# ASSESSMENT OF ROCK-RAMP FISHWAYS

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## Contents

# INTRODUCTION

At least 40% of freshwater fish species in South-eastern Australia regularly migrate over some distance (Mallen-Cooper and Harris 1990, McDowall 1996). These migrations may be an integral part of their life cycle, such as in spawning migrations or may be in response to fluctuations in habitat conditions.

Recent studies have shown that river regulation with dams and weirs which create large barriers to fish migration can greatly reduce the abundance of native species (Mallen-Cooper and Brand 1992, Harris and Mallen-Cooper 1994, Mallen-Cooper *et al.* 1995). Whilst large dams can often extinguish migratory species upstream, the impact on fish populations of low barriers such as weirs, floodgates, road crossings and culverts is usually not so extreme. But their cumulative impact may be large because of the prevalence of these structures (Harris 1984). This is especially important in Australia because of the abundance of catadromous* species whose juveniles must migrate upstream, as well as amphidromous* and potamodromous* species.

The cumulative effects of the thousands of such barriers to migration are believed to be implicated in the extensive declines of native fish in Australia (Harris and Mallen-Cooper 1994, Wager and Jackson 1993, NSW Fisheries unpublished data). In low or moderate streamflows when low barriers are not drowned-out, fish congregate in large numbers downstream (Harris 1984). High mortality rates from predation, competition and disease often result. It is only during higher flows, when these low barriers are completely drowned-out, that fish have the opportunity to migrate upstream (Mallen-Cooper and Thorncraft 1992, Harris *et al.* 1992). However, small larvae or juveniles may not possess sufficient swimming ability to negotiate drowned-out barriers, and some species, especially catadromous ones, may therefore become locally extinct in the upstream catchment.

The cost of providing formal pool-type fishways on existing low barriers may be prohibitive for some situations. Alternative, low-cost solutions are needed. In Europe and North America, 'nature-like' weirs have been used in providing instream erosion control and for habitat restoration. These structures, which are designed to mimic natural stream riffles, may also provide fish passage (Hader 1991, Newbury and Gaboury 1988). As a fishway design, this has the advantage of being cheap to construct if building materials, such as rocks or logs, are readily available. However, this type of 'rock-ramp' fishway has not been tested in Australia.

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* ***Potamodromous*** - fish that migrate wholly within freshwater, ***Catadromous*** - fish that spend most of their life in freshwater and migrate to the sea to breed, ***Amphidromous*** - fish that migrate between the sea and fresh water, but not for the purpose of breeding (Mallen-Cooper *et al.* 1995).

The aim of our study was to assess the effectiveness of rock-ramps in providing passage for Australia migratory fish. To achieve this the species and size-classes of fish attempting to ascend the fishway need to be compared with those that are successful. The fishway design also needs to be assessed on both eastern coastal rivers and western inland rivers to test its suitability for a range of different species.

## 2. METHODS

### *2.1 Experimental sites*

Experimental rock-ramp fishways were built on two tidal and two inland rivers in New South Wales (Fig. 1) by the (then) NSW Department of Water Resources (three sites) and Wyong Council (one site). The rock-ramp design used was adapted from those used by Newbury and Gaboury (1988). Construction methods and the type of rock used varied between sites, however each fishway incorporated several key features. Each ramp has a downstream slope of 20:1 and a series of transverse parallel ridges at approximately 2 m intervals on the surface which were designed to create a series of pools and falls (see Fig. 2).

#### *2.1.1 McDonald's Weir, Macquarie Rivulet*

This was an existing concrete weir that formed the tidal barrier, limiting upstream intrusion of estuarine waters to providing local landholders with a constant source of fresh water. The fishway was built in January 1993 (Photographs 1 and 2) with funding from the NSW Environmental Protection Authority - Environmental Trust Fund. The ramp was formed by dumping quarry-run rock below the existing 0.8 m high weir (headloss) and forming it up with a hydraulic excavator. Problems were experienced with water tunnelling under the surface, and surface rocks moving away from the old weir crest under high flow conditions. A hydraulic excavator was subsequently brought in to add "Geotech" fabric and place larger rocks on the crest (Photograph 3). The tunnelling was stopped, though some movement of rock is still occurring. However, it has not exposed the old weir crest again (Photograph 4).

