Fish passage and fishways in the Mekong Basin: getting past the barriers.

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ABSTRACT

Wild fisheries are declining in the Mekong Basin. One of the many reasons for this is that we are changing rivers so that fish can no longer have free passage for breeding, dispersion and growth. Trying to provide fish passage past the hundreds of large dams in the basin would be difficult, and in the end might not be successful. However, providing fish passage past the thousands of smaller barriers is possible and I believe, together with other fisheries management actions, would help maintain local fish fisheries. Fishways, which are structures designed to allow fish to move upstream past barriers like dams and weirs, have been used in many countries to try and protect wild fisheries. But in many cases they have failed to do the job they were built for. Only recently have fisheries biologists become closely involved in fishway projects from start to finish. Deciding what you want a fishway to achieve, and what will happen to the fish after they pass, is a key step toward judging the need and likely success of a fishway. Choosing a fishway design that has been shown to work for the species you wish to give passage to is another step. Looking at the proposed plans for a fishway, not as an engineer, but as a biologist who understands fish behaviour is another. Once built, assessing the fishways effectiveness, learning from any mistakes, and then using the fishway as a means of monitoring the river fishery over long time-periods is the final step.

KEYWORDS: Fish; Migration; Passage; Fishway; Design; Mekong; Barrier; Dam; Weir; Culvert.

INTRODUCTION

Inland fisheries throughout the world are an important source of food and income for many people, but with increasing human pressure these fisheries are undergoing change (Cowx *et al*., 2004). In the Mekong Basin, this is taking the form of declining catch of the larger longer-lived species, with the fishery in many areas becoming more dependent on smaller, faster-maturing species (van Zalinge *et al*., 2004). Initiatives such as Community Co-management of fisheries (Baird, 2001) are being promoted to improve management of these resources, especially in rural areas where fish are a major source of protein for sustenance and income, but where ownership of the resource is uncertain.

Activities not directly related to fishing, such as land clearance for agriculture and infrastructure development for water storage and hydropower production, are accelerating as Mekong Basin countries develop economically. This type of development can cause major changes in river flow and flooding cycles which can significantly disrupt recruitment and growth cycles of both large and small native species (Arthington *et al*., 2004a; Welcomme and Hall, 2004;); and approaches to mitigating some of these impacts such as environmental flow protection are being developed (Arthington *et al*., 2004b). However, rivers with large floodplains such as the Mekong are complex

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systems (Junk and Wantzen, 2004) and many processes within the system may be critical over time in maintaining fish diversity and abundance.

Fish passage and fishways

Loss of river continuum, where fish are prevented either physically or behaviourally from migrating longitudinally along rivers and laterally across floodplains has been identified as one of these key threatening processes (Northcote, 1998; Jungwirth, 1998). In many developed countries today, new barriers are not being built due to community concerns over the negative impacts of barriers on rivers and fisheries, and some barriers are being removed completely just to re-establish fish passage. However, in the Mekong Basin rapid economic development is a high priority and large numbers of new barriers are still being proposed and built.

Physically providing fish passage longitudinally along rivers, by providing pathways (fishways) that allow fish to swim upstream past barriers have been developed, especially in North America, Europe and Australia (Clay, 1995; Mallen-Cooper, 1996 and 1999; Stuart and Mallen-Cooper, 1999; Thorncraft and Harris, 2000; Stuart and Berghuis, 2002; Larinier and Marmulla, 2004; Stuart *et al*., 2004; Baumgartner, 2005). But fishways are generally not designed to provide downstream fish passage, especially when water is released through hydropower generation, gates or spillways. Providing downstream passage has focused more on fish friendly ways of releasing water using fish screens, bypasses and overshot rather than undershot gates (Clay, 1995; Odeh and Orvis 1998; and Baumgartner *et al*., 2006).

