae
39	CROSIA	white		*Crossocheilus siamensis*	Cyprinidae
40	CYCAPO	grey	Least Concern	*Cyclocheilichthys apogon*	Cyprinidae
41	CYCARM	grey		*Cyclocheilichthys armatus*	Cyprinidae
42	CYCENO	grey	Least Concern	*Cyclocheilichthys enoplos*	Cyprinidae
43	CYCLAG	grey	Least Concern	*Cyclocheilichthys lagleri*	Cyprinidae
44	CYCREP	grey		*Cyclocheilichthys repasson*	Cyprinidae
45	CYCSIA	grey		*Cyclocheilichthys siaja*	Cyprinidae
46	CYPCAR	grey	Vulnerable	*Cyprinus carpio*	Cyprinidae
47	DANSIA	grey		*Dangila siamensis*	Cyprinidae
48	DATMIC	grey		*Datnioides microlepis*	Datniodidae
49	DEVSPP			*Devario spp*	Cyprinidae
50	EPAFRE	grey		*Epalzeorhynchos frenatum*	Cyprinidae
51	ESOLON	grey	Data Deficient	*Esomus longimanus*	Cyprinidae
52	ESOMET	grey	Least Concern	*Esomus metallicus*	Cyprinidae
53	GYRPEN	white	Least Concern	*Gyrinocheilus pennocki*	Gyrinocheilidae
54	HAMDIS	grey	Least Concern	*Hampala dispar*	Cyprinidae
55	HAMMAC	grey	Least Concern	*Hampala macrolepidota*	Cyprinidae
56	HEMLAB	white	Not Evaluated	*Hemibarbus labeo*	Cyprinidae
57	HEMNEM	grey	Least Concern	*Hemibagrus nemurus*	Bagridae
58	HEMSPI	grey	Least Concern	*Hemibagrus spilopterus*	Bagridae
59	HEMSPP			*Hemibagrus spp*	Bagridae
60	HEMWYC	grey	Least Concern	*Hemibagrus wyckioides*	Bagridae
61	HENLOB	grey	Least Concern	*Henicorhynchus lobatus*	Cyprinidae
62	HENORN	black	Not Evaluated	*Henicorhynchus ornatipinnis*	Cyprinidae
63	HENSIA	grey	Least Concern	*Henicorhynchus siamensis*	Cyprinidae

Number	Species Code	Ecology	IUCN Red List Category	Species Name	Family
64	HOMLEO	white	Least Concern	*Homaloptera leonardi*	Balitoridae
65	HOMSMI	white	Least Concern	*Homaloptera smithi*	Balitoridae
66	HOMSPP			*Homaloptera spp*	Balitoridae
67	HYPLAG	grey	Vulnerable	*Hypsibarbus lagleri*	Cyprinidae
68	HYPMAL	white	Least Concern	*Hypsibarbus malcolmi*	Cyprinidae
69	HYPMOL	grey	Near Threatened	*Hypophthalmichthys molitrix*	Cyprinidae
70	HYPNOB	grey	Data Deficient	*Hypophthalmichthys nobilis*	Cyprinidae
71	HYPVER	white	Least Concern	*Hypsibarbus vernayi*	Cyprinidae
72	HYPWET	white	Least Concern	*Hypsibarbus wetmorei*	Cyprinidae
73	KRYBIC	grey	Least Concern	*Kryptopterus bicirrhis*	Siluridae
74	KRYCHE	grey	Data Deficient	*Kryptopterus cheveyi*	Siluridae
75	KRYCRY	grey	Least Concern	*Kryptopterus cryptopterus*	Siluridae
76	KRYGEM	grey	Least Concern	*Kryptopterus geminus*	Siluridae
77	LABCHR	grey	Least Concern	*Labeo chrysophekadion*	Cyprinidae
78	LABLEP	grey	Not Evaluated	*Labiobarbus leptocheilus*	Cyprinidae
79	LABSIA	grey	Least Concern	*Labiobarbus siamensis*	Cyprinidae
80	LAILON	white	Least Concern	*Laides longibarbis*	Schilbeidae
81	LEPHAS	grey	Least Concern	*Lepidocephalichthys hasselti*	Cobitidae
82	LUCBLE	grey	Least Concern	*Luciosoma bleekeri*	Cyprinidae
83	MACSEM	black	Least Concern	*Macrognathus semiocellatus*	Mastacembelidae
84	MACSIA	black	Least Concern	*Macrognathus siamensis*	Mastacembelidae
85	MASARM	grey	Least Concern	*Mastacembelus armatus*	Mastacembelidae
