Department of Water
Government of Western Australia

Reconnecting off-channel habitats to waterways – using engineering techniques to restore fish passage.

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Abstract

The Department of Water (previously the Department of Environment) has been involved in the construction of several fishways to restore fish passage along waterways. These include rock ramp fishways built at weirs on Margaret River in the Margaret River town site and the Hotham River in Boddington. A vertical slot fishway has also been installed on the Goodga River near Albany. These fishways have successfully facilitated the migration of native freshwater fish over the weirs for breeding and other lifecycle processes. Additionally, two waterway crossings have been retrofitted to enable fish passage through road culverts.

Restoring the longitudinal connection along a waterway is only part of the approach needed to restore habitats for native fish. Lateral connections to floodplains, wetlands, anabranches and billabongs are also important. Altered hydrologic regimes, due to river regulation, channelisation, weirs and dams, have restricted the availability of these areas as habitats for fish and other aquatic organisms.

Floodplains, wetlands, anabranches and billabongs provide important feeding areas, spawning and nursery habitats and provide protection during flood events. However, there has been very limited restoration of lateral connectivity (between waterways and off-channel habitats) in Western Australia.

This paper will outline the recent success in applying fishway technology to restore fish passage on waterways in south-west Western Australia and how these techniques could be used to restore connections between off-channel habitats and waterways in order to facilitate fish migration and improve freshwater fish habitat.

Introduction

The restoration of fish passage is still a fairly new concept in Western Australia and to date, has only considered the restoration of longitudinal fish passage (fish passage along the length of a waterway). The Department of Water has successfully completed a number of projects to restore fish passage over weirs along waterways in the south-west of Western Australia since 2003 (Torre *et al. in press*). These projects have allowed native south-west freshwater fish species to successfully migrate upstream to undertake life-cycle processes (Morgan and Beatty 2003; Morgan and Beatty 2004a; Morgan and Beatty 2004b; Morgan and Beatty 2004c; Morgan and Beatty 2005).

Many fish species also benefit from access to an off-channel habitat, such as a floodplain, wetland or billabong, for breeding and feeding (Junk *et al*. 1989). Aquatic fauna access these areas during flooding or high flow events, and have potentially adapted to these events and a regular connection to off-channel habitats (Bayley 1995; Junk *et al*. 1989).

Since European settlement, changes to the natural hydrological regime, including weirs, dams, diversions, allocation and levees, have caused a disconnection between off-channel habitats and the main channel of waterways. Aquatic fauna in the main channel are no longer able to access important habitat in off-channel areas to coincide with life-cycle events.

Major projects to reconnect off-channel habitats are currently being considered in Eastern Australia (Graham and Harris 2005; Nichols and Gilligan 2003; Mallen-Cooper 2001). However no work has been undertaken in Western Australia. The engineering approaches that have been successfully used to restore longitudinal fish passage (such as fishways, waterway crossing retrofits and minor earthworks) can also be applied to lateral fish passage (i.e. access to off-channel habitats). This paper will highlight how the techniques that have been successfully applied in Western Australia to facilitate fish passage can also be used to reconnect off-channel habitats.

Importance of off-channel habitat

Off-channel habitats are habitats that are adjacent to the main waterway and are hydrologically linked during overbank flows. These areas include floodplains, wetlands, billabongs and anabranches.

Off-channel habitats are extremely productive areas, and floodplains and off-channel wetlands are used for agriculture and farming worldwide (Bayley 1995). During flooding these areas are replenished with silt, nutrients and organic matter washed from upstream (Bayley 1995; Cullen 2001). Likewise these areas provide important inputs into the main channel during flooding events, as nutrients, plant matter, detritus and sediments are washed back into the main channel (Junk *et al*. 1989). These flood-pulses contribute significantly to nutrient cycling in the waterway ecosystem (Junk *et al*. 1989) (Figure 1).

