# Science for Policy

## Research findings in brief

Project 3.3.7

Threatened Species Recovery Hub

National Environmental Science Programme

# Interactions between water depth, velocity and body size on fish swimming performance: Implications for "fish-friendly" culvert design

## In brief

Culverts are everywhere in urban and rural landscapes. Designed primarily to move water, they often create issues for fish movement. While there is a general consensus that larger fish struggle with shallow water, and smaller fish struggle against higher water velocities, there has been no data specific for Australian fish available to aid fisheries managers and civil engineers designing 'fish-friendly' structures. In this study, we start to fill this knowledge gap, providing data for silver perch, eel-tail catfish and Murray cod. These species cover a range of body types with varied swimming capabilities and can act as proxies for similarly sized or shaped species. We quantified and compared their performance and rates of traversing a 12-metre experimental channel under nine treatments: three water depths and three water velocities for each species. We found that while shallow water and fast-moving water generally impeded swimming performance, fish size and differences between species determined the magnitude of the effect on swimming performance and traverse success. Our study provides the first quantitative data for Australian fish species that waterway and catchment managers can use when designing and adapting manmade barriers for fish passage. Adopting culvert designs that reflect these findings will help achieve positive outcomes for communities of declining and threatened native freshwater fish.

## Context

Freshwater ecosystems support more than 40% of all fish diversity; however, these habitats are seeing large declines in fish populations in Australia and around the world. The declines are due to a range of human activities, including the construction of barriers to fish passage, such as dams, weirs, barrages, road-crossings and culverts, that fragment habitats and reduce waterway connectivity. These limit the movement of adult and juvenile fish, preventing them from accessing preferred habitats including spawning grounds and foraging areas, and impacting their ability to avoid predators. Reducing the impact of manmade barriers on native fish populations requires an understanding of fish movement abilities, and an understanding of how, why and when culverts impede fish movement.

The swimming capacities of fish are directly influenced by the movement and behaviour of water in their environment ('hydrodynamics'). Culverts can significantly alter the hydrodynamics of waterways, particularly affecting water velocity and depth, which can significantly limit the capacity of fish to swim through/past the structure. Additionally, the capacity for fish to respond to these environmental changes is constrained by fish size: for example, big fish can swim faster than small fish and so are less likely to be negatively affected by high water velocities through culverts. However, culverts often change multiple hydrodynamic properties of the waterway simultaneously.

*Figure 1. A large and small Murray cod swimming in the same shallow water conditions in the experimental channel. The large fish struggles to make headway in the shallows water while the small fish has progressed much further along the channel. Images: Jabin Watson*

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## Context (continued)

Understanding how different hydrodynamic properties interact to affect the swimming performance of different sized fish in the environment is important for designing effective 'fish-friendly' culverts or remediating existing structures.

Although the performance of smaller fish should be reduced with increasing water velocity, while larger fish should be increasingly challenged by decreasing water depth, these assumptions were largely based on studies of high performing north American and European fish species, and there were no data available specific to Australian fish species.

We aimed to address this knowledge gap by examining the swimming performance of juvenile and sub-adult fish of three large-bodied native Australian fish species – silver perch (*Bidyanus bidyanus*), eel-tail catfish (*Tandanus tandanus*) and Murray cod (*Maccullochella peelii*) – all three of which are both ecologically and recreationally important. These three species have maximum recorded adult sizes of 40 cm, 90 cm and 180 cm, respectively. Physically, they cover a range of body sizes, types and swimming styles. Murray cod may undertake seasonal upstream migrations of up to 130 km; however, they and eel-tail catfish generally inhabit slower moving waters and often move less than 10 km from their home range. By contrast, silver perch are excellent swimmers that prefer fast-flowing waters and migrate large distances (> 500 km) upstream.

Populations of all three species have declined by up to 90% in Australian waterways since European arrival. These declines are largely due to artificial barriers to fish movement and extensive regulation of water flows. While there is a significant body of research into improving fish passage at large-scale barriers like weirs, much less attention has been given to small-scale barriers like road crossings and culverts, which numerically account for the majority of barriers to fish passage. Culverts are relatively inexpensive structures designed primarily to maximise their water carrying capacity. However, an increased understanding of the potential for poorly designed culverts to significantly affect fish passage in Australian waterways has meant that new culverts also need to consider the movement requirements of fish in the local environment. Good culvert management, including culvert design that is more effective for fish passage, especially in the middle and upper catchments of the Murray–Darling Basin, can therefore help with recovering the populations of these threatened fish species.

*Figure 2. Depth and velocity are highly dynamic in the field. These images are of the same culvert taken less than 24 hours apart, and show how the depth and velocity changes over time, but also that it can differ between cells within the same culvert. Images: Jabin Watson*

Juvenile Murray cod ready to swim. Photo: Jabin Watson

## Research aims

In New South Wales, current culvert guidelines make recommendations about maximum water velocities (0.3 m $s^{-1}$) and minimum depths (0.2 m); however, despite best practice in the design and construction of new culverts, the planned velocity and depth can be limited by local rainfall and weather extremes. Both high water velocities and shallow water depths are undesirable for fish passage: high water velocities negatively impact the movement of small-bodied fish, while shallow depths negatively impact the movement of larger fish. We aimed to understand how water depth and velocity interact to influence the swimming performance of different size classes of Australian fish.

We hypothesised that high velocity water would reduce the swimming performance of all fish, but that large fish would be disproportionally more affected at shallow water depths. We used endurance capacity (the capacity of fish to maintain their position in the experimental channel without fatiguing), and transverse success (the capacity of fish to move 8 m upstream in the experimental channel) as our metrics of fish performance. We set 8 m as traverse distance as this is the most common length of culverts in New South Wales.