Whilst much emphasis has been placed on providing fish passage past large instream barriers throughout the world; provision of fish passage past the much more numerous smaller barriers laterally across floodplains using low-cost fishways or fish friendly culvert designs has not been addressed until relatively recently (Cowx, I.G. 1998; Newbury and Gaboury 1988; Bates and Powers, 1998; Larinier *et al*, 2002; Marsden *et al*. 2003a; Marsden *et al*. 2003b; Marsden *et al*. 2003c).

In the Mekong Basin, only a few fishways have been built, and as a mitigation tool they are not generally accepted as being either required or effective. Many reasons exist for this, most based on the belief that fishways are too expensive, don't work and any loss of natural production can be replaced with hatchery stocking. This view has been supported by the few poorly-performing fishways that have been built in the basin, which were based on fishway designs unsuitable for the height of the barrier and also for the behaviour and swimming ability of local fish species. This has resulted in high profile failures of fishways, and this is now a major impediment to the further use of fishways to mitigate barriers to fish passage in the Mekong Basin.

Critics of fishways do have many valid points including:

- fishways alone do not ensure fish passage past a barrier as many other factors, such as environmental cues required to stimulate migration, need to be maintained;
- fishways can be very expensive to build, especially on high barriers and/or if a wide range of fish species requiring passage are to be catered for;
- fishways require maintenance and finding money for this will be an ongoing problem to the owner of the fishway;
- fishways are often vulnerable to unauthorised trapping of fish;
- even if fish can get upstream past a barrier, they may not be able to complete their life cycles, especially for large dams where the reservoir may also be both an upstream and downstream barrier, and critical habitats may be altered;
- the cost of retrofitting fishways on the hundreds of large dams and thousands of smaller barriers already existing in the basin would be very high;
- the extra cost of building a fishway may make the cost of a development project too high, even though the benefits of the project to the local community would be substantial; and
- fishways do not usually provide downstream migration passage so in effect they only address half the problem.

So is there a future for fishways in the Mekong Basin?

Before advocating the use of fishways in the Mekong Basin, two things need to be resolved. The first is to put forward arguments for including effective fishways on barriers of various types, and the second is what work would be required to allow effective fishway designs to be developed. Therefore, a clear idea of what can be achieved and how the various problems can be addressed is needed. The first question can be resolved by considering the reasons for building fishways as opposed to not building them, and include:

- with the increasing awareness of the other impacts of dams and weirs on river ecology, mitigation measures such as multi-level intakes to ensure good water quality (including thermal pollution) and provision of environmental flows will be used, and whilst this will improve riverine conditions downstream, it may ultimately only result in more fish accumulating below a barrier;
- with increasing effort going into placing not only an economic but also a social and environmental value on fishery resources, the relative cost of a fishway (especially in relation to the overall cost of building the barrier) makes fishways a more cost-effective

alternative to stocking hundreds of kilometres of river using hatcheries that can usually only produce a limited number of species;

- dams and weirs also require continual maintenance and incorporating the maintenance programme for a fishway in the overall structures maintenance programme is only logical, and as the owner of the dam is the one gaining a benefit from its existence, it is also logical that they pay for the construction and maintenance of the fishways;
- community co-management systems that in effect confer ownership of the fisheries resources to local people also aim to educate people on good management practices, particularly the need to allow fish to complete their life cycles to ensure maximum production potential, so a fishway not only needs to be accepted as being important to the local community but also, by actively monitoring fish passage through them, local co-management groups can assess the effectiveness of their management actions and some sustainable harvesting of fishways may be part of this process;
- providing fish passage does have its limitations, so having a clear idea of what it is that you want to or can achieve is vital in any decision process developed by resource managers to assess if a fishway is to be required for any particular project;
- eventually all structures need major repairs or modifications which would provide the opportunity to retrofit a fishway, and in those cases where providing fish passage at a large barrier would have limited or no benefit, the retro-fitting of fishways at existing lower-barriers in other areas where it would be of benefit could be considered as a legitimate impact mitigation action;
- a major cost in retrofitting fishways is in the modification of the existing structure, particularly to allow a fishway channel to pass through the wall of the structure, so even if a fishway cannot be afforded at the time of construction, simple design considerations for future retrofitting can be of considerable future value for little or no immediate cost; and
- though fishways do not usually provide downstream passage, the process of studying migratory fish behaviour, developing fishway design criteria, assessing the effectiveness of new fishways built and the long-term monitoring of upstream migrations can provide valuable insights into how to provide for downstream migration as well as providing feedback on the success of any measures undertaken in subsequent upstream return migrations.