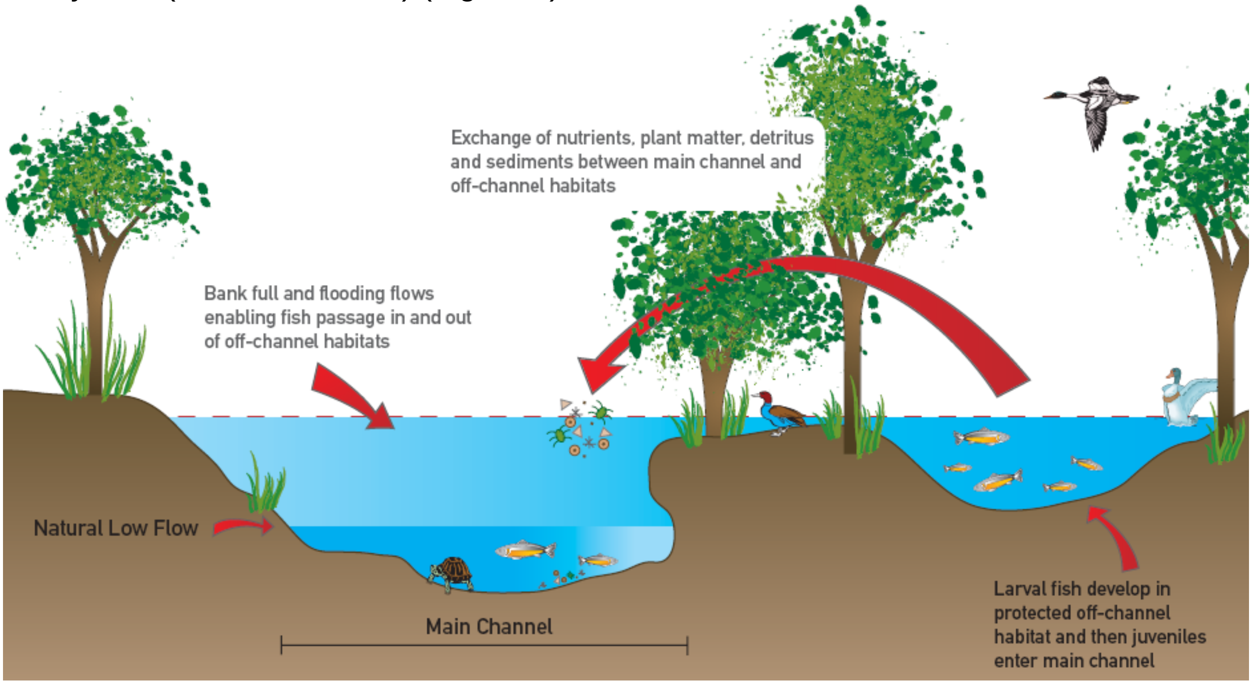

*Figure 1***.** Connections between main channel and off-channel habitats**.**

Off-channel habitats are extremely diverse and, under flooding conditions, many animals emerge from eggs, cysts and burrows in the soil (Cullen 2001). Upon wetting these areas become extremely productive (Cullen 2001). A variety of aquatic fauna, including fish, move from the main channel to off-channel habitats during overbank flows and off-channel areas provide important habitats for these species.

The Flood Pulse Concept details how a floodplain or off-channel area is adapted to regular flooding and a recurring connection to the main waterway channel (Junk *et al*. 1989). Flood events are part of the natural hydrological regime and the off-channel environment has adapted accordingly (Junk *et al*. 1989). Changes in water level are often breeding cues for fish, which have adapted to utilise the off-channel areas for these and other life cycle processes. Fish use off-channel habitats for a variety of reasons, including shelter, feeding, spawning and recruitment (Junk *et al*. 1989). Off-channel habitats provide shelter during flood events, away from the fast flows of the main channel. The slow water velocity and high productivity of off-channel habitats makes them important feeding and nursery areas. Spawning in off-channel habitats can provide larvae and juveniles with safer conditions (e.g. protection from predation) and more food than the main waterway channel.

Many south-west Western Australian fish breed and shelter in off-channel habitats. The Western mud minnow (*Galaxiella munda)* spawns among flooded fringing vegetation (Pen 1999). The Western pygmy perch (*Edelia vittata)* will spawn in well-vegetated floodwaters (Pen 1999). Larval Western trout minnow (*Galaxias truttaceus hesperius)* will feed in lake nursery areas and then migrate back into the river system (Department of Environment and Heritage 2006). Balston's pygmy perch (*Nannatherina balstoni*) is commonly associated with inundated riparian vegetation (Department of Environment and Heritage 2005).

Although these species use off-channel habitats, there has been little research done on the importance of these habitats for south-west Western Australian fish. Fish movement during flooding is generally unknown, and the dependence on off-channel habitats has not been thoroughly researched.

Disconnection of off-channel habitats

River management since European settlement has seen the regulation of rivers and the proliferation of drains, dams, weirs, diversions and levees. Water abstraction and allocation is widespread and many major waterways no longer receive natural flows, resulting in a decrease in flood frequency. Previously an off-channel wetland or billabong may have been inundated every 2 out of 3 years during an event that overtopped the banks of the main channel, providing access to these habitats for aquatic fauna. A decrease in this flood frequency can result in major impacts on the river ecology.

However in some areas of Western Australia, such as the Wheatbelt, there are increased river flows due to catchment clearing. Many waterway modifications, such as the construction of drains and levees, have been undertaken for flood protection and land drainage. These modifications have separated the connection between off-channel habitats and the main river channel and resulted in floodplain areas receiving less frequent inundation.

The flooding of off-channel habitats is an essential process for many waterway ecosystems and has been described as the Flood Pulse Concept (Junk *et al.* 1989).

The effects of disconnection on the biota and ecology of off-channel habitats is poorly understood (Kingsford 2000). Barriers along waterways have been shown to cause local extinction of migratory species upstream and possibly downstream (Pethebridge *et al.* 1998). Several projects are currently being conducted in the

Eastern States to assess barriers to fish passage within off-channel habitats (Leigh and Zampatti 2005) and assess the requirements for fish to access off-channel habitats (Graham and Harris 2005; Nichols and Gilligan 2003; Mallen-Cooper 2001).

