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Simultaneous assessment of two passage facilities for maintaining hydrological connectivity for subtropical coastal riverine fish

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ABSTRACT

Engineering solutions that aim to restore hydrological connectivity in river systems fragmented by dams and weirs frequently include the installation of fish passage facilities (i.e. fishways). Assessment of fish passage performance is often limited to single fishway designs and with a focus on species of commercial or conservation significance, meaning that conclusions regarding fishway success may not apply to all species that require access to fragmented habitats. We simultaneously compared the population structure and fish assemblage composition at two fishways (vertical slot and fish lock designs) at weirs in a subtropical coastal river system. We used hydrological and physico-chemical water quality data to explore if fishway performance was linked to particular environmental conditions. At both fishways, fish assemblage composition differed between fishway exit and downstream river samples, yet differences between exit and river samples were not associated with hydrological variables related to the size and frequency of weir drown-out events or water quality. Population structure of the most abundant species (sea mullet, *Mugil cephalus*; 61% of fish samples) also differed significantly among fishway exit and river habitats. A low-level structure spanning the river channel downstream of one weir was not associated with differences in fish assemblage composition indicating that access to the fishway entrance (and therefore fishway use) was not hindered by in-stream obstructions. Eight and seven species (predominantly small-bodied species that migrate within freshwater systems) were exclusively sampled in downstream river locations at the vertical slot and fish lock fishways, respectively, indicating that neither design was fully capable of facilitating the passage of the local fish fauna. Further assessment over a broader range of hydrological conditions will be necessary to determine if use of either fishway by fish is affected by low flows. Coupled with evidence produced from landscape-scale analysis of spatial and temporal variation in fish assemblage structure and dispersal patterns of diadromous species associated with river flow regime highlight that hydrological connectivity may be maintained by natural weir drown-out events. This study highlights that factors controlling hydrological connectivity for riverine biota need to be integrated among co-occurring anthropogenic impacts to identify and overcome constraints to effective conservation management in rivers subject to water resource development.

1. Introduction

Hydrological connectivity within the majority of the world's river systems has been altered by anthropogenic activities (e.g. dam and weir construction) to enhance water security, control flooding, and generate electricity (Fullerton et al., 2010). These activities typically decrease riverine connectivity, leading to fragmented species populations and changes to multi-species assemblages (e.g. Joy and Death, 2001; Gehrke et al., 2002; Mueller et al., 2011; Yoon et al., 2017; Newton et al., 2018). Equally, longitudinal hydrological connectivity can be increased by dams that create reservoirs over natural obstacles or by elevated discharge of water downstream of dams (e.g. Vitule et al., 2012). Because connectivity and dispersal are key aspects of riverine fish populations and their productivity, the provision of passage facilities is often required when constructing and operating dams, weirs and culverts to mitigate the effects of water resource infrastructure on aquatic fauna (Muir and Williams, 2012).

There are multiple ways in which hydrological connectivity can be managed to provide adequate passage for riverine fish (Harris et al., 2017). When artificial riverine infrastructure has ceased to provide human benefits, complete removal of these redundant barriers can restore longitudinal connectivity to habitats necessary for sustaining

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Table 1
Summary of published studies empirically assessing the performance of passage facilities on longitudinal dispersal by riverine fish in Australia sourced via Web of Science.*