However, fishways do cost money (up to 5% of the total cost of a project if the fishway is built at the same time the barrier is built), so if fisheries-resource management agencies are going to consider the use of fishways as a possible mitigation tool, then they be must prepared to defend their

Case Study 1: Meeting the Dam Developer

Your boss walks into your office and tells you that you have to go to a meeting about a new water infrastructure development tomorrow. The developer of the project may be another government department wanting to build a new irrigation dam or a business group wanting to invest in hydropower; and your job will be to present your departments concerns for the areas fisheries resources. This time you are lucky, the developer has completed an Environmental Impact Assessment (EIA) and it does have a fisheries section, so you will know something about the project before the meeting starts, if you can find the time to read it before your meeting tomorrow.

The meeting will not be held in your office, it will be held at their very large and expensive offices in the middle of the city. If the developers have read the EIA, they will know that if not handled carefully, the potential impact of the project on local fisheries could be a problem for them. Therefore, as you walk into the meeting room you see not only the developer and the senior project engineer, but also representatives from their environmental consultants. As you sit down you wish that your boss had come as well, as you now feel very much outnumbered and a little intimidated by all these people dressed in expensive business suits. But you settle down quickly as the developer is making a lot of effort to be friendly and make sure you are well looked after.

Down to business, but you seem to be doing most of the listening as the developer tells you how good this project will be for the country, the local economy and the local community. But as the projects environmental consultant quickly runs over how there really will be no great impact on the local fisheries, in fact they should improve greatly as their will now be more water stored behind the dam, you shift uneasily in your chair. Taking a deep breath you start talking about the research your department has done, as well as work done by other countries fisheries groups. You point out that in fact there are a lot of migratory fish in this area, and they are very important for the local economy as well as a major source of protein for the rural villagers.

This makes the fisheries consultant sit back, but the developer has a solution though no one seems to be smiling at you anymore. Don't worry, we will stock the dam with fish for the locals; in fact we might even be able to build them a large hatchery next to the reservoir. Though you could point out that the local community has very little experience with running a large hatchery or the money to operate one, you feel the need to point out the wider problems first. If the fish cannot migrate and complete their life cycles, then areas upstream and downstream of the dam will be impacted, perhaps for hundreds of kilometres away from the dam; and though hatcheries are good for supporting aquaculture development of a few fish species, they are of no use in the maintenance of more complex and diverse native fish communities.

Now for the first time the engineer sits forward and starts talking about how there is no way that the dam gates can be opened to allow fish passage, as it would waste all the water and cost too much. And as you know, fishways do not work for fish in this country so there is really very little we can do for you. Though you don't feel very confident, you do speak up and point out that the fishways that have been built here before have been done so by engineers using designs developed in other regions in the world and not adapted for local native-fish behaviour.

Now the engineer is smiling at you as he starts to spread out the design plans for the dam and asks a series of questions without waiting for any answers. What type of fishway are you talking about? What slope does it need to be? What is the maximum water velocity and turbulence you can have in it? How wide and deep does the channel need to be? How many cumecs of water will it use? Will it need to operate all the time or only for short periods? At what river flow do fish migrate and where should we put the entrance and exit for the fishway?