In some instances off-channel habitats are in better condition than the main waterway, for example where the waterway has been subject to channelisation, desnagging, vegetation clearing or erosion. In these cases, restoring connection to the off-channel habitat will provide aquatic fauna with access to a good condition habitat as well as a suitable habitat for breeding.

Engineering techniques to restore connection

Engineering techniques have been successfully utilised to restore longitudinal connections along waterways in south-west Western Australia (Torre *et al*. *in press*). These techniques include the construction of three rock ramp fishways and one vertical slot fishway. Waterway crossings have also been retrofitted to facilitate fish passage through culverts (Torre *et al*. *in press*).

In the Eastern States, similar techniques are being proposed to restore lateral connections to off-channel habitats for aquatic fauna along the Murray Darling River system (Graham and Harris 2005; Nichols and Gilligan 2003; Mallen-Cooper 2001). Techniques used to reconnect fish passage along a waterway could be applied to a variety of off-channel habitats in Western Australia, which are no longer connected to the main waterway channel.

Restoration techniques are site specific and this paper provides some options to restore connections to off-channel habitats based on successful fish passage projects in Western Australia. Hydrological studies and fish surveys should be undertaken prior to designing and implementing engineering works, to ensure that fish passage will be enabled for the desired species at the desired time of year.

Fishways
A fishway is an engineered structure designed to allow fish passage or migration over a barrier, such as a weir, dam or crossing. Fishways commonly consist of a series of waterway “steps”, interspaced with resting pools on a low gradient to gradually step up and over the obstacle. The fishway is designed to slow velocity and turbulence, creating flow conditions that the target fish species can traverse. Fish jump or swim upwards over a small step and rest, before negotiating the next step. Similarly the fishway can be used to migrate downstream. Fishways could be used to reconnect off-channel habitats where the barrier between the main channel and the off-channel habitat can not be removed.

The following four fishways have been constructed in the south-west of Western Australia since 2003:
- Goodga River Weir vertical slot fishway, Albany
- Two rock ramp fishways at weirs on Margaret River, Margaret River town site
- Hotham River Weir rock ramp fishway, Boddington

These fishways have been constructed to facilitate migration of specific fish species. The Goodga River vertical slot fishway was constructed to facilitate migration of the rare Western trout minnow over a 1.4 m high weir (Morgan and Beatty 2004a). The Western trout minnow is the most restricted fish species in WA (Morgan and Beatty 2005). Margaret River contains five of the south-west's eight endemic freshwater fishes, as well as the pouched lamprey (*Geotria australis*) (Morgan and Beatty 2003). The two fishways on Margaret River were constructed to allow fish access to important refuge habitat upstream of the Margaret River town site (Morgan and Beatty 2003). The Hotham River rock ramp fishway was constructed to facilitate fish passage of the Western minnow (*Galaxias occidentalis*) and nightfish (*Bostockia porosa*).

Vertical slot fishways
These fishways are usually concreted channel structures with baffles installed at regular intervals to create a series of pools (Katopodis 1992; Mallen-Cooper 2001). The small gap between each baffle allows the fish to burst through the faster flowing water, against the current, before resting in a pool (Figure 2).

These fishways are more expensive to design and construct, however the flow velocities, turbulence and water depths can be more accurately estimated and controlled due to the hard engineering of the structure. This also means that the fishway can be designed to operate at low flows (Torre *et al*. *in press*).

