

A preliminary assessment of fish passage through a Denil fishway on the Edward River, Australia

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NON-TECHNICAL SUMMARY

A preliminary assessment of fish passage through a Denil fishway on the Edward River, Australia

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OBJECTIVES:

- To perform a short-term assessment of fish passage through a Denil fishway on the Edward River offtake regulator;
- To undertake a survey of fish communities upstream and downstream of the Edward River offtake regulator;
- To 'benchmark' fish communities in Gulpa Creek prior to fishway construction.

NON-TECHNICAL SUMMARY:

The obstruction of migration pathways is frequently implicated in the worldwide declines of freshwater fish. Fishways are commonly constructed to overcome these effects of weirs and fishway technology is advancing rapidly. Although many different concepts have been trailed in Australia, the Denil fishway is a relatively inexpensive design with substantial potential for widespread application. A Denil fishway can be simply described as an open channel containing a series of upstream-sloping 'U'-shaped baffles without intervening pools. Denil fishways have been constructed worldwide and provide passage for many species, with varying degrees of success.

A Denil fishway was constructed at the Edward River offtake regulator in 1998. The installation is unusual because the fishway was actually designed and constructed for another site, Brewarrina Weir. Fisheries managers have previously questioned the effectiveness of such an installation in NSW because the design operating range (originally based on Darling River flows) does not match the flow conditions experienced in the Edward River. This study was subsequently undertaken to address these concerns experimentally, by determining the size range and composition of species using the structure. Electrofishing was also used determine any differences between fish communities upstream and downstream of the regulator.

A total of 222 fish (7 species) and 5,036 freshwater shrimp (1 species) were sampled from the exit of the Denil fishway during the study period. Surprisingly, small-bodied species such as Australian smelt, flyspecked hardyhead and western carp gudgeon largely dominated fishway catches. Many species also accumulated downstream of the structure suggesting fish passage was inefficient for some size classes.

Several operational issues severely compromised fishway operation, including a limited ability to cope with water level fluctuations, inefficient entrance location, baffle instability and a mesh barrier over the entrance. Operation of the fishway could be immediately improved by 1) Raising the fishway 600mm to improve entrance conditions, 2) Bolting or pinning each baffle into place to

prevent movement during high flows and 3) removing all gridding from the entrance and exit to enable the passage of large fish and to prevent fouling.

The study also sought to document the structure of migratory fish assemblages downstream of the Gulpa Creek regulator. Electrofishing surveys determined that both small and large-bodied species (from 13-516mm) accumulated downstream of the structure. These results suggest that a fishway is needed at this site that should provide passage for a wide range of species and size classes. The most suitable design would be a low-gradient vertical slot fishway provided it is appropriately sited and is constructed to criteria that permits the passage of both small and large-bodied species.

1. INTRODUCTION

The obstruction of migration pathways is frequently implicated in the worldwide declines of freshwater fish (Lucas and Baras, 2001). In the Murray-Darling Basin, increased river regulation has fundamentally changed the nature of flows since European settlement. Flow peaks historically occurred in winter and spring (Walker, 1985) but now more frequently occur in summer and coincide with increased irrigation demand. These flow alterations have coincided with large-scale declines in the abundance and distribution of many key species over the past 100 years (Mallen-Cooper, 1988).

There are now over 100 storages in the Murray sub-system, located mostly on tributary rivers (Walker, 1985), and a series of barrages at the tidal limit (Lay and Baumgartner, 2004). In addition, 17 weirs were constructed on the main channel of the Murray River to increase navigability for boats and other recreational users. Consequently, the main channel of the Murray River is now characterised by a series of large fragmented weir pools with suppressed flow peaks and disrupted longitudinal connectivity (Walker, 1985).

Fishways are commonly constructed to mitigate the effects of weirs and fishway technology is developing rapidly (Stuart *et al.*, 2004). Although many different designs have been trailed in Australia, an experimental design with potential for widespread application is the Denil fishway (Figure 1). A Denil fishway can be simply described as an open channel containing a series of upstream-sloping 'U'-shaped baffles without intervening pools (Thorncraft and Harris, 2000).