As you leave the meeting with a promise by the developer to look into the possibility of building a number of small simple to operate and widely-dispersed hatcheries for the local people, you think to yourself "I really wish I could have had some answers for that dam developer's engineer". So maybe it is time to talk to the boss about starting a research program aimed at generating fishway design criteria for our local fish species; and that we need to do it in partnership with engineers so the results can be easily understood and accepted by the developers.

position. The following short story (Case Study 1.) maybe something that fisheries officers working in the Mekong Basin are facing now or will in the near future.

What design, what costs, what risks?

A key point in deciding for or against the use of fishways is to understand that there are different types of fishway designs, and that each design is different in terms of its cost and its ability to provide fish passage at different structures, especially if only limited knowledge of local fish species, behaviour and swimming ability is available. Based on increasing height of the barrier this can be generally summarised as set-out below:

- low barriers up to 2 m headloss* have a low-level of risk of not working and generally low cost:- usually between US$100 and US$10,000 (Figures 1, 2 and 3);
- medium barriers up to 6 m headloss have a medium-level of risk and medium cost:- usually between US$10,000 and US$500,000 (Figures 4 and 5);
- high barriers over 6 m headloss have a high-level of risk and high cost:- usually more than US$500,000 (Figures 6 and 7).

Figure 1. Fish-friendly designs for high water velocity barriers (example of a culvert design creating controlled water velocities and increased depth to facilitate fish passage in Queensland, Australia)

However, with increased understanding of local fish species swimming ability and behaviour, local design criteria can be applied and these general guidelines can be adjusted so the risk of a fishway design failing to provide fish passage can be reduced. However, the higher the barrier to fish

* Headloss is the difference between upstream and downstream water levels, usually but not always determined by the physical height of the barrier. However, with increased understanding of local fish species swimming ability and behaviour, local design criteria can be applied and these general guidelines can be adjusted so the risk of a fishway design failing to provide fish passage can be reduced. However, the higher the barrier to fish passage the greater the problems with fish not being able to ascend the fishway and then find their way through the reservoir upstream of the barrier. For larger barriers, knowledge of what would happen to any fish after using the fishway needs to be considered before deciding if a fishway would be effective.

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Figure 2. Fishway suitable for barriers up to 2 metres (example of a rock-ramp fishway in Phou Khao Khouay, Lao P.D.R.)

Figure 3. (left). Fishway suitable for barriers up to 2 metres (example of a bypass fishway in Queensland, Australia)

Figure 4. (right) Fishway suitable for barriers up to 6 metres (example of a vertical-slot fishway in Queensland, Australia)

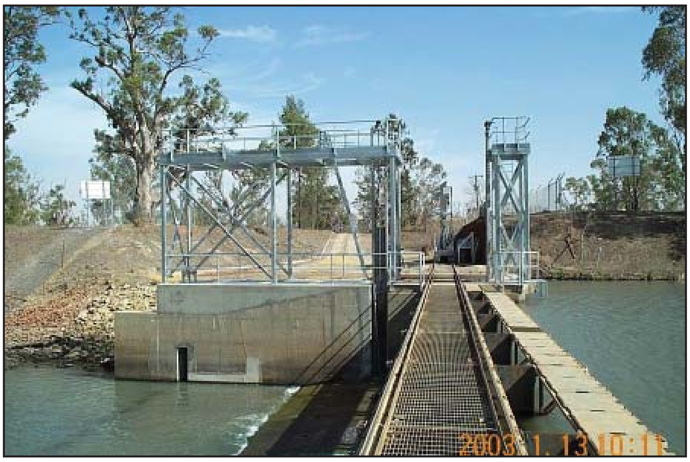

Figure 5. Fishway suitable for barriers up to 6 metres (example of a Dealder Lock in New South Wales, Australia)