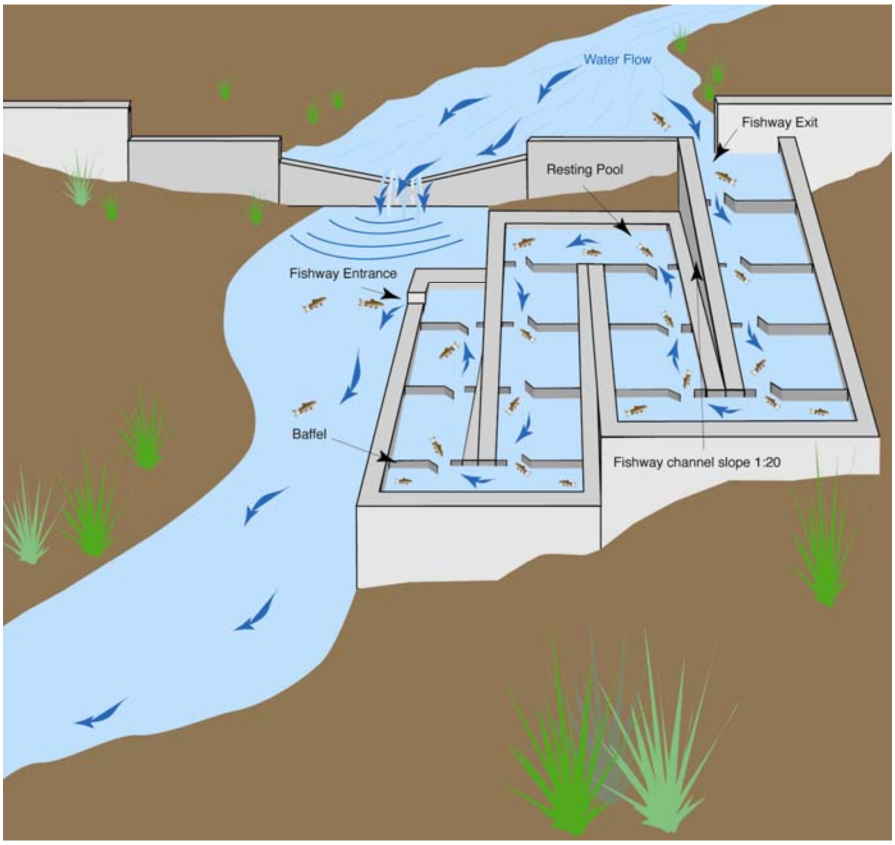

Figure 2. A vertical slot fishway (Department of Fisheries).

Rock ramp fishways

Rock ramp fishways have a series of rocky steps climbing up to the top of a barrier. The fishway is lined with a clay geotextile to hold water within the pools. Large rocks are used to construct ridges to form the pools and smaller rocks are placed to line the pool floor between the ridges (Figure 3). The different sized rocks and more natural construction (compared to a vertical slot fishway) create differing flow velocities and eddies along the structure, providing a variety of potential paths that fish can select to swim up and over the structure.

Rock ramp fishways are usually constructed for barriers that are less than 2 m high. Larger barriers would require a vertical slot or other type of more highly engineered fishway (e.g. a hydraulic lock or lift fishway). Rock ramp fishways are less expensive to construct and maintain than vertical slot structures and are generally more aesthetically appealing. If made from local materials, they can make an attractive and natural looking feature in the landscape.

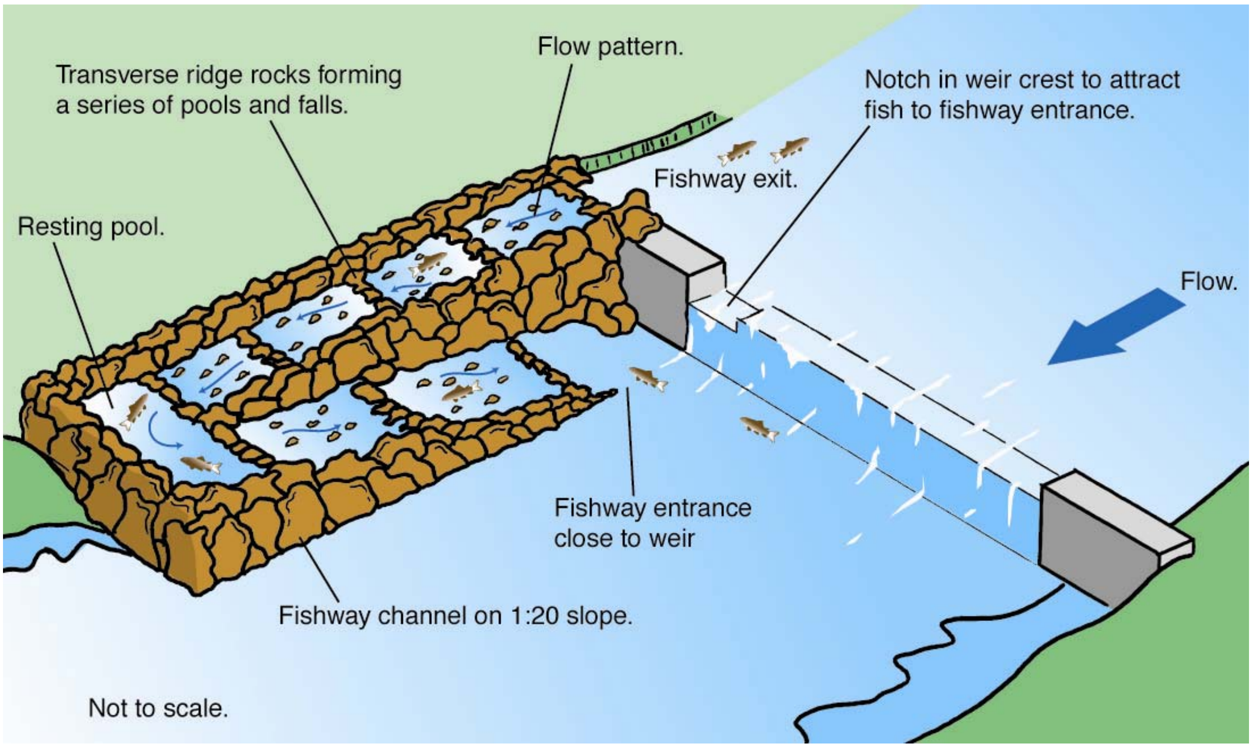

Figure 3. A rock ramp fishway.