#### *2.1.2 Lower Wyong Weir, Wyong River*

This was an existing sheet-pile and concrete weir that formed the tidal barrier, limiting upstream intrusion of estuarine waters to provide local landholders and Wyong Shire Council with a constant source of fresh water. A rock-ramp fishway was built in September 1993 (Photographs 5 and 6). The weir has a headloss of 1 m, with the crest 0.2 m lower on the left side looking downstream. The fishway was constructed using sandstone blocks set on their longest edges and back-filled with smaller rocks. Only small-scale movement of rocks has occurred at this site.

### *2.1.3 Bell River*

Three erosion-control weirs were built on the Bell River near the junction with the Macquarie River by the then Department of Water Resources in June 1993. The furthest downstream of these structures has a headloss of 1.5 m, a slope of 20:1 and was used as an experimental site. The weirs were again formed of rock, but it was constrained upstream and downstream by sheet-pile walls (Photographs 7 and 8). Rock of a diameter greater than 1 m was used as a veneer over the surface of the weir. No movement of rock has been observed at this site.

### *2.1.4 Goondiwindi Weir, Macintyre River*

This timber-and-concrete weir is managed by the Border River Commission and a rock-ramp was built on it in August 1993. The weir has a head loss of 1.2 metres. The ramp design was unusual. Because of the high cost of transporting rock to the site, and to limit the volume of rock required, gabion walls were used to confine the ramp to a 10 m wide channel down the centre of the river (Photograph 9). The weir crests on each side of the channel were raised to direct water through the fishway.

However, this arrangement created a problem because when fishway entrances are located downstream of the main flow areas in this way they cause difficulties for fish in finding fishways (Clay 1995). Fish travelling upstream can miss the entrance, moving past it to be obstructed below the weir wall itself. This arrangement can then form a kind of behavioural trap. To assess the extent of the problem at this site, temporary guiding fences were designed to extend from each bank to the fishway entrance (Photograph 10). No movement of rock has been observed at this site.

## *2.2 Comparison of fish populations above and below fishways*

Previous assessments of New South Wales fishways have compared fish populations that were successful in ascending with those below that were attempting to migrate (Mallen-Cooper 1995) and this concept was used for assessing the rock-ramp fishways. The four rock-ramp fishways were sampled using a paired-day sampling regime. On the first day the exit of the fishway (i.e., in the upstream pool) was trapped to capture fish that had swum upstream through the fishway. On the following day the area immediately downstream of the entrance was trapped to capture potentially migrating fish. This routine then constituted a pair of days' sampling.

In assessing a formal pool-type fishway, water velocities can be controlled to allow all potentially migrating fish to enter a trap placed in the entrance. A similar trap can also be placed over the exit to capture fish successfully ascending the fishway. The catches from these traps then allow a direct comparison of the abundance and size-class frequencies of each species attempting to migrate with those successfully ascending the fishway. Unfortunately, the informal channel of a rock-ramp does not allow the manipulation of flow and velocity. The variation in width, depths and flow patterns at top and bottom of the ramp also prevented the use of a consistent type or set of gear to be used to sample at both the entrance and exit. To overcome this problem a variety of nets and traps were employed to obtain a sample of the size-class frequencies of each species in each location. However, the use of different types of gear above and below the rock-ramps has limited this study to the comparison of size-classes, with the assumption that sampling effort is high enough for all size-classes present to be caught. It is also assumed that all size-classes of a species caught below the fishway are attempting to migrate, except in those species where there are behavioural differences between the different size-classes. Because of these limitations associated with the informal structure of rock-ramp fishways, no quantitative comparison between the abundance of fish at the top and bottom, and therefore the capacity of the fishway, is possible.