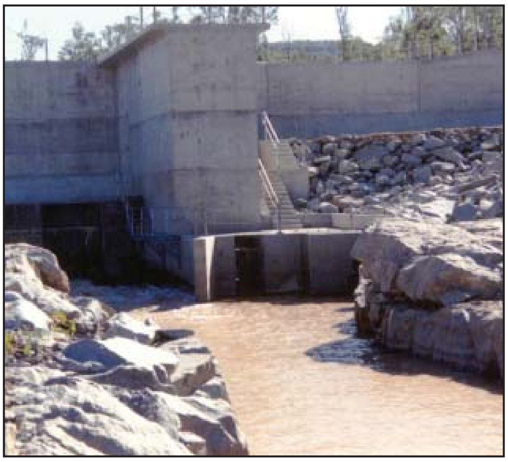

Figure 6. Fishway suitable for barriers over 6 metres (example of a lock fishway from Queensland, Australia)

Figure 7. Fishway suitable for barriers over 6 metres (example of a lift fishway under construction on left side of spillway in the photo from Queensland, Australia)

How do you develop fishway design criteria?

Like fishways themselves, the process of developing fishway design criteria is best approached as a series of relatively small steps. The key to this approach being that fishway design criteria needs to be developed based on the fish expected to use the fishway. For example, the Lower Mekong Basin it might initially be broken down into smaller eco-regions:

- Lower Mekong River mainstream reaches and estuarine interface with its large number of species, size ranges and fish abundance;
- Mekong tributaries and floodplains with its mix of white and black water species;
- Mekong tributary uplands with species adapted to high water-velocity environments.

It would be smart to start with research into small barriers first, as lessons learnt at these sites can be used later to reduce the risk of making an expensive mistake at the larger barriers. Once divided into discrete areas of research, fishway design criteria can be developed through a series of field-based experiments. During periods of fish migration, experimental sites at existing barriers can be set up to determine criteria such as:

- the species, timing, numbers and areas where fish accumulate below a barrier;
- maximum water velocity and turbulence that fish can negotiate;
- minimum depth, passage width and light conditions fish require;
- time required and the maximum height fish can ascend in the fishway.

An example of how fishway research was approached in Australia is outlined in Case Study 2.

Whilst in developed countries like Australia the public funding of research and fishway construction has been possible, in the Lower Mekong Basin a different approach may be required because of limited availability of public funding combined with the need to address other high-priority research areas. A number of options for fisheries resource managers in Mekong countries are available at the present time and these include:

- have no publicly funded fishway research programme, but place the requirement for providing effective fish passage on the developer (industry) and let them bear the risk of building ineffective fishways (present situation);
- wait until public concern over declining fish numbers and the importance of restoring fish passage results in a publicly funded research programme, the results of which can then be made available to developers;
- use relatively small amounts of public funding (targeted funding), perhaps supported by a series of international technical assistance programmes targeted at a developing local

Case Study 2: Australian Fish Passage Development

The Murray-Darling Basin (MDB) represents the largest catchment on the Australian continent and in many ways it is analogous to the Mekong River. In particular, the MDB supports large regions of agricultural production (MDBC, 2003), it has undergone substantial development (Mallen-Cooper, 1996), it supports a large population (Jacobs, 1990) and it is co-managed by four separate state governments.

Given this degree of development, it was recently estimated that over 95% of the Murray-Darling Basin was degraded in some capacity and that 40% of the river length contained biota that had declined in both range and abundance (Norris *et al*, 2001). Whilst the degradation of the Murray River has had detrimental effects on virtually all resident biota (Gippel and Blackham, 2002), impacts on the abundance and diversity of native fish have been particularly profound (Lake, 1971; Brumley, 1987; Cadwallader and Lawrence, 1990).

Fishways have been constructed in Australia since 1912 (Hooker, 1966) and at least 76 are currently operational in New South Wales (Mallen-Cooper, 2000; Thorncraft and Harris, 2000). However, early designs were based of criteria developed for strong-swimming northern hemisphere salmonids (Mallen-Cooper. 1996) and almost all were ineffective for Australian fish. Therefore, fish passage development was seldom progressed in Australia because people thought the simply didn't work.