Bypass channel fishways

Bypass channel fishways are simple structures that allow fish movement past low barriers through the creation of a channel around either side of the barrier (Water and Rivers Commission 2002). These channels contain flow control structures, such as rock riffles, to prevent erosion and slowly step up and around the barrier. Construction of channels can also be used to reconnect floodplain habitats, which may be disconnected by a barrier (Figure 4). Bypass channels can be designed to mimic natural streams and can be quite simple and inexpensive to construct.

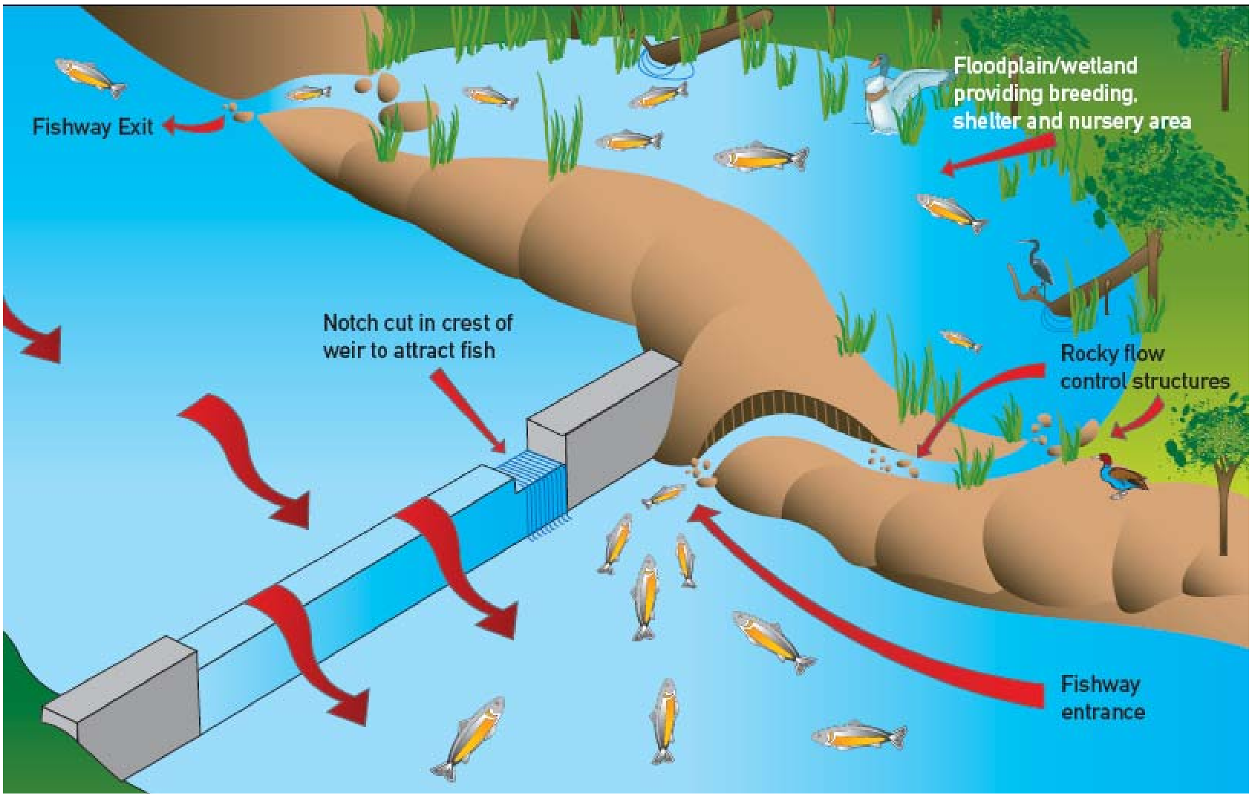

Figure 4. Bypass channel fishway connecting an off-channel habitat.

Using fishways to reconnect off-channel habitats
Fishways could be used to reconnect off-channel habitats to the main channel. Creating a fishway that operates during the periods of fish migration would allow fish access to important off-channel habitats.

There are several principles that need to be considered before deciding to construct a fishway into an off-channel habitat:

- The fishway must operate over periods when fish are migrating and therefore knowledge of the species present and their requirements is critical (Pethebridge *et al.* 1998).
- Native freshwater fish in the south- west of Western Australia are relatively small in size (most ranging between 50 – 190 mm in length) and consequently have limited swimming ability compared to some eastern states and overseas fishes. They are unable to negotiate steps higher than approximately 0.1m.
- A gradient of 1:20 should be applied to allow native fish to swim up the fishway steps.