### *2.3 Fish sampling methods*

One large trap was used to cover the exit of the fishway. It consisted of a 4 m long cylinder of netting (0.01 m stretched mesh size) with two 0.9 m diameter cones and two 7 m long guide walls of 0.025 m mesh net. This double-cone trap was set with the opening facing downstream towards the fishway exit and the guide walls stretched to each side of the fishway channel. Its purpose was to trap all large fish as they exited the top of the fishway, without catching fish already present in the weir pool. In addition, four single-entrance bait-traps (0.25 m square covered in 0.005 m mesh) were set on the crest facing downstream to obtain samples of smaller fish as they exited the top of the fishway.

The double-cone trap proved to be less effective in catching fish when set downstream of the fishway. Therefore, to obtain a comprehensive sample of the range of species and size-classes of fish present below the fishway, a number of different types of nets were set. Multi-panel gill nets (15 m total length, 5 m each of 0.025m, 0.050 m and 0.100 m stretched-mesh monofilament net) were set parallel to the flow and adjacent to the entrance. Fyke nets (0.025 m mesh) (a multi-cone type of trap) were also set adjacent to the entrance. A minimum of two and a maximum of four each of panel and fyke nets were set, depending on the width of the stream. Four single-entrance bait-traps identical to those used at the crest were also set on the toe of the ramp facing downstream to obtain samples of smaller fish as they entered the fishway. To avoid crowding and interference with the other nets, the bait-traps were set downstream on the first day and then upstream on the second day.

All sampling gear was set approximately two hours before sunset and retrieved two hours after sunrise on the following day. Each fish caught was identified to species and its length was recorded. This was done for all fish caught, except for *Hypseleotris* species from the Macintyre River, which were only able to be identified in the field to genus level.

### 2.4 Additional sampling

It was considered that the layout of the Goondiwindi Weir Rock-ramp, with the entrance of the fishway more than 20 m downstream of the main weir crest, would probably reduce the effectiveness of the fishway (section 2.1.4). In medium to high flows, water falling over the side crest would attract fish, delaying or preventing them from finding the fishway entrance. The value of a fence or wall to guide fish to the entrance of the fishway therefore needed to be investigated. In November 1995 the fishway was trapped using a sampling regime carried out over three consecutive days to assess the effectiveness of a fence in helping fish to find the entrance. This consisted of two days trapping above the fishway, randomly allocating one day with the fence in and one day with the fence out, and then further trapping for one day below the fishway. It was assumed that greater numbers of fish finding the fishway entrance would result in higher catches at the exit.

## 3. RESULTS

### 3.1 McDonald's Weir, Macquarie Rivulet

The McDonald's Weir Fishway was assessed on four occasions to give a total of six paired-day samples (Table 1) and a total of 17 species of fish were caught. Of these, the six estuarine species caught are among those which may occasionally move into fresh water, as evident in the capture of one silver bream (*Acanthopagrus australis,* 99 mm length) at the top of the fishway. However, these species are not dependent on upstream migration into fresh water as part of their life cycle. The alien species, gambusia (*Gambusia holbrooki*), which was caught in small numbers, is also not considered to be migratory.

The low abundance below the fishway of two species known to be migratory, Cox's gudgeon (*Gobiomorphus coxii*) and Australian bass (*Macquaria novemaculeata*), is assumed to indicate they were not attempting to move upstream at the time of sampling, and/or that they have been reduced to low abundances in this system. The length-frequency distribution of the catches of the remaining eight species from above and below the fishway were compared (Fig. 3). The differences in cumulative length frequency classes below and above were tested using the Kolmogorov-Smirnov two-tailed nonparametric statistic (Siegel and Castellan 1988).

