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Comparing fishway designs for application in a large tropical river system

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ABSTRACT

River infrastructure poses a serious threat to diverse and productive fish stocks in many tropical river-floodplain systems; particularly the Lower Mekong River, where the fisheries are vital for food security. Dams and weirs block fish migration pathways and prevent access to feeding, spawning or nursery habitat. Fishways are becoming increasingly important for mitigating the effects of barriers; however, knowledge regarding their effectiveness for the biodiverse tropical river systems is still scant. This study examined the effectiveness of differing low-cost fishway designs for rehabilitating degraded floodplain fisheries in the Lower Mekong Basin (LMB) in Laos: (1) vertical slot; (2) submerged orifice — 150 mm square opening; and (3) submerged orifice — 300 mm square opening. Day and night *in situ* field experiments were undertaken to compare the abundance, biomass, species richness and size range of fish able to pass through each design with relatively low drops between pools (i.e. 150 mm each) and low water velocities (i.e. 1.71 ms^{-1}). Passage of a total of 73 species was supported by the fishway designs at a similar abundance, biomass, species richness and size range of fish, during both the day and night; although, the vertical slot design supported a different suite of fish species to that of the other two designs during the day. This suggests that each of these fishway designs could be successfully used to support the rehabilitation of fisheries in the LMB and potentially other large tropical river systems with relatively diverse migratory fish communities and variable hydrological characteristics. However, the vertical slot provides greater design and operational flexibility over the submerged orifice designs particularly in tropical systems with inherently variable hydrology. The final fishway design choice ultimately depends on the fish species and size classes being prioritised for restoration and the unique hydrological characteristics of the site.

1. Introduction

The development of large tropical river-floodplain systems worldwide for irrigation and energy requirements, poses a threat to fisheries sustainability (Oldani and Baigún, 2002; Ziv et al., 2012). Large tropical river-floodplain systems typically contain highly productive and diverse fish communities that provide important environmental, social and economic benefits to their neighbouring human populations (Dudgeon, 2000; Winemiller, 2003). Yet, they are rapidly being exploited to construct dams, weirs, floodplain regulators and other management structures, which impede access to fish spawning, feeding and nursery habitat, and thereby prevent the completion of important life history stages (Dugan et al., 2010; Pringle et al., 2000). The fish in impacted systems often fail to spawn at all or do not recruit effectively (Pringle et al., 2000). Over time, these impacts reduce the diversity and productivity of the fishery, and ultimately the benefits of development projects (such as increased water security) may become negatively offset by the loss in fisheries resources (Baumgartner, 2016; Orr et al., 2012).

Recently there has been a growing emphasis on the use of fishways to ameliorate the barrier impacts caused by infrastructure in large tropical river systems (Baumgartner et al., 2012; Oldani and Baigún, 2002). Many fishway designs are available, with some of the more commonly used ones including vertical slot, pool and weir (e.g.

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submerged orifice) and Denil passes (Baumgartner et al., 2012; Stuart and Berghuis, 2002). However, despite the growing emphasis on the use of fishways, and the large number of designs available, little consideration has been given to empirically comparing their effectiveness to date (Foulds and Lucas, 2013; Schwalme et al., 1985). Much of the existing knowledge regarding the effectiveness of fishway designs has been for temperate species, and/or has come from laboratory-based trials (Mallen-Cooper, 1992), while little of the knowledge has been obtained via *in situ* field-based experiments (Baumgartner et al., 2012). In addition, most *in situ* studies only consider one design (Oldani and Baigún, 2002; Stuart et al., 2007), and/or have focused on the outcomes for individual economically important species, such as salmonids (Williams et al., 2012). Thus, *in situ* experiments that compare fishway designs and consider outcomes for whole fish communities, are likely to be fundamental for informing fishway design selection to maximise the sustainability of fisheries, particularly in large tropical river systems like the Mekong, where the fisheries play a critical role in supporting food security (Baumgartner et al., 2012).

The Mekong River is one of the largest rivers in the world, with a total length of 4800 km, and a drainage area of 795 000 km^2 (Lu and Siew, 2006). Its basin stretches from the Tibetan highlands all the way to the South China Sea through six countries: China, Myanmar, Lao PDR, Thailand, Cambodia and Vietnam (Dutta et al., 2007). The river is essentially regarded as a tropical system, apart from the relatively small upper section located in the Tibetan highlands (Kummu and Varis, 2007). Fish and other aquatic animals are immensely important throughout the Lower Mekong Basin (the LMB, which is the Mekong drainage within Lao PDR, Thailand, Cambodia and Vietnam), and provide on average 48% and 79% of the animal protein intake in Lao PDR and Cambodia, respectively (Hortle, 2007). However, the LMB is currently facing an unprecedented level of irrigation development (Orr et al., 2012; Ziv et al., 2012). Many dams, weirs and regulators are being constructed annually, and there are substantial concerns for the welfare of fisheries resources largely in part because of the impediments being imposed upon their migrations (Orr et al., 2012; Ziv et al., 2012). There is an urgent need to develop robust criteria, for fishway design, to incorporate into future development projects.