- The hydrology of the waterway needs to be investigated to determine the depth and velocity of flow down the fishway at different times of the year, particularly during peak migratory periods. How the structure will perform under flood conditions also needs to be checked.
- Fish need an attractant flow to enter a fishway.
- If connection to an off-channel habitat was proposed, the fishway would need to be constructed so that it was not detrimentally draining the off-channel habitat.
- Downstream passage and passage back into the main waterway needs to be considered.
- The fishway must not permit the spread of feral fish species to new habitats.

Case study - Margaret River Apex Weir Fishway
A fishway was constructed at the Apex Weir downstream of the Margaret River town site in March 2003 (Figure 4). Margaret River was a high priority area to restore fish passage, as it is one of a few south-west rivers that have low salinity and good condition riparian vegetation (Torre *et al. in press*).

Figure 4. The Margaret River Apex Weir Fishway.

The Apex Weir fishway creates a series of twenty 0.1 m high step pools to assist fish over the 2m weir. The fishway is approximately 40 m long and consists of two flights of ramp (Morgan and Beatty 2004b). The first ramp extends 26 m downstream from the weir wall, enters a turn-around pool, and the second flight extends 14 m back towards the weir wall. The entry had to be located near the weir wall as fish are attracted to the main flow over the weir. The fishway was constructed of locally donated laterite and granite, with a clay geotextile liner and cost approximately $15 000 to build.

Monitoring was conducted by the Centre for Fish and Fisheries Research at Murdoch University between August and November 2003 (Morgan and Beatty 2004b). The fishway captured a total of 980 endemic freshwater fish on 14 sampling occasions (Figure 5).

These results show that fish were using the fishway to move up (and down) stream. Large numbers of western minnows were found on the fishway in September, which coincides with their spawning migration in early spring (Morgan and Beatty 2004b).

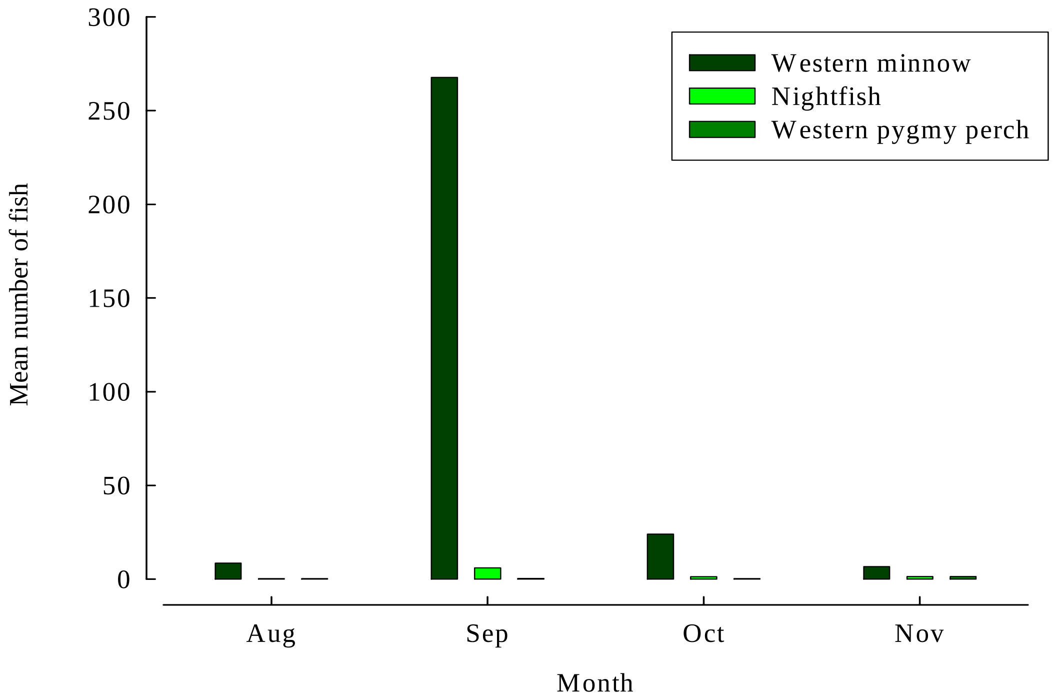

Figure 5. The mean number of each species of fish captured on the Margaret River fishway on each sampling occasion August -November 2003 (Morgan and Beatty 2004b).

Waterway crossings

Roads are frequent barriers between waterways and off-channel habitats. Many roads have been constructed through wetlands, changing their hydrology and causing disconnection of habitat. Open span structures, such as bridges, provide the best conditions for aquatic fauna movement as they do not interfere directly with the flow or aquatic habitat (Fairfull and Witheridge 2003). However bridges are very expensive and culverts are more commonly used. Culverts allow for water exchange between the two areas, but most culverts create unfavourable habitats for aquatic fauna due to high velocity flows and the absence of natural light. Many culverts have a drop at the downstream end which can be a barrier to fish passage.

