Science for Saving Species

Research findings factsheet

Project 3.3.7

Threatened Species Recovery Hub

National Environmental Science Programme

Breaking down barriers to fish passage

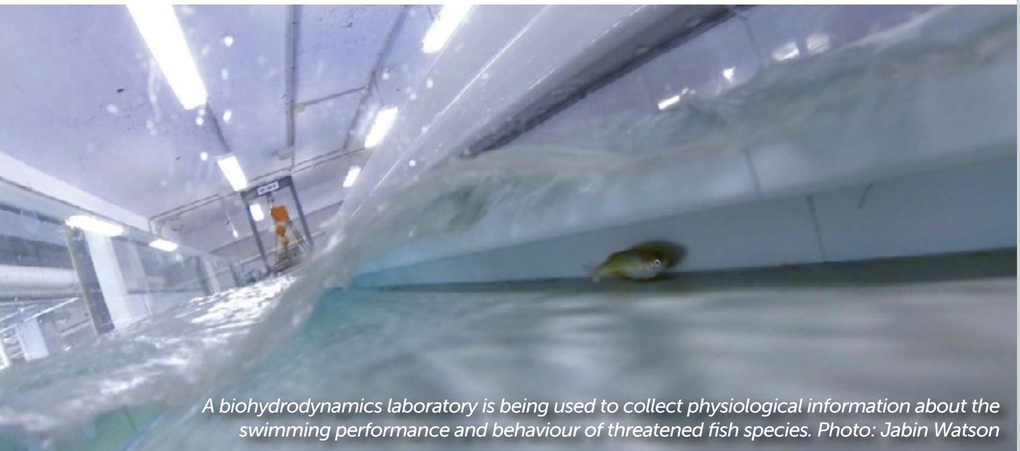
Fish passage: Defining the problem

Freshwater ecosystems are one of the habitats most threatened by human activity. The fish that inhabit these diverse freshwater ecosystems are a direct resource for humans, but their role in maintaining the health, functionality and ecosystem robustness is often ignored. In the Murray-Darling Basin, native fish are estimated to have declined to just 10% of pre-European levels.

A major cause of fish population declines, and the cascading losses of freshwater biodiversity, is habitat fragmentation. This fragmentation is caused by artificial instream barriers such as dams, weirs and culverts (the pipes that carry water under roads, railways and embankments). There are over 5000 such physical barriers in New South Wales alone. These barriers prevent fish from migrating, accessing habitat and escaping predators.

Culverts were originally designed to maximise their water carrying capacity with little to no regard for fish passage. This is a problem because when streams pass through a culvert, the flow is concentrated, which increases the speed of water flowing beneath them. These high water flows can be impossible for many native fish to navigate as they can't swim fast enough for long enough. Smaller species and juvenile fish are particularly impacted.

Previous efforts aimed at improving fish movement through culverts primarily focused on large-bodied, commercially important species like salmon and sturgeon, so the swimming abilities of smaller-bodied and juvenile Australian fishes was a major knowledge gap. Our research addresses this knowledge gap. We have developed and tested a new culvert remediation design that significantly improves the performance of juvenile and small-bodied Australian fish species in high-velocity water flows.



A biohydrodynamics laboratory is being used to collect physiological information about the swimming performance and behaviour of threatened fish species. Photo: Jabin Watson

Existing culvert fish passage designs

The current design of many culverts combines concentrated flow with decreased surface roughness (smooth culvert surfaces). This increases the speed of water flow through the structure and eliminates any low velocity areas that fish could exploit to rest or traverse the culvert. Current strategies that aid fish to pass through culverts include increasing the culvert cross-sectional area, adding baffles or roughening the channel bed by attaching rocks to the floor of the culvert.

Increasing the channel cross-section reduces the concentration of the flow, but can make the water too shallow for some fish species under low flow conditions. Baffles slow the flow of water behind them, providing rest areas that some fish can use to recover after making it past a previous baffle. Bed roughening increases the friction at the water-culvert interface which slows the speed of the water close to the surface – this slower flowing area is known as the 'boundary layer'.

Although these strategies have been effective in allowing a number of larger-bodied commercially important fish species and some small-bodied native Australian fish to traverse culverts, they are not without their problems. Both baffles and bed roughening can create a lot of turbulence in the water flow that can be too great for fish to swim against.