86	MASFAV	white	Least Concern	*Mastacembelus favus*	Mastacembelidae
87	MONALB	grey	Least Concern	*Monopterus albus*	Synbranchidae
88	MYSALB	grey	Least Concern	*Mystus albolineatus*	Bagridae
89	MYSATR	grey	Least Concern	*Mystus atrifasciatus*	Bagridae
90	MYSCHI	grey	Least Concern	*Mystacoleucus chilopterus*	Cyprinidae
91	MYSECT	white	Least Concern	*Mystacoleucus ectypus*	Cyprinidae
92	MYSMAR	grey	Least Concern	*Mystacoleucus marginatus*	Cyprinidae
93	MYSMUL	grey	Least Concern	*Mystus multiradiatus*	Bagridae
94	MYSMYS	grey	Least Concern	*Mystus mysticetus*	Bagridae
95	MYSNEM	grey		*Mystus nemurus*	Bagridae
96	MYSSIN	grey	Least Concern	*Mystus singaringan*	Bagridae
97	NANOXY	grey	Least Concern	*Nandus oxyrhynchus*	Nandidae

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98	NEMLON	white	Least Concern	*Nemacheilus longistriatus*	Nemacheilidae
99	NEMPAL		Least Concern	*Nemacheilus pallidus*	Nemacheilidae
100	NEMPLA	white	Data Deficient	*Nemacheilus platiceps*	Nemacheilinae
101	NEMSPP			*Nemacheilus spp*	Balitoridae
102	NEOAUR	black	Least Concern	*Neodontobutis aurarmus*	Odontobutidae
103	NOTNOT	grey	Least Concern	*Notopterus notopterus*	Notopteridae
104	OMPBIM	grey	Near Threatened	*Ompok bimaculatus*	Siluridae
105	ONYFUS	white	Least Concern	*Onychostoma fusiforme*	Cyprinidae
106	OPSKOR	white	Least Concern	*Opsarius koratensis*	Cyprinidae
107	ORENIL	grey	Not Evaluated	*Oreochromis niloticus*	Cichlidae
108	OREPAR	white	Data Deficient	*Oreichthys parvus*	Cyprinidae
109	OSTHAS	grey	Least Concern	*Osteochilus hasselti*	Cyprinidae
110	OSTLIN	grey	Least Concern	*Osteochilus lini*	Cyprinidae
111	OSTSCH	grey	Least Concern	*Osteochilus schlegelii*	Cyprinidae
112	OSTWAA	grey	Least Concern	*Osteochilus waandersii*	Cyprinidae
113	OXYMAR	grey	Least Concern	*Oxyeleotris marmorata*	Eleotridae
114	OXYPOI	white	Vulnerable	*Oxygaster pointoni*	Cyprinidae
115	PANMAC	grey	Least Concern	*Pangasius macronema*	Pangasiidae
116	PANPLE	grey	Not Evaluated	*Pangasius pleurotaenia*	Pangasiidae
117	PARACSIA	grey	Least Concern	*Parachela siamensis*	Cyprinidae
118	PARMAC	grey	Least Concern	*Parasikukia maculata*	Cyprinidae
119	PAROXY	grey	Least Concern	*Parachela oxygastroides*	Cyprinidae
120	PARSIA	grey	Least Concern	*Parambassis siamensis*	Ambassidae
121	PARSPP			*Parachela spp*	Cyprinidae
122	PARTYP	grey	Least Concern	*Paralaubuca typus*	Cyprinidae
123	PARWIL	grey	Least Concern	*Parachela williaminae*	Cyprinidae
124	PORLAO	white	Least Concern	*Poropuntius laoensis*	Cyprinidae
125	PORNOR	white	Least Concern	*Poropuntius normani*	Cyprinidae
126	PORSPP			*Poropuntius spp*	Cyprinidae
127	PRIFAS	grey	Least Concern	*Pristolepis fasciata*	Nandidae
128	PROJUL	grey	Endangered	*Probarbus jullieni*	Cyprinidae
129	PSEPLE	grey	Least Concern	*Pseudolais pleurotaenia*	Pangasiidae
130	PSESIA	white	Least Concern	*Pseudomystus siamensis*	Bagridae
131	PUNAUR	grey	Least Concern	*Puntius aurotaeniatus*	Cyprinidae