There are several simple principles that can be applied to construct fish-friendly waterway crossings:

- The crossings should maintain the cross-sectional area of the channels and endeavour to retain the hydraulic characteristics of the area, such that similar water volumes and velocities are maintained.
- Pipe culverts are not recommended due to jetting effects.
- Multi-celled box culverts are preferred to re-create the cross-sectional size and shape of the channel (Figure 6).
- At least one culvert should be set below bed level to allow sediment to accumulate and create a more natural environment for aquatic fauna. Alternatively the base can be roughened or baffles or boulders inserted to break up the flow within the culvert (Figure 7). This will reduce the laminar flow and allow spaces for fish and aquatic fauna to rest. The culvert selected for faunal passage should be located nearest to the riverbank, not in the centre of the channel, as fauna tend to move along the sheltered zone adjacent to fringing vegetation.
- There should be adequate depth of flow through the culvert during periods of fish migration. Generally, a minimum water depth of 0.1m is recommended inside the culvert to allow passage for most south-west freshwater species.
- Culverts should aim to let in as much light as possible. Skylights can be installed along long culverts to increase the amount of light in the culvert and help replicate more natural conditions to increase the chance of fish swimming through the culvert.
- At least one of the culverts (the culvert designated for fish passage) should be constructed on a flat base, not sloping, so that there is no change in water velocity through the culvert.

Figure 6. A multi-celled box culvert crossing to allow movement of aquatic and terrestrial fauna beneath a road crossing (Fairfull and Witheridge, 2003)

Figure 7. Rocks adhered to the base of a culvert beneath the South West Highway crossing on Bancell Brook, Waroona, to break up flows and provide resting zones for fish.

Designing waterway crossings and culverts to reconnect off-channel habitats
Connections to off-channel habitats can be recreated using appropriate culvert design under a road or other obstruction. Culverts can be designed to reconnect off-channel habitats to the main channel during high flow conditions by locating the culvert above the bed level of the main channel and applying a rock apron.

Similarly, simple techniques can be applied to retrofit existing crossings and make them more fish-friendly. Installing baffles along the walls or base of a culvert or adhering rocks to the base of the culvert will break up the flow, reducing the "shooting" effect of flows through the culvert, and provide areas for fish to rest as they swim through the culvert. If the invert of the culvert is not at or below bed level, the "step" between the culvert and the downstream water level may form a barrier to fish passage. This can be resolved by a constructing small rock riffle downstream to drown out the "step", such that the water level backs up in the culvert (Figure 8). A rock apron or fishway could also be constructed to allow fish to climb up the step between the bottom of the culvert and the downstream water level.

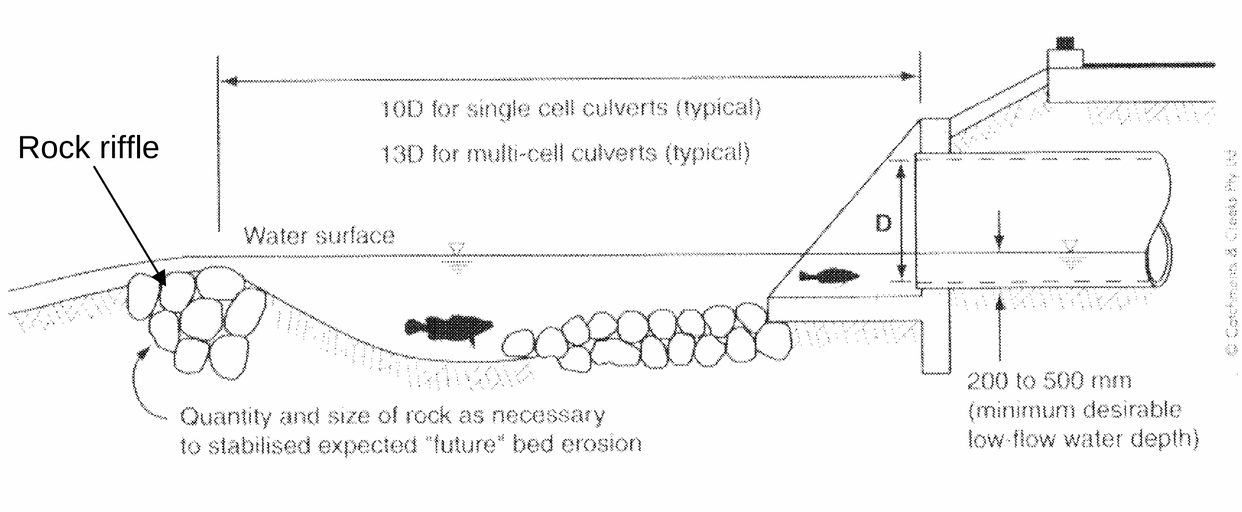

Figure 8. Rock riffle built downstream of a culvert crossing to backflood the step between the culvert and the riverbed and to create sufficient depth in the culvert to enable fish passage (Fairfull and Witheridge, 2003).