Location	Fishway design	Sampling approach	Level of ecological organisation	Key findings	References
Cardinia Creek, Victoria (coastal)	Baffles retrofitted to pipe culvert	Before-after control-impact	Population	Probability of successful passage of juvenile *Galaxias* spp. increased from 0.03 to 0.41 following modification by reducing water velocity through the culvert	Amtstaetter et al. (2017)
Murrumbidgee River, NSW (inland)	Deelder fish lock	Paired entrance-exit samples	Population and assemblage	Deelder lock was effective in the upstream passage of broad size range of native fish, albeit abundances of fish sampled in exit traps were lower than entrance traps	Baumgartner and Harris (2007)
Murray River, NSW/Victoria (inland)	Vertical slot	Paired entrance-exit samples, tagging of individuals moving through fishway	Population and assemblage	Fishways can still restrict small-bodied fish movement upstream, but no species was entirely prevented from dispersing via fishways	Baumgartner et al. (2010)
Murray River, South Australia (coastal)	Vertical slot	Paired entrance-exit monitoring of two fishways with different slot widths and channel hydraulics	Population and assemblage	Composition of fish passing each fishway was similar between differing fishway dimensions, however passage efficiency of small (< 100 mm) bodied taxa was greater for smaller vertical slot designs	Bice et al. (2017)
Cotter River, ACT (inland)	Rock ramp	Longitudinal monitoring of Macquarie perch upstream and downstream of a newly installed fishway	Population	Post-installation monitoring showed that Macquarie perch had expanded their population, spawning and nursery distribution throughout the upper Cotter River	Broadhurst et al. (2012)
Cotter River, ACT (inland)	Rock ramp	Longitudinal monitoring of Macquarie perch upstream and downstream of a newly installed fishway	Population	Range expansion of Macquarie perch was delayed with no fish detected upstream of the fishway in the first two years following construction	Broadhurst et al. (2013)
Tributary of the Picton River, Tasmania (coastal)	Baffles retrofitted to pipe culvert	Addition of individual *Galaxias* spp. at the downstream end of culvert (control or treatment) and observing fish moving upstream	Population	Passage of fish in treatment culverts was 73–86 times greater than in control culverts. Passage in control culverts decreased with increasing discharge for both study species, yet passage of *Galaxias truttaceus* was not impacted by discharge in treatment culverts	MacDonald and Davies (2007)
Murray River, NSW/Victoria (inland)	Vertical slot	Paired sampling at fishway entrance and along fishway channel	Population and assemblage	Many fish species use fishways more so during daylight conditions than under low light; exposing fishways to natural light could enhance fishway use	Jones et al. (2017)
Murray River, NSW/Victoria (inland)	Salmonid fishway (pools separated by baffles)	Paired entrance and exit trapping samples, ongoing exit trap monitoring spanning a 55 year period	Population	Many native fish were either unable to ascend the fishway or in much lower numbers compared to those attempting to disperse upstream. Dispersal of small bodied size cohorts was often inhibited by the fishway. Fish passage monitoring is a low-cost approach to determine long-term trends in fish biodiversity, population size, and productivity	Mallen-Cooper and Brand (2007)
Murray River, NSW/Victoria (inland)	Denil	Paired entrance and exit trapping samples	Population	Denil fishway designs can be modified or designed to facilitate the passage of a wide range of species based on differences in swimming abilities	Mallen-Cooper and Stuart (2007)
Goodga River, WA (coastal)	Vertical slot	Paired manipulative dewatering of fishway and sampling of fish upstream and downstream of the weir	Population	Installation of fishway increased usable habitat for *Galaxias truttaceus* and *G. maculatus* and the fishway passed comparable sizes of fish that were present downstream. Migrations of recruits occurred during low flow	Morgan and Beatty (2006)
Burnett River, QLD (coastal)	Vertical slot (upgraded from a pool and weir fishway)	Paired entrance and exit samples	Population	Retrofitting of vertical slot fishway lead to a 33-fold increase in the number of individuals ascending fishway; passage of small fish remained hindered by vertical slot fishway and width of slots can hinder movement of larger taxa. Wide pools and low turbulence pass greatest range of taxa	Stuart and Berghuis (2002)
Fitzroy River, QLD (coastal)	Vertical slot (upgraded from a pool and weir fishway)	Paired entrance and exit samples	Population	Vertical slot design allowed upstream passage for a broader range of species and size classes of fish, although organisms with poor swimming abilities were unable to fully negotiate the fishway. Passage facilities are likely to have a maximum passage rate	Stuart and Mallen-Cooper (1999)
Fitzroy River, QLD (coastal)	Fish lock	Paired entrance and exit samples	Population	Fish locks may be unsuitable for rivers with variable hydrology, but under low flows, fish locks are capable of transferring broad size range of fish and most taxa within the downstream vicinity of the weir	Stuart et al. (2007)
Murray River, NSW/Victoria	Vertical slot	Paired entrance and exit samples	Population	Small bodied taxa and individuals were hindered in their upstream migrations by the fishway	Stuart et al. (2008a,b)

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