## What we did

For this study, we used a 12-metre experimental channel at the Biohydrodynamics Laboratory at The University of Queensland. We sourced fish of the three species as juveniles from commercial hatcheries and transported them to the laboratory, where they were separated by species, kept in tanks under controlled conditions and fed once daily to satiation. We fasted the fish for 24 hours before each swimming performance trial to ensure food from the last feeding had been digested.

We swam each of the three species in nine treatments, which consisted of three water velocities (species-specific, to reflect their different swimming capabilities) at three water depths (5, 10 and 15 cm, kept constant across the test species). We measured how long it took the fish to fatigue (capped at 60 minutes) and their traverse success rates over 8 m of flume length. We then determined how the three factors of water velocity, depth and fish body size interacted to affect the swimming performance of the three fish species.

For the Murray cod and eel-tail catfish, we quantified endurance swimming performance by measuring how long it took for the fish to fatigue at a constant water velocity and depth. We simultaneously quantified traverse success by recording whether or not the individual fish traversed 8 m of the flume without encouragement from the point of release.

We treated the silver perch slightly differently. In their case, we quantified swimming performance as the time taken for the fish to traverse up to 8 m of the flume from the point of release. We used this method due to the exceptionally strong performance of adult silver perch and the physical limitations of the flume: beyond a maximum water velocity at each of the test depths, further increases in velocity would cause the depth to increase. During each trial, individual silver perch that did not traverse 8 m of the flume had their time to fatigue recorded; for individual fish that successfully traversed up 8 m of the flume, the time taken to complete the 8 m traverse was recorded.

## Key findings

Swimming endurance times decreased with decreasing water depth and increasing water velocities for Murray cod and eel-tailed catfish, but not silver perch. Larger Murray cod and eel-tailed catfish could not swim for longer than their smaller counterparts, particularly at shallow depths and high velocity waters. Silver perch were the strongest swimmers, with larger fish having shorter traverse times independent of both water depth and velocity.

For all species, traverse success increased with increasing water depth: fish were less likely to fatigue and to show longer swimming endurance times in deeper water. Conversely, fatigue set in earlier at shallower depths: fish were significantly more likely to fatigue when swum at 5 cm depths compared with fish swum at 15 cm depths.

High water velocities generally predicted poor fish traverse success across all three species; however, the performance of big fish (>200 mm) was less severely affected by high water velocities than that of small fish. Nevertheless, when large fish were swum at high water velocities and shallow water depth, their performance was significantly poorer than when they were swum at the same velocity in deeper water. This suggests that shallow water can surpass velocity as the main challenge to the swimming performance and traverse success rates of large body fish species.

Importantly, for Murray cod and eel-tailed catfish, the magnitude of the impact of water velocities and water depths was non-linear ('U' shaped) across the range of body sizes examined in this study. This means that water depth and water velocity had disproportionally larger negative effects on the smallest and the largest fish of the species (i.e., fish that were less than 100 mm or greater than 250 mm in length). Smaller-sized fish had an increased risk of fatigue and shorter endurance times in high water velocities compared to larger-sized fish; however, larger fish were only advantaged until shallow water depths limited their ability to swim.

Despite silver perch displaying stronger swimming capabilities and a higher probability of traverse success for all test velocities, the largest individuals were hindered by shallow water depths, with some observed resorting to swimming on their sides. This mode of swimming is likely more energetically costly, and may explain why silver perch larger than 250 mm were less likely to traverse the full length of the flume at the shallowest water depth than smaller members of the species.

## Cited material

Shiau, J., Watson, J., Cramp, R., Gordos, M., Franklin, C. 2019. Interactions between water depth, velocity and body size on fish swimming performance: Implications for culvert hydrodynamics. *Ecological Engineering* 156:105987. doi: 10.1016/j.ecoleng.2020.105987.

## Related work by the Franklin Eco-lab

For an overall project summary please visit: https://www.nespthreatenedspecies.edu.au/_images/Projects/3.3.7%20Fish%20barriers%20Factsheet_v4.pdf

Swimming performance data for Australian species was scarce before we characterised twenty-one native fish species using a range of equipment and metrics. https://www.nespthreatenedspecies.edu.au/3.3.7%20swimming%20performance%20of%20fish_V3.pdf

We developed a novel culvert remediation design that greatly improved swimming endurance times and rates of traverse success in an experimental channel. https://www.nespthreatenedspecies.edu.au/3.3.7%20fish%20barriers%20findings%20factsheet.pdf

## Implications and recommendations

Our findings have important implications for understanding how common hydrological conditions generated in culverts can affect fish movements and the probability of the structures successfully passing fish. Importantly, the nature of the interaction between water depth, velocity and body size on swimming performance is complex and highly species-specific. Consequently, fisheries managers and civil engineers tasked with designing or managing culverts for fish passage need to consider that these hydrological variables do interact to affect fish swimming performance, and the effects differ both across and within species, reflective of their morphology and individual size.

The challenges facing the management of fish passage in highly modified freshwater systems are amplified by the effects of climate change. Reduced rainfall and prolonged droughts in localised regions can extend the dry season. This can cause shallow water depths which will largely have a negative effect on fish movement, particularly for larger fish, potentially reducing the spawning movements of large-bodied silver perch and Murray cod.

Although our understanding of how to mitigate the impacts of in-stream barriers to fish passage in Australia's highly variable environment is improving, significant knowledge gaps remain, especially for culverts with poor water flow conditions. We recommend working to increase our understanding of how specific culvert conditions impact the health and survival of fish species so that the design guidelines and regulations for new structures can continue to be improved for sensitive freshwater environments.

## Further Information

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*Juvenile eel-tailed catfish. Photo: Jabin Watson*

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