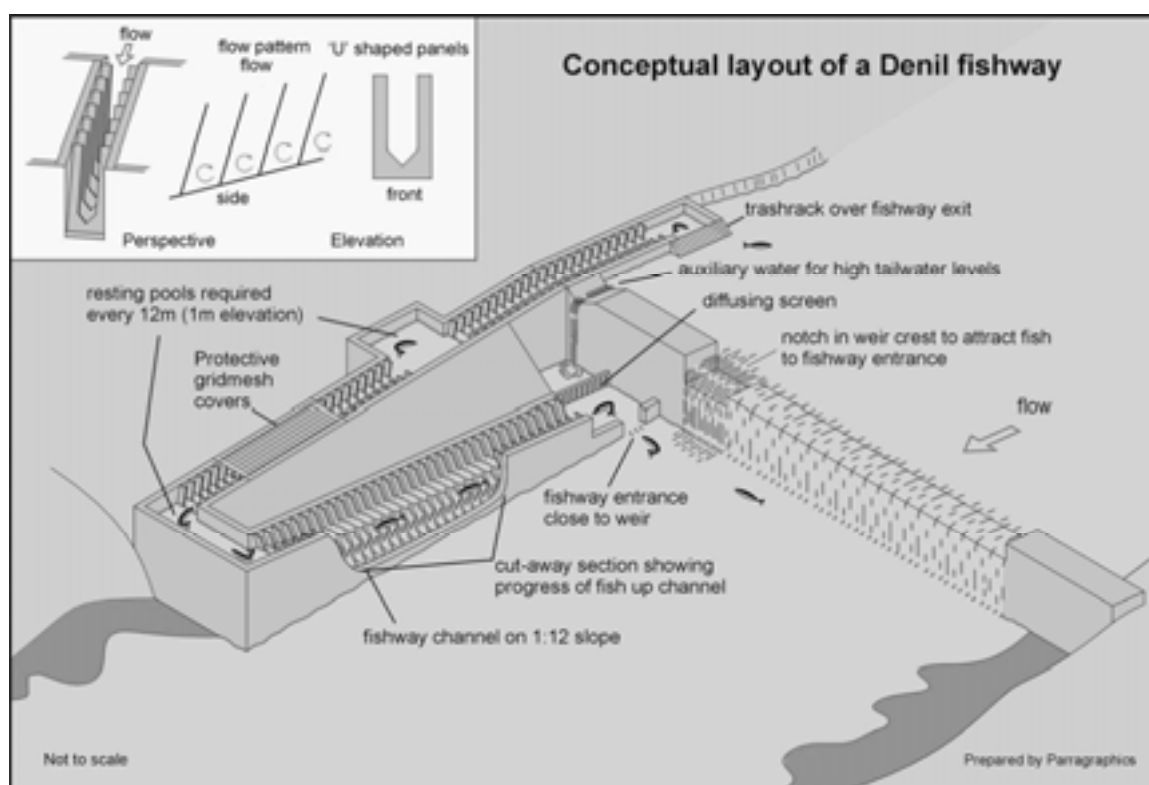


Figure 1. Conceptual operation of a Denil fishway demonstrating baffle layout and floor slope (From Thorncraft and Harris, 2000).

The first Denil fishway was installed on the Ourthe River in Belgium (Denil, 1909). Since then, Denil fishways have been constructed worldwide and have been the subject of much research on the relationship between internal hydraulics and fish passage success (Ziemer, 1962; Laine *et al*, 1998; Kamula and Barthel, 2000; Bunt *et al*, 2001).

In Australian systems, the three completed Denil fishways have received scant assessment. Mallen-Cooper and White (1995) performed a small study on an experimental fishway at Euston Weir on the Murray River and determined efficient passage on slopes less than 1:12. Although studies are currently underway on the two existing Denil fishways in the Murray-Darling Basin, these will not be completed in the near future. Therefore, the applicability of Denil fishways for wider application throughout the Murray-Darling Basin remains largely unknown.