Presently there are two fishway designs which have been implemented in the LMB. Firstly, a vertical slot fishway was constructed in Cambodia (Bernacsek, 1997). The design was a direct copy of a similar system installed in Australia and has been recommended for installation at other sites (Baumgartner et al., 2012). Secondly, submerged orifice fishways have been extensively constructed in Thailand (Jutagate et al., 2001). These designs are primarily based on specifications developed for Northern Hemisphere salmonids (Roberts, 2001) and include both large and small orifices. In both cases, there was no evidence that local ecology was taken into account when these fishways were designed and constructed. But local species may differ from those upon which the original designs were based.

This study experimentally performed a preliminary examination on the effectiveness of existing fishway designs for rehabilitating degraded floodplain fisheries in the LMB in Laos. We sought to assess the characteristics of designs that had been previously used. These included (1) vertical slot (1400 mm high with a slot width of 150 mm); (2) submerged orifice — 150 mm square opening; and (3) submerged orifice — 300 mm square opening fishways. These fishway designs were based on existing fishways installed in the LMB. Determining success is an important pre-cursor to more detailed fishway experiments on internal hydraulics and performance. The study specifically focused on (1) vertical slot fishways, since they can operate with widely fluctuating headwater and tailwater conditions, and earlier investigations suggested that LMB fish species can use them (Baumgartner, 2016; Baumgartner et al., 2012); and (2) submerged orifice fishways, since despite being largely developed for salmonids, these fishways are still being widely constructed throughout tropical rivers globally (Baumgartner et al., 2012; Rodríguez et al., 2006). No comparative analysis has previously been performed of these fishways under field conditions in the Lower Mekong.

We aimed to assess fishway effectiveness during both the day and night to consider the potential influence of variation in diel fish movement patterns (Hard and Kynard, 1997; Morgan and Beatty, 2006). We hypothesised that (1) all of the fishway designs would be capable of supporting the movement of a range of LMB fish species and size classes during both the day and night; and (2) the vertical slot design would support the movement of a greater abundance, biomass and species richness of fish owing to its greater capacity to function under variable hydrological conditions. We assumed that the designs would significantly differ in terms of hydraulics. For the purposes of this comparative study, we did not attempt to standardise hydraulics. The intent was to investigate any fish passage differences in designs presently being implemented.

2. Methods

2.1. Study site

The LMB comprises 78% of the total Mekong River basin area, and has two distinct seasons — a wet season from June to October and a generally dry season for the rest of the year (Lu and Siew, 2006). Mean annual precipitation in the LMB ranges from over 3000 mm in Lao PDR and Cambodia to 1000 mm in the semi-arid Korat Plateau in Northeast Thailand (Mekong River Commission, 2003). The Mekong River level usually begins rising in May and peaks in September or October, with the average peak flow at 45,000 m^3 s^{-1}. Flows then start receding again and reach their lowest levels in March and April, at approximately 1500 m^3 s^{-1} (Kite, 2001).

The study was undertaken at a floodplain regulator, next to the Mekong River at Pak Peung village (Bolikhamxay Province) in the LMB in central Laos. The regulator was installed in the 1960s to prevent inundation of floodplain rice crops throughout periods of rising Mekong water levels during the wet season (Baumgartner et al., 2012). It is 10 m high and has three sluice gates, which can control water exchange between an upstream wetland and the river. The regulator completely obstructs upstream fish movements (from the river to the floodplain), but fish may move through the gates, from the floodplain to the river, when they are open (Baumgartner et al., 2012).

2.2. Fishway channel

At the time of this study, a concrete channel was being prepared for the construction of a permanent fishway adjacent to the regulator, between the river and the wetland. The permanent fishway was being constructed as part of a longer-term study, and local fish migration data were needed to inform its design requirements (Baumgartner, 2016). A steel fabricated fishway was placed within the concrete channel and comprised four pools, which were 1500 mm × 1000 mm in size. Larger pool sizes were considered, but accommodating a larger pool size would require greater volumes of water, which would increase the overall weight of the fishway. It was also expected that mostly small-bodied black species (fish that only live on the floodplain), grey species (fish which live in both the main stem and floodplain) and sub-adult white species (those species that live predominantly in main channel habitats), would attempt to access floodplain habitat, so a smaller pool size was selected (Baumgartner et al., 2012). The entrance to the concrete channel was situated at the upstream limit of migration on the Mekong River side of the regulator. Discharge through the channel was controlled by a sluice gate installed on the upstream side. Water levels in the channel were dependent on Mekong River levels, which vary with local rainfall. Nevertheless, the fishway channel was adjusted prior to the commencement of each experimental replicate, so that the water level in the fishway entrance aligned with that in the Mekong tailwater; thus protecting internal hydraulics. The fishway channel was operated