Case Study - William Street Crossing – Hotham River Boddington

A retrofit of the William Street crossing over the Hotham River in Boddington was undertaken in March 2005. The crossing consisted of a 600 mm diameter pipe culvert below the gravel crossing (Figure 9). High velocity flows prohibited fish passage through the pipe and created a safety hazard. The pipe was replaced with a series of box culverts, one of which was recessed and the base roughened by shaping cement into hemispheres in alternating patterns on the base of the culvert to allow fish passage (Figure 10).

Similar techniques can be applied to restore hydrological and ecological connectivity where off-channel habitats are separated from the main channel by a road or other obstruction.

Figure 9. Hotham River William Street crossing prior to retrofitting, September 2004.

Figure 10. Box culverts installed at William Street crossing to facilitate fish passage on Hotham River, July 2005.

Earthworks

Reconnection to off-channel habitats may in some cases be provided by some minor earthworks. This would most commonly apply in an area where levee banks have been excavated or the channel has deepened. In these areas, increasing the frequency of connection to the off-channel habitats could simply be provided by excavating a channel or lowering/removing part of the levee (Figure 11). The increased flood frequency would need to be modelled to check that the works would not increase the risk to public safety and property or adversely impact adjacent land uses. If necessary, this excavated channel could be designed to only operate at high flow periods. Rock protection at the entry and exit of the channel would be required to prevent erosion.

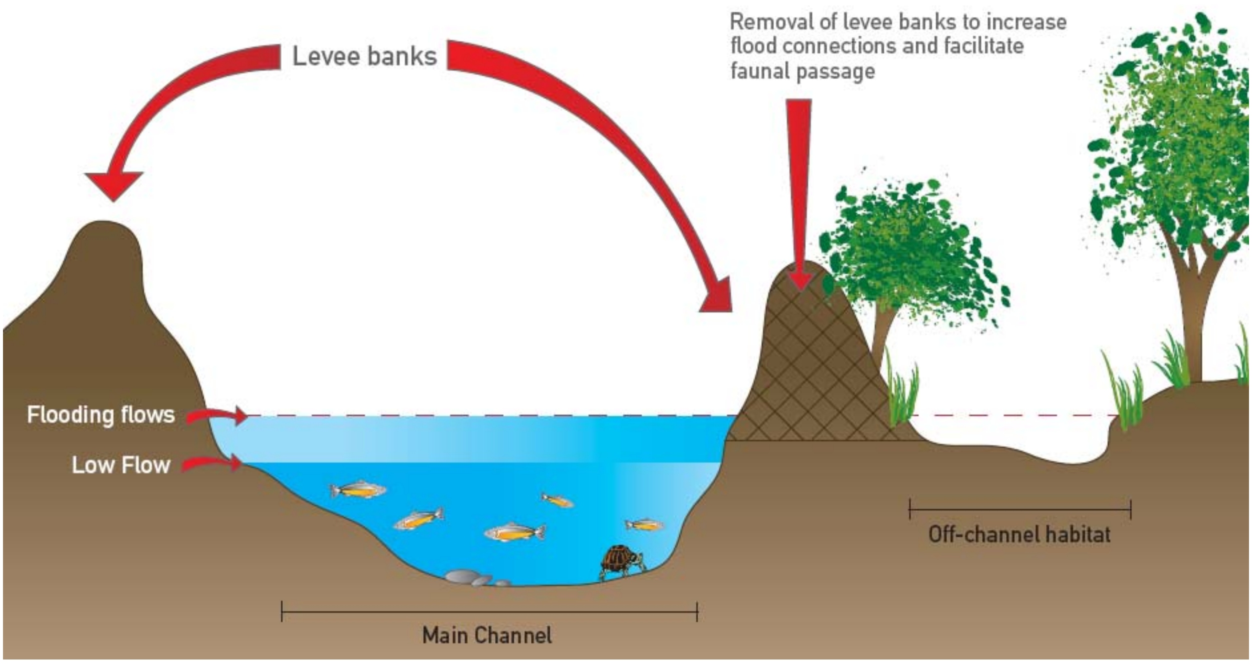

Figure 11. Earthworks to remove levee banks and restore connection to an off-channel habitat.

Conclusion

Prior to European settlement, south-west Western Australian fish would have had connections to off-channel habitats such as floodplains, wetlands, anabranches and billabongs. These areas would have been important habitat at certain times of year for life-cycle processes. In addition, the connection between off-channel habitats and waterways provided an important nutrient cycling function.

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Increasing available habitat for native freshwater fish should be a priority for fish conservation in Western Australia and in many cases this would include reconnection of the main waterway channel with off-channel habitats. Reconnection of off-channel habitats has been identified as a high priority for fish conservation and protection in the eastern states of Australia.

The engineering techniques that have been recently applied in Western Australia to successfully reconnect longitudinal fish passage can easily be adapted to reconnect lateral fish passage. In general, these techniques are inexpensive and provide considerable benefit to native fish by increasing available habitat and facilitating natural migration. Further research is crucial to understand the significance of these off-channel habitats for native fish and to prioritise these areas for works to restore passage for aquatic fauna.

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