A Denil fishway was installed at the Edward River offtake regulator in 1998. The installation is unusual because the fishway was actually designed and constructed for another site in NSW, Brewarrina Weir. Fisheries managers have previously questioned the effectiveness of such an installation because the design operating range (originally based on Darling River flows) does not match the flow conditions experienced in the Edward River. This study was subsequently undertaken to address these concerns and determine the size range and composition of species using the structure. Electrofishing was also used to determine any differences between fish communities upstream and downstream of the regulator. Similar samples were also collected in the nearby Gulpa Creek regulator.

2. METHODS

2.1. Study sites

The Murray River is a highly regulated stream, draining 1,061,469 km² with a total length of 2,575km. The main channel incorporates fourteen weirs along its length and two major storages, Yarrawonga and Hume Dams. All work in this project was undertaken in the Edward River and Gulpa Creek, an anabranch system, which commences at Picnic Point and discharges back into the Murray at Wakool junction (Figure 2). Flow in the Edward River is controlled via an undershot regulator situated downstream of the Murray junction. The regulator was upgraded to an automated structure in 1998 and, to comply with state legislation, a Denil fishway was constructed to provide passage for native fish (Figure 3).

2.2. Fish community sampling

Fish were collected on five occasions between October 2005 and April 2006 using a boat mounted 7.5kW Smith-Root Model GPP 7.5 H/L electrofishing system. Six sites were sampled to provide a comparison between fish communities upstream (0km upstream of regulator, 5km upstream of Murray confluence and 5km downstream Murray River confluence) and downstream (0km, 1km and 5km downstream) of the Edward River offtake regulator (Figure 2). In addition, two sites were also sampled downstream of Gulpa Creek (0km and 5km) regulator to 'benchmark' migratory fish communities prior to fishway construction (Figure 2). Sampling operations consisted of 12 X 90-second (elapsed) electrofishing 'shots' during daylight hours. Fish were collected via dip net and placed into a live well for recovery prior to identification and measurement (fork length). Each individual was inspected for diseases, parasites or injuries. Any positively identified fish unable to be dip netted were recorded as "observed". When large numbers of fish were caught, a random subsample of 20 individuals were measured per shot. All fish greater than 150mm total length were fitted with an external dart and a Texas Instruments eco-version 23mm passive integrated transponder (PIT tag). The subsequent recapture of tagged fish by anglers or researchers was used to determine any larger-scale migrations that may have occurred outside the study area.