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132	PUNBRE	grey	Least Concern	*Puntius brevis*	Cyprinidae
133	PUNFAL	grey	Least Concern	*Puntioplites falcifer*	Cyprinidae
134	PUNJAC	grey	Least Concern	*Puntius jacobusboehlkei*	Cyprinidae
135	PUNORP	grey	Not Evaluated	*Puntius orphoides*	Cyprinidae
136	PUNPAR	grey	Least Concern	*Puntius partipentazona*	Cyprinidae
137	PUNPRO	grey	Least Concern	*Puntius proctozystron*	Cyprinidae
138	PUNSPP			*Puntius spp*	Cyprinidae
139	PUNSTO			*Puntius stolickzcanus*	
140	RAIGUT	grey	Least Concern	*Raiamas guttatus*	Cyprinidae
141	RASAUR	grey	Least Concern	*Rasbora aurotaenia*	Cyprinidae
142	RASBOR	grey	Least Concern	*Rasbora borapetensis*	Cyprinidae
143	RASDAN	grey	Least Concern	*Rasbora daniconius*	Cyprinidae
144	RASDUS	grey	Not Evaluated	*Rasbora dusonensis*	Cyprinidae
145	RASPAU	grey	Least Concern	*Rasbora pauciperforata*	Cyprinidae
146	RASPAV	grey	Least Concern	*Rasbora paviana*	Cyprinidae
147	RASRUB	grey	Least Concern	*Rasbora rubrodorsalis*	Cyprinidae
148	RASSPI	black	Least Concern	*Rasbora spilocerca*	Cyprinidae
149	RASSTE	grey	Least Concern	*Rasbora steineri*	Cyprinidae
150	RASTRI	grey	Least Concern	*Rasbora trilineata*	Cyprinidae
151	RHIMEK	white	Least Concern	*Rhinogobius mekongianus*	Gobiidae
152	SCABAN	grey	Vulnerable	*Scaphognathops bandanensis*	Cyprinidae
153	SCASPP			*Scaphognathops spp*	Cyprinidae
154	SCASTE	grey	Least Concern	*Scaphognathops stejnegeri*	Cyprinidae
155	SCHSPP			*Schistura spp*	Nemacheilidae
156	SIKGUD	grey	Data Deficient	*Sikukia gudgeri*	Cyprinidae
157	SINMEL	white	Data Deficient	*Sinibrama melrosei*	Cyprinidae
158	SPIHOL	white	Data Deficient	*Spinibarbus hollandi*	Cyprinidae
159	SQUATR	white	Least Concern	*Squalidus atromaculatus*	Cyprinidae
160	TENTHI	grey	Vulnerable	*Tenualosa thibaudeaui*	Clupeidae
161	TETCAM	white	Least Concern	*Tetraodon cambodgiensis*	Tetraodontidae
162	TETSUV	white	Least Concern	*Tetraodon suvatti*	Tetraodontidae
163	THYTHY	grey	Least Concern	*Thynnichthys thynnoides*	Cyprinidae
164	TOXCHA	grey	Not Evaluated	*Toxotes chatareus*	Toxotidae
165	TRIMIC	grey	Least Concern	*Trichopodus microlepis*	Osphronemidae

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166	TRIPEC	grey	Least Concern	*Trichopodus pectoralis*	Osphronemidae
167	TRIPUM	black	Least Concern	*Trichopsis pumila*	Osphronemidae
168	TRISCH	grey	Least Concern	*Trichopsis schalleri*	Osphronemidae
169	TRITRI	grey	Least Concern	*Trichopodus trichopterus*	Osphronemidae
170	TRIVIT	black	Least Concern	*Trichopsis vittata*	Osphronemidae
171	WALATT	grey	Near Threatened	*Wallago attu*	Siluridae
172	XENCAN	grey	Least Concern	*Xenentodon cancila*	Belonidae
173	XENSPP			*Xenentodon sp.*	Belonidae
174	YASCAU	white	Least Concern	*Yasuhikotakia caudipunctata*	Cobitidae
175	YASLEC	white	Least Concern	*Yasuhikotakia lecontei*	Cobitidae
176	YASLON	grey	Data Deficient	*Yasuhikotakia longidorsalis*	Cobitidae
177	YASMOR	grey	Least Concern	*Yasuhikotakia morleti*	Cobitidae