Four species showed no significant difference: long-finned eel (*Anguilla reinhardtii,* $D_{10,10}$=30 $p>0.05$), common jollytail (*Galaxias maculatus,* $D_{655,57}$=0.0465 $p>0.05$), striped gudgeon (*Gobiomorphus australis,* $D_{21,4}$=22 $p>0.05$) and empirefish (*Hypseleotris compressa,* $D_{29,5}$=0.2965 $p>0.05$). However, significant differences were found with striped mullet (*Mugil cephalus,* $D_{80,8}$=0.9375 $p<0.05$), flathead gudgeon (*Philypnodon grandiceps,* $D_{49,62}$=0.5810 $p<0.05$) and dwarf flathead gudgeon (*Philypnodon sp.*, $D_{22,66}$=0.3636 $p<0.05$) with more small fish of each species passing

**Table 1.** Total numbers of fish caught potentially migrating below McDonald's Weir Rock-ramp Fishway, Macquarie Rivulet, and the total numbers of fish caught successfully exiting from above (N= number of paired-days).

| Species | December 1993 N=1 | | March 1994 N=1 | | January 1995 N=1 | | September 1995 N=3 | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Below | Above | Below | Above | Below | Above | Below | Above | |
| *Anguilla reinhardtii*+ Long-finned eel | 2 | 0 | 0 | 1 | 0 | 6 | 8 | 3 | 20 |
| *Galaxias maculatus*+ Common jollytail | 0 | 0 | 0 | 0 | 0 | 0 | 655 | 57 | 712 |
| *Gobiomorphus australis*+ Striped gudgeon | 6 | 0 | 0 | 0 | 15 | 4 | 0 | 1 | 26 |
| *Gobiomorphus coxii*+ Cox's gudgeon | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 3 |
| *Hypseleotris compressa* Empirefish | 17 | 5 | 0 | 0 | 11 | 0 | 1 | 0 | 34 |
| *Macquaria novemaculeata*+ Australian bass | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 4 |
| *Mugil cephalus*+ Striped mullet | 1 | 0 | 0 | 0 | 2 | 8 | 77 | 0 | 88 |
| *Notesthes robusta*+ Bullrout | 0 | 0 | 8 | 1 | 0 | 0 | 3 | 0 | 12 |
| *Philypnodon grandiceps* Flathead gudgeon | 14 | 50 | 4 | 1 | 28 | 10 | 3 | 1 | 111 |
| *Philypnodon sp.* Dwarf flathead gudgeon | 8 | 37 | 0 | 1 | 8 | 27 | 6 | 1 | 88 |
| *Acanthopagrus australis** Silver bream | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 3 |
| *Ambassis jacksoniensis** Glass perchlet | 0 | 0 | 2 | 0 | 1 | 0 | 9 | 0 | 12 |
| *Herklotsichthys castelnaui** Southern herring | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| *Liza argentea** Flat-tailed mullet | 15 | 0 | 4 | 0 | 1 | 0 | 0 | 0 | 20 |
| *Macquaria colonorum** Estuary perch | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Pomatomus saltatrix** Tailor | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 0 | 21 |
| *Gambusia holbrooki*# Gambusia | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |

+Migratory (Mallen-Cooper and Harris 1990)
*Mainly estuarine species.
#Alien species.

upstream. Only one bullrout (*Notesthes robusta*) was caught above the fishway, but it was the smallest of this species.

### *3.2 Lower Wyong Weir, Wyong River*

The Lower Wyong Weir Fishway was assessed on four occasions to give a total of six paired-day samples (Table 2) and a total of 17 species of fish were caught. Of these, the seven estuarine species caught are among those which may occasionally move into fresh water, as evident in the capture of one blackfish (*Girella tricuspidata,* 105 mm length) and one glass perchlet (*Ambassis jacksoniensis,* 27 mm length) at the top of the fishway. However, these species are not dependent on upstream migration into fresh water as part of their life cycle. The alien species gambusia, which was caught in small numbers, is also not considered to be migratory.

The low abundance below the fishway of three species known to be migratory, Australian bass, dwarf flathead gudgeon and bullrout, is assumed to indicate they were not attempting to move upstream at the time of sampling, and/or that they have been reduced to low abundances in this system. The length-frequency distributions of the catches of the remaining six species from above and below the fishway were compared (Fig. 4) and the differences in cumulative relative length frequency below and above were again tested.