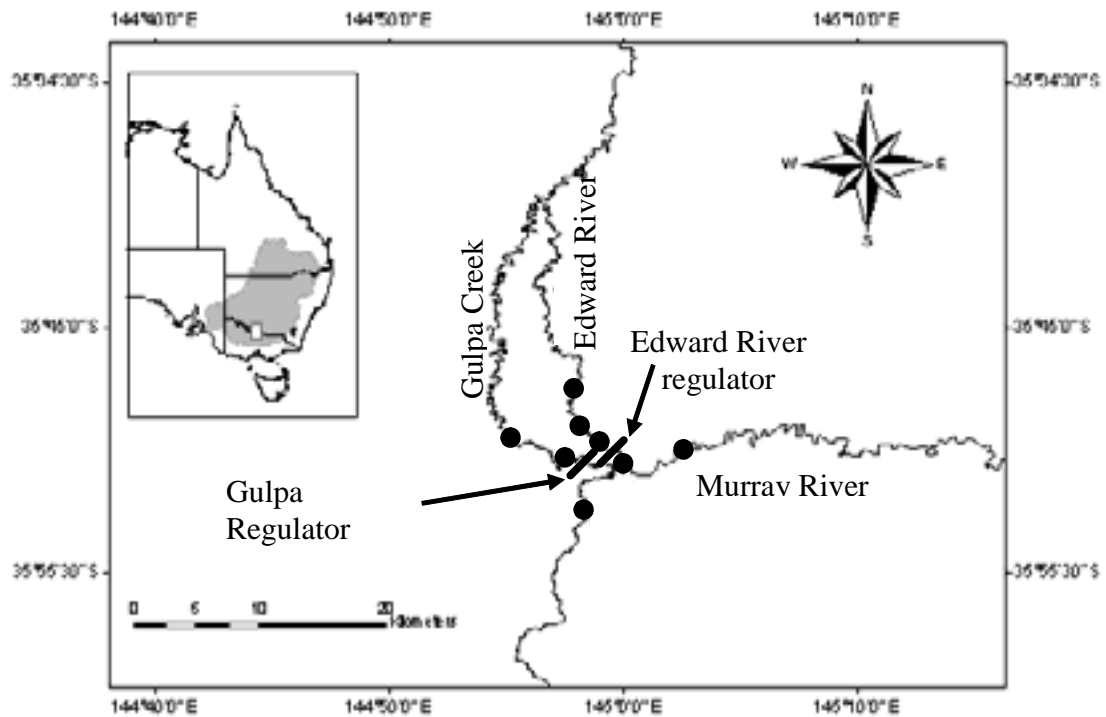


Figure 2. Map of the Barmah-Millewa region highlighting the eight sites (black dots) sampled as part of this study. Flow through the anabranch system is in a northerly direction.



Figure 3. The Edward River Offtake regulator. The retrofitted Denil fishway is located at the right hand side of the structure.

Table 1. Technical specifications of the Denil fishway and Edward River Offtake Regulator.

<u>Denil Fishway</u>	
Floor slope	1:12
Channel length	24m (with resting pool at 12m)
Material	Fibreglass
Baffle dimensions (L x W) (mm)	2400 x 550
Slow width and invert (mm)	330 x 120
<u>Edward River Offtake Regulator</u>	
Height	3.0m
Gate Design	Stainless Steel undershot release
Mean flow during study	1,759±219 ML.day ⁻¹
Mean Head difference	143±23mm
<u>Gulpa Creek regulator</u>	
Height	2.4m
Gate Design	Stainless Steel undershot release
Mean flow during study	723±210 ML.day ⁻¹
Mean Head difference	460±39mm

2.3. Fishway trapping

A total of 16 collections were taken from the fishway exit during the study. Excessive tailwater level and operational concerns prevented the collection of entrance samples. Subsequently, electrofishing data were used to compare the length of fish caught within the fishway and those accumulating downstream of the regulator. To collect fish, a trap was placed over the fishway exit (1.5m high x 60cm wide, 2mm mesh) for a total of 24 hours. When the trap was retrieved all fish were transferred into a fish box prior to processing. All fish and macroinvertebrates collected by the trap were counted, inspected for diseases or parasites, measured and released upstream of the fishway.

2.4. Data analysis

Data were analysed using the PRIMER (Version 5.0) multivariate statistical package and S-PLUS 2000 (Insightful corporation, 2001). Multidimensional scaling ordinations of Bray-Curtis similarity measures were used to plot fish community data, in two dimensions, after pooling replicate shots at each site. For the purposes of this study, fish communities were defined by the relative abundance of species sampled during the course of routine electrofishing.

Two-way analyses of similarities (ANOSIM), (as described in Clarke and Warwick, 1994), using sites as factors were performed on fourth-root transformed data to determine any differences between fish communities sampled upstream and downstream of the offtake regulator on the Edward River and Gulpa Creek. Where possible, each test was conducted using 20,000 Monte Carlo randomisations to calculate probabilities. A similarity percentages (SIMPER) test was subsequently performed to identify species contributing most to average dissimilarities within and between factors.

Two tailed Kolmogorov-Smirnov tests (KS: Sokal and Rohlf, 2001) were performed on the most common species from each site to assess differences in length frequency distributions between fish collected from the fishway and immediately downstream of the offtake regulator. Length frequency analysis revealed whether all size classes of fish attempting to pass the weir were successfully negotiating the fishway.