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Existing culvert fish passage designs (cont)

They may also trap debris, which can cause water to back up behind the culvert, making them an ongoing maintenance concern. When devising novel alternatives to the current remediation strategies, the team purposefully considered these impacts to civil performance.

Most native fish would be unable to move past this road culvert under most flow conditions. Photo: Matthew Gordos

Our research

To close the knowledge gap about small-bodied and juvenile fish, we tested the swimming ability of six native Australian fish species that are less than 10 cm in total length – glassfish (*Ambassis agassizii*), Pacific blue eye (*Pseudomugil signifer*), empire gudgeon (*Hypseleotris compressa*), and juveniles of golden perch (*Macquaria ambigua*), eel-tailed catfish (*Tandanus tandanus*) and Murray cod (*Maccullochella peelii*). These species are endemic to Australia and represent a variety of body shapes, levels of swimming performance and ecological habits, allowing them to act as proxies for other species.

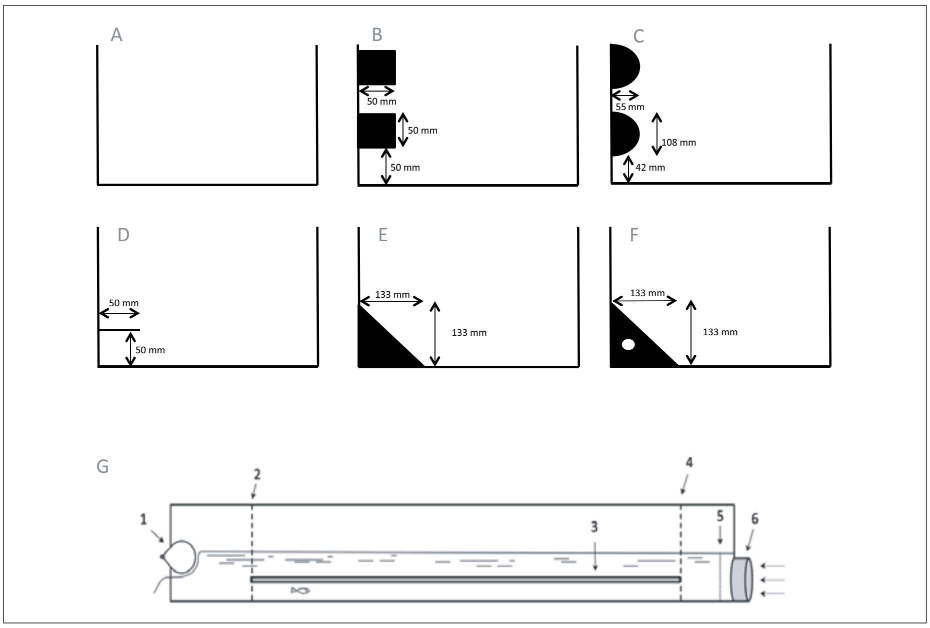
The team used these six species to test the effectiveness of three novel fish passage designs and two baffle designs, when compared to a control channel with no internal modifications.

In developing these new fish passage designs, we built on previous work and observations showing that native Australian small-bodied and juvenile fish tended to position themselves in the corner of the channel where the boundary layer of the bed and wall join. When adjoining boundary layers merge, they create a zone which is larger than the thickness of an individual boundary layer. To exploit this phenomenon, we developed a beam design that runs the length of the channel.

Our hypothesis was that if positioned on the wall near the corner of the channel, the beam would introduce a third boundary layer that would merge with the other two boundary layers to create an even larger low velocity zone that fish could then utilise. We expected the fish to actively seek out these regions to enhance their swimming endurance and increase their ability to traverse culverts.

The team created beams that were square, round and a ledge in cross-section, and compared these to two novel triangular baffle treatments spaced 0.66 m apart that have been shown to have the best compliance with the civil requirements of available baffle designs. We measured the velocity of the zone under the beams, and near the baffles and compared these to other parts of the channel under different rates of channel flow.

Figure 1 (below): Schematic diagram of flume setup and cross-section profiles of the designs. We tested a control channel (A) against a square beam (B), circular beam (C), ledge (D), baffle (E) and baffle with hole (F). B, C and D ran longitudinally through the channel, while E and F were spaced 0.66 m apart. Schematic representation of 12 m glass flume (G) used throughout the swimming trials showing the depth adjustment gate (1), wire barrier to catch fatigued fish (2), culvert remediation design (3), wire barrier to prevent fish entering the inlet chamber (4), flow straighteners (5) and the water inlet (6). Not drawn to scale.