Four species showed no significant difference: long-finned eel ($D_{15,12}$=36 $p>0.05$), striped gudgeon ($D_{130,572}$=0.1035>0.05), empirefish ($D_{19,106}$=0.1132 $p>0.05$) and flathead gudgeon ($D_{18,32}$=0.0.3993 $p>0.05$). However, a significant difference was found with striped mullet ($D_{8,16}$=112 $p<0.05$), with more small fish (<80 mm) passing upstream. The small sample size of common jollytail caught below the fishway prevents testing, though there do not appear to be differences in length frequencies.

### *3.3 Bell River*

The Bell River Fishway was assessed on two occasions to give a total of two paired-day samples (Table 3) and a total of six species of fish were caught. Total fish abundance was very low and catches were dominated by alien species, with only five individual native fish being caught. One of these native species, freshwater catfish (*Tandanus tandanus*), is not considered to be migratory. The alien species caught, goldfish (*Carassius auratus*) and gambusia, are also not considered to be migratory.

The low abundance below the fishway of Australian smelt (*Retropinna semoni*), which is known to be migratory, is assumed to indicate it was not attempting to move upstream at the time of sampling or else it has been reduced to very low abundance in this system. However, larger numbers of the alien species, carp (*Cyprinus carpio*) above, and redfin perch (*Perca fluviatilis*) below the fishway were caught (Fig. 5). Because of the low numbers of native fish available, this fishway was abandoned as an experimental site and no further analysis has been undertaken.

**Table 2.** Total numbers of fish caught potentially migrating below Lower Wyong Weir Rock-ramp Fishway, Wyong River, and the total numbers of fish caught successfully exiting from above (N= number of paired-days).

| Species | January 1995 N=1 | | October 1995 N=1 | | November 1995 N=3 | | December 1995 N=1 | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Below | Above | Below | Above | Below | Above | Below | Above | |
| *Anguilla reinhardtii*+ Long-finned eel | 7 | 6 | 6 | 5 | 0 | 1 | 2 | 0 | 27 |
| *Galaxias maculatus*+ Common jollytail | 1 | 0 | 0 | 12 | 1 | 6 | 0 | 0 | 20 |
| *Gobiomorphus australis*+ Striped gudgeon | 18 | 4 | 77 | 170 | 30 | 393 | 5 | 5 | 702 |
| *Hypseleotris compressa* Empirefish | 8 | 4 | 0 | 1 | 10 | 95 | 1 | 6 | 125 |
| *Macquaria novemaculeata*+ Australia bass | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 4 |
| *Mugil cephalus*+ Striped mullet | 0 | 0 | 7 | 15 | 0 | 1 | 1 | 0 | 24 |
| *Notesthes robusta*+ Bullrout | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Philypnodon grandiceps* Flatheaded gudgeon | 6 | 4 | 7 | 3 | 5 | 19 | 0 | 6 | 50 |
| *Philypnodon sp.* Dwarf flatheaded gudgeon | 3 | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 8 |
| *Acanthopagrus australis** *Silver bream* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Ambassis jacksoniensis** Glass perchlet | 119 | 0 | 242 | 0 | 1 | 1 | 0 | 0 | 363 |
| *Girella tricuspidata** Blackfish | 0 | 0 | 15 | 1 | 0 | 0 | 0 | 0 | 16 |
| *Herklotsichthys castelnaui** Southern herring | 5 | 0 | 57 | 0 | 0 | 0 | 0 | 0 | 62 |
| *Hyporhamphus ardelio** River garfish | 1 | 0 | 6 | 0 | 0 | 0 | 1 | 0 | 8 |
| *Liza argentea** Flat-tailed mullet | 1 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 18 |
| *Pomatomus saltatrix** Tailor | 3 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 10 |
| *Gambusia holbrooki*# Gambusia | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |

+Migratory (Mallen-Cooper and Harris 1990)
*Mainly estuarine species.
# Alien species.