3. RESULTS

3.1. Electrofishing summary

Boat electrofishing yielded 11 fish species upstream and downstream of the Edward River offtake regulator. Australian smelt, Common carp and fly-specked hardyhead were the most dominant species (Table 2), comprising 95% of total catch. Significant differences were detected between upstream and downstream fish communities (ANOSIM: *Global R*=0.325, $p<0.01$, Figure 4). Australian smelt (*Retropinna semoni*) contributed most to the observed differences and was sampled in greater abundance from upstream zones (SIMPER: Table 3). In contrast, flyspecked hardyhead (*Craterocephalus stercusmuscarum*), Murray rainbowfish (*Melanotaenia fluviatilis*) and western-carp gudgeon (*Hypseleotris* spp) were more prevalent in downstream samples (SIMPER: Table 3).

Table 2. A summary of fish catches from each site sampled upstream and downstream of the Edward River Offtake Regulator. Abundance is pooled across the five samples. Upstream sites are 0km (upstream of the regulator) 5km DS (in the Murray River 5km downstream of the Edward River confluence and 5km US (in the Murray River 5km upstream of the Edward River confluence).

	Downstream			Upstream		
	0km	1km	5km	0km	5km DS	5km US
Australian smelt						
<i>Retropinna semoni</i>	773	531	1,015	598	1,049	834
Murray rainbowfish						
<i>Melanotaenia fluviatilis</i>	19	35	20	1	0	0
Common carp						
<i>Cyprinus carpio</i>	51	50	22	48	27	36
Flyspecked hardyhead						
<i>Craterocephalus stercusmuscarum</i>	64	353	193	41	162	56
Golden perch						
<i>Macquaria ambigua</i>	2	2	5	4	4	8
Goldfish						
<i>Carassius auratus</i>	10	12	5	26	3	4
Western carp gudgeon						
<i>Hypseleotris</i> spp	23	21	9	1	0	1
Mosquitofish						
<i>Gambusia holbrooki</i>	0	4	0	1	0	0
Murray cod						
<i>Maccullochella peelii peelii</i>	12	6	14	2	0	9
Redfin perch						
<i>Perca fluviatilis</i>	8	0	0	1	1	4
Silver perch						
<i>Bidyanus bidyanus</i>	0	0	0	1	4	0

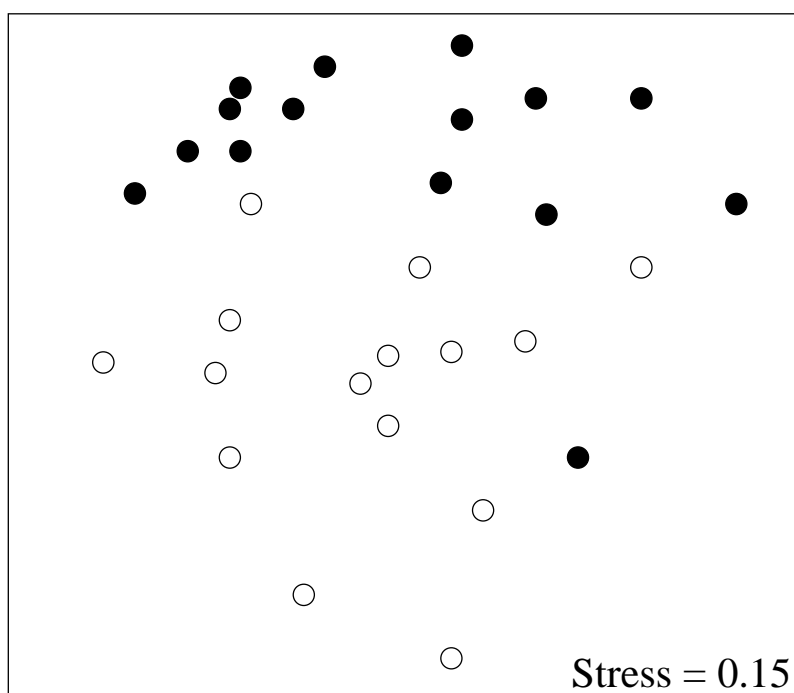


Figure 4. A multidimensional scaling (MDS) ordination of fish communities upstream (white) and downstream (black) of Edward River offtake regulator.