Findings

The square, circle and ledge designs all expanded the area of the lower-velocity zone in the corner of the channel. This reduced velocity zone under the beam was extensively utilised by the fish in the trials. In the square design, the velocity in this zone was reduced by up to 30% compared to the main channel flow rate.

All three beam shapes significantly benefited all of the fish species examined. The square profile provided the greatest benefit across a range of body types and swimming styles. The square beam design was the only treatment to significantly increase fish swimming endurance across all species compared to the smooth control channel and to significantly increase traversability in four of the six species.

The data showed that the beam designs also caused minimal change to the channel's overall hydraulic performance, which was tested by comparing to the smooth control channel. Compared to baffles and bed roughening, the beams had far less impact on discharge capacity and given their streamline shape, are also less likely to accumulate debris. This may give beam designs added appeal to infrastructure managers and increase their utility for fish passage in new and remediated culverts.

The two baffle designs tested were the only modifications that had a negative effect on the ability of fish to swim. They even decreased the average endurance times of some species when compared to the smooth control channel. Baffles can generate a lot of turbulence at high water velocities which may impair the swimming capacity of the fish. The implications of this for small-bodied and juvenile native fish are significant, as this is currently a widely used remediation strategy.

The beam designs did not create high turbulence , and increased the swimming performance of all fish tested, regardless of differences between species morphology and ecology. Also in contrast to the triangular baffles, the fish were very often found to be within or close to the beam designs. We propose that in addition to the favourable hydraulic conditions for swimming performance that these beam designs create, they may also act as a behavioural refuge for small fish from predators.

The biohydrodynamics flume with two circular beams installed, prior to filling with water. Photo: Jabin Watson

Our methods

The research utilised a 12-metre-long flume in the biohydrodynamics lab at The University of Queensland. Fifteen individuals from each species were individually swum and we recorded their endurance swimming capacity – or time taken to fatigue at a set water velocity – across each modification treatment and the smooth channel control. Swimming trials lasted a maximum of 60 minutes and no fish were swum in the same treatment more than once. All fish were rested for at least 14 days between trials to prevent training effects.

We also measured traverse success, which we defined as the ability of the individual to move through 8 m of the channel without encouragement (the average length of a culvert in New South Wales waterways ranges from 8 to 10 m in length). Additionally, we determined if performance improvements were due to the fish utilising the modification by timing fish position during each swimming trial. Utilisation was defined as the fish swimming underneath, behind, above or directly beside the modification where the slower flowing water was created by the fishway design.

Juvenile eel-tailed catfish in holding tanks at The University of Queensland. This species is affected negatively by culvert designs that generate turbulence. By avoiding generating turbulence, the beam designs greatly improved their swimming endurance. Photo: Jabin Watson

Where did the fish come from?

Commercial hatcheries in south-east Queensland supplied the fish, which we held in 40 L aquariums that formed part of three 1000 L recirculating systems, in turn part of a 40,000 L custom-built biohydrodynamics laboratory and fish-holding facility at The University of Queensland. We maintained water temperature at 25°C, exposed the fish to a 12:12 light–dark cycle, and fed them to satiation daily with commercially sourced pellets and frozen bloodworms.

The high velocities of concentrated water coming through most culverts are difficult for small or juvenile fish to pass. Photo: Matthew Gordos

BELOW: Freshwater Catfish (Tandanus tandanus). Photo: Gunther Schmida www.guntherschmida.com.au.

Summary

A square beam installed along the wall of the channel a small distance above the channel bed created a zone under the beam which reduced water velocity in this area by 30% compared to the main channel. This design increased the swimming endurance of all six fish species tested and increased the traversing ability of four of the six species.

The beam designs out-performed both of the novel baffle designs in improving fish passage and maintained overall channel hydraulic performance. The square design is the most promising so far of the three beam designs tested for use as a fish passage strategy for new and existing culverts.

We have begun work to optimise the dimensions of this chosen profile design to maximise the reduction in velocity in the zone below the beam. Following field trials, deployment of the device may help restore populations of native fish.

References

Watson, J. R., Goodrich, H. R., Cramp, R. L., Gordos, M. A., & Franklin, C. E. (2018). Utilising the boundary layer to help restore the connectivity of fish habitats and populations. *Ecological Engineering*, 122, 286–294. http://doi.org/10.1016/j.ecoleng.2018.08.008

Further Information

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