**Table 3.** Total numbers of fish caught potentially migrating below Bell River Rock-ramp Fishway and the total numbers of fish caught successfully exiting from above (N= number of paired-days).

| Species | February 1994 N=1 | | February 1995 N=1 | | Total |
|---|---|---|---|---|---|
| | Below | Above | Below | Above | |
| *Retropinna semoni*+ Australian smelt | 1 | 0 | 0 | 1 | 2 |
| *Tandanus tandanus* Catfish | 0 | 0 | 2 | 0 | 2 |
| *Carassius auratus*# Goldfish | 0 | 0 | 1 | 0 | 1 |
| *Cyprinus carpio*+# Carp | 0 | 0 | 1 | 43 | 44 |
| *Gambusia holbrooki*# Gambusia | 0 | 0 | 3 | 0 | 3 |
| *Perca fluviatilis*+# Redfin perch | 10 | 0 | 3 | 1 | 14 |

+Migratory (Mallen-Cooper and Harris 1990, Mallen-Cooper *et al.* 1995 )
# Alien species.

### *3.4 Goondiwindi Weir, Macintyre River*

The Goondiwindi Weir Fishway was assessed on two occasions to give a total of five paired-day samples (Table 4) and a total 12 species of fish were caught, seven of which are known to migrate. One native species, freshwater catfish, was caught in small numbers and is not considered to be migratory. The alien species, goldfish, is also not considered to be migratory.

The low abundance below the fishway of three native fish species: silver perch (*Bidyanus bidyanus*), Murray cod (*Maccullochella peeli*) and Australian smelt, which are migratory, is assumed to indicate either they were not attempting to migrate upstream at the time of sampling or that they have been reduced to very low abundance in this system. The alien species, carp, is migratory but was also found in small numbers. The length-frequency distribution of the catches of the remaining six species from above and below the fishway were compared (Fig. 6) and the differences in cumulative length frequencies below and above were tested. No significant difference was found for western chanda perch (*Ambassis castelnaui*, $D_{18,15}$=114 p>0.05). However a significant difference in length frequencies was found for bony herring (*Nematalosa erebi*, $D_{271,1118}$=0.5560 p<0.05), with a higher abundance of smaller size fish found above. The small sample size of gudgeons (*Hypseleotris sp.*) and golden perch (*Macquaria ambigua*) caught above the fishway prevents testing, although smaller size classes were caught above. There were no Mitchellian hardyhead (*Craterocephalus stercusmuscarum*) or spangled perch (*Leiopotherapon unicolor*) caught above the fishway, despite substantial numbers being caught downstream.

### *3.5 Additional sampling*

At Goondiwindi Weir the effect of a guiding fence (see section 2.4) on catches of bony herring above the fishway was examined twice using a three-day sampling regime. During the first sampling visit a larger number of bony herring reached the top of the fishway with the fence in place than when the fence was removed (Fig. 7), at a time when flows were greater then 600 ML/day (Photograph 11). However, a decrease in flow to less than 300 ML/day before the second sampling visit resulted in little or no flow over the side crest, with all flow being directed down the fishway channel (Photographs 12). During this second sampling, a larger number of bony herring were caught with the fence removed than with it in place. The number of bony herring caught below the fishway decreased between the first and second sampling visits. Further sampling was abandoned due to decreasing stream flows, and therefore no further estimate of variation in bony herring numbers was able to be determined.