To progress work on fish passage in Australia, the NSW government commissioned George Eicher, a prominent US ecologist, to develop a fish passage facility programme for Australia (Eicher, 1982). This report resulted in a well-directed research program that sought to determine optimal design criteria for Australian fish. The work culminated in two landmark studies, each which determined fish passage criteria for a number of commercially important species through a series of controlled laboratory tests (Mallen-Cooper, 1992, 1994).

With the development of laboratory criteria, the Australian government funded the construction of a vertical-slot fishway built to these specifications (Mallen-Cooper, 1996). The project was a resounding success and the fishway passed over 100,000 fish in its first 8 years of operation (NSW DPI, unpublished data). Since this landmark study, further research determined that many more species of fish are migratory than first thought (Stuart et al, 2004; Baumgartner 2005). Subsequently, fish passage criteria are constantly adapted and the current Australian approach is to provide passage for entire ecological communities (fish 20 mm-1500 mm in length and also macroinvertebrates).

In 2002, the Murray-Darling Basin Commission (formed and funded by the four MDB governments) committed to a $AUD25 Million program to restore fish passage to over 1,700km of the Murray-Darling Basin. The work involves the construction of 14 fishways at each major structure on the Murray River. The project incorporates a major biological assessment program to determine the effectiveness of each fishway. Since completion of the first fishway in 2003, over 150,000 fish have gained passage and the assessment team are providing important information to improve the function of future fish passage facilities (Stuart *et al*, 2004).

This Australian example is an excellent case of biologists, engineers, managers and governments working in co-operation to develop practical on-ground outcomes for fish and regional agricultural communities. It is important to note that such co-operation is necessary to develop a program that delivers favourable outcomes for all partner organisations and stakeholders.

fisheries research skills, to undertake a series of limited research projects on low-cost fishways at small barriers, and make those results available to developers overtime; and

- use targeted public funding in combination with and supporting industry initiated fishway construction projects (though still focusing initially on small and medium barriers), so that risks are shared between both groups with the trade-off being that lessons learned will be more readily taken up by the industry.

The opportunity to initiate the two last approaches listed above currently exists in Lao P.D.R. due to intensive international interest in a number of large development projects in the country. Similar opportunities may also exist in other basin countries. The authors of this paper are currently in a very early stage of exploring opportunities to initiate these approaches in Lao P.D.R., with the aim of supplying the required international assistance to help develop local fish passage research skills.

However, each of the countries in the Lower Mekong Basin will need to make their own decisions on how to approach the issue of barriers to fish passage. But by integrating their actions with the other countries within the basin, and particularly with the water infrastructure development industry in the basin, then fish passage problems can be addressed now rather than later when the cost of rehabilitating rivers in the basin and the impact on local fishing-dependant communities will be much higher.

CONCLUSIONS

As fisheries researchers and managers in the Mekong Basin, we need to keep the impacts of development upon fisheries at the forefront of discussions with resource developers and those communities affected by the loss of healthy fisheries. Fish passage along rivers and across floodplains is one of the key environmental processes that maintain healthy fisheries. By mitigating the impacts of barriers to fish passage wherever possible, development can be more effectively managed. However, fishways are not the answer to mitigating all the impacts of barriers on fish; they are just one of the tools available in a range of mitigation actions possible; which must include the option of not building the barrier or removing old barriers. Fishways do have limitations on the type of barriers they can provide fish passage past; and they require minimum levels of knowledge to employ effectively, particularly in relation to the species expected to use them. Our first step with fishways should be to develop appropriate design criteria and demonstrate their effectiveness for fish in the Mekong Basin, next we should talk to engineers about how to build fishways using these design criteria, and the last should be to use fishways as a very powerful long-term fisheries monitoring tool. Then we can sit down with resource managers, developers and the community and demonstrate that fish passage is an important issue which needs to be tackled head-on now, not dealt with as an afterthought when the fish have already disappeared.

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