**Table 4.** Total number of fish caught potentially migrating below Goondiwindi Weir Rock-ramp Fishway, Macintyre River, and the total numbers of fish caught successfully exiting from above (N= number of paired-days).

| Species | November 1994 N=3 | | November 1995 N=2 | | Total |
|---|---|---|---|---|---|
| | Below | Above | Below | Above | |
| *Ambassis castelnaui* Western chanda perch | 0 | 0 | 18 | 15 | 33 |
| *Bidyanus bidyanus*+ Silver perch | 2 | 0 | 0 | 0 | 2 |
| *Craterocephalus stercusmuscarum* Mitchellian hardyhead | 0 | 0 | 69 | 0 | 69 |
| *Hypseleotris sp.* Gudgeon | 13 | 0 | 0 | 3 | 16 |
| *Leiopotherapon unicolor*+ Spangled perch | 3 | 0 | 14 | 0 | 17 |
| *Macquaria ambigua*+ Golden perch | 13 | 1 | 10 | 0 | 24 |
| *Maccullochella peelii*+ Murray cod | 0 | 0 | 1 | 0 | 1 |
| *Nematalosa erebi*+ Bony herring | 83 | 106 | 188 | 1012 | 1389 |
| *Retropinna semoni*+ Australian smelt | 0 | 0 | 0 | 1 | 1 |
| *Tandanus tandanus* Catfish | 2 | 0 | 2 | 0 | 4 |
| *Carassius auratus*# Goldfish | 2 | 0 | 0 | 0 | 2 |
| *Cyprinus carpio*+# Carp | 2 | 0 | 2 | 0 | 4 |

+Migratory (Mallen-Cooper and Harris 1990, Mallen-Cooper *et al.* 1995)
# Alien species.

# 4. DISCUSSION

## *4.1 Design of Rock-ramp Fishways*

The design of each of the four rock ramp fishways assessed differed depending on the purpose of the structure, the nature of the site, the constructing authority involved and materials that were available. Each rock-ramp therefore had a unique physical appearance. Also the stream flows that occurred during the study varied considerably between sites, though low flows predominated. This resulted in each rock-ramp having different flow conditions which fish had to negotiate to migrate upstream, and raises the question of whether the results from this study could be used to determine the suitability of rock-ramps for use at other sites. However, it has been assumed that the design requirements of 20:1 downstream slope, maximum headloss of about 1m, and carefully structured transverse rock ridges on each rock-ramp have created enough similar features to ensure a level of consistency in flow conditions on these and future rock-ramp fishways.

The rock-ramps settled after construction and some movement of surface rocks occurred during high flows. However, only the rock-ramp at McDonald's Weir on the Macquarie Rivulet altered from the design requirements as the result of settling. The loss of the regular transverse ridges after a high-flow event within the first 12 months of construction can be seen in Photographs 3 and 4. Substantial reconstruction was required to restore the fishway's function. The movement of rock away from the weir crest affected the rock-ramp's performance by exposing the old existing weir. This was repaired by placing larger rock (greater than 1m diameter) on the top section of the rock-ramp (section 2.1.1).

In hindsight, it may have been better to remove or lower the old weir so that subsequent rock settling would not affect the fishway exit. In future, if the removal of an old weir is not possible, it is recommended that only large rocks be placed on the surface of the ramp, as was the case with the Bell River rock-ramp (Photograph 7).

The general layout of any fishway needs to be such that fish can easily find the entrance (Clay 1995). The use of gabions to confine the rock-ramp at Goondiwindi Weir on the Macintyre River greatly reduced the width and cost of the fishway but, unfortunately, resulted in the entrance being well downstream of the original weir crest. In high flows the effectiveness of the fishway is greatly reduced as many fish are attracted to the flows at the base of these side crests. Observations made in March 1996 of large numbers of spangled perch unsuccessfully leaping at the side crest in moderate (900 ML/day) flow conditions (Photographs 13 and 14) support the finding that large numbers of fish are having difficulties locating the entrance of the fishway (Photographs 13 and 14) in anything other than low flows. This conclusion was reinforced by the results which showed good passage through the fishway in low flows, when there was no confusing discharge over the side crest, and much poorer results in a moderate flow, when a large proportion of fish missed the entrance.

This constrained-channel layout should be avoided, or else some form of permanent guiding wall should be incorporated into the design to prevent fish swimming upstream past the fishway entrance. In the case of Goondiwindi Weir Fishway a permanent guiding wall will be needed at the level of the fishway entrance to achieve acceptable performance.

### *4.2 Performance of the fishway design*

Rock-ramp fishways were successful in allowing free passage for most of the fish sizes and species found potentially migrating. The majority of fish caught below the fishways were juveniles or smaller-sized species which are relatively weaker swimmers than larger fish (Videler and Wardle 1991, Mallen-Cooper 1992, Mallen-Cooper 1994). These smaller size-classes were well represented in catches above the fishway, indicating that water velocities on the rock-ramps were not preventing fish passage.

In all cases where the results showed significant differences in the size-frequencies of fish potentially migrating below rock-ramp fishways compared to those successfully exiting above, more small fish had passed upstream. While this result could be interpreted as showing an inhibition of larger fish, or result from the differences in sampling gear, it probably reflects the intense migratory activity of the juveniles and sub-adults of many Australian native fish in inland drainages (Harris *et al.* 1992; Harris and Mallen-Cooper 1994, Mallen-Cooper *et al.* 1995; McDowall 1996) as well as in coastal systems (Harris 1984; Mallen-Cooper 1992). In many cases, larger individuals of species such as striped mullet, longfinned eels, Australian bass or bony herring are likely to be foraging within their home range when caught below fishways, while it is the younger fish which are predominantly travelling through.

Spangled perch and Mitchellian hardyhead were abundant below Goondiwindi Weir, but not found above the fishway. As spangled perch are known to be migratory (McDowall 1996) and were observed actively attempting to migrating at higher flows, it is likely that factors such an increase in flows and water depths may be needed to stimulate migration of this and other species with similar behaviour (Harris and Mallen-Cooper 1994; Mallen-Cooper *et al.* 1995).

Larger fish species, such as Australian bass and golden perch, which are known to be migratory, were found to be only occasionally using the fishways, though they were generally found in low abundance downstream. This probably indicates that these fish were not migrating at the time of sampling. The result could possibly also indicate a behavioral problem with these species, such as a reluctance for larger fish to enter the relatively shallow water on the rock-ramps in low-flows, although many such species have been observed to move through shallow waters. As assessment was limited to periods of low flow because of difficulties setting the sampling gear in high flows, no direct evidence was available.

Assessment of the Bell River rock-ramp fishway was disappointing because of the very low numbers of native fish migrating. This site is a short distance upstream of the confluence with the Macquarie River, which has been shown to be profoundly affected by cold-water pollution from deep outlets of Burrendong Dam, upstream of Wellington (NSW Fisheries, unpublished data). Temperature suppression in the river is believed to be implicated in the very low numbers of native fish found in this reach of the Macquarie River, and also to affect fish behaviour patterns, including migration. This process probably explains the paucity of migrating native fish at the Bell River rock-ramp. Other experimental means of assessing the structure are being developed.

## 5. CONCLUSIONS

The results of our assessment show that rock-ramp fishways can provide effective passage for native fish. They are a useful, simple and relatively low-cost adjunct to more formally engineered fishway designs, particularly for overcoming low barriers. Rock-ramp fishways may be added to existing weirs or built as part of a new weir following consultation with the relevant Fisheries authority. Until further evidence shows their effectiveness at steeper slopes, the rock-ramps should meet the criteria set down for the structures assessed. They should be built on a slope of 20:1, and large rocks should be placed to form a series of transverse small pools and falls at about two metre intervals. Care should be taken to ensure that surface rocks do not move away from any existing weir crest and that the general layout is designed so that fish can easily find the entrance. The existing weir crest should either be partially removed, or else the uppermost ridge of rocks should submerge the crest, even at low flows. The maximum headloss across the rock-ramp should be one metre, unless substantial resting pools are included. The majority of small and juvenile migrating fish species tested were able to ascend rock-ramp fishways in low flow conditions. However, higher flows may be necessary to stimulate some species to migrate or to allow larger fish to ascend the fishway.

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