Table 3. The contribution of individual species to observed differences in fish communities upstream and downstream of Edward River Offtake Regulator as determined by SIMPER analysis. Mean dissimilarity was 31.52%. Mean abundance is the average percentage occurrence of fish from each sampling zone, CR is the consistency ratio, with higher values indicating species were more consistently contributing to differences. The cumulative % denotes the cumulative contributions of species to observed differences.

Species	Mean abundance (Downstream)	Mean abundance (Upstream)	Consistency Ratio	Cumulative %
Australian smelt	154.60	165.40	1.37	30.76
Flyspecked hardyhead	40.67	17.27	1.26	48.30
Murray rainbowfish	4.93	0.07	2.65	60.54
Western carp gudgeon	3.53	0.13	1.41	69.68
Murray cod	2.13	0.73	1.38	76.56
Goldfish	1.80	2.20	1.23	82.92
Common carp	8.13	7.40	1.34	88.80
Golden perch	0.60	1.07	1.25	93.34
Redfin Perch	0.53	0.40	0.87	96.68
Silver Perch	0.00	0.33	0.58	98.54
Mosquitofish	0.27	0.07	0.46	100.00

Interestingly, samples were dominated by smaller-bodied species (< 80mm at adulthood), rather than larger, more migratory species. Common carp (*Cyprinus carpio*), western carp gudgeon, redfin perch (*Perca fluviatilis*) and Murray cod (*Maccullochella peelii*) were the only species that were more abundant immediately downstream of the regulator. Other species such as golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and redfin perch (*Perca fluviatilis*) were sampled in low abundances from both upstream and downstream regions. Their absence from both electrofishing samples and fishway trapping may suggest a lack of migratory activity during the study period.

3.2. Fishway catches

A total of 222 fish (7 species) and 5,036 freshwater shrimp (1 species) were sampled from the exit of the Denil fishway during the study period. Freshwater shrimp numerically dominated catches whilst Australian smelt and flyspecked hardyhead were the most commonly collected fish (Table 4). Length-frequency analyses were only possible for flyspecked hardyhead, western carp gudgeon, Murray rainbowfish and Australian smelt (Figure 5). Significant differences were detected for flyspecked hardyhead (KS: $D=0.601$, $p<0.001$) and Murray rainbowfish (KS: $D=0.211$, $p<0.001$) where more smaller fish were detected accumulating at the regulator. No differences were detected for Australian smelt (KS: $D=0.247$, $p=0.235$) or western carp gudgeon (KS: $D=0.104$, $p=0.902$). Other species were sampled either too infrequently or in insufficient numbers to permit length-frequency analysis. Nevertheless, some juvenile Murray cod (74mm) and trout cod (52mm) were observed to successfully negotiate the fishway.

3.3. Gulpa Creek sampling

Sampling from the two sites in Gulpa Creek yielded 11 species of fish from both the regulator and 5km downstream. Australian smelt were the most dominant species with Murray rainbowfish, common carp and flyspecked hardyhead also sampled in relatively high abundances. Broad size ranges of fish were collected from Gulpa Creek and both adults and juveniles were collected. Immediately downstream of the regulator, extremely small individuals of flyspecked hardyhead, western carp gudgeon and Murray rainbowfish accumulated near the regulator gates (Table 5). In addition, large individuals of common carp and golden perch were also collected in the vicinity of the weir. Larger-sized Murray cod, goldfish and golden perch were present further downstream (Table 5).

Table 4. Total numbers of fish and macroinvertebrates caught from the exit of the Edward River offtake fishway. Abundance is pooled across all 15 samples and lengths are given in mm. Means are shown as the average \pm standard deviation.

Species	Abundance	Mean Length	Length Range
<u>Fish</u>			
Australian smelt	88	36 \pm 6	27-68
Murray rainbowfish	28	62 \pm 7	52-77
Common carp	1	283	283-283
Flyspecked hardyhead	70	46 \pm 6	35-63
Western carp gudgeon	22	36 \pm 4	26-43
Murray cod	7	223 \pm 82	74-373
Trout cod	6	101 \pm 86	52-282
<u>Invertebrates</u>			
Freshwater shrimp	5,036	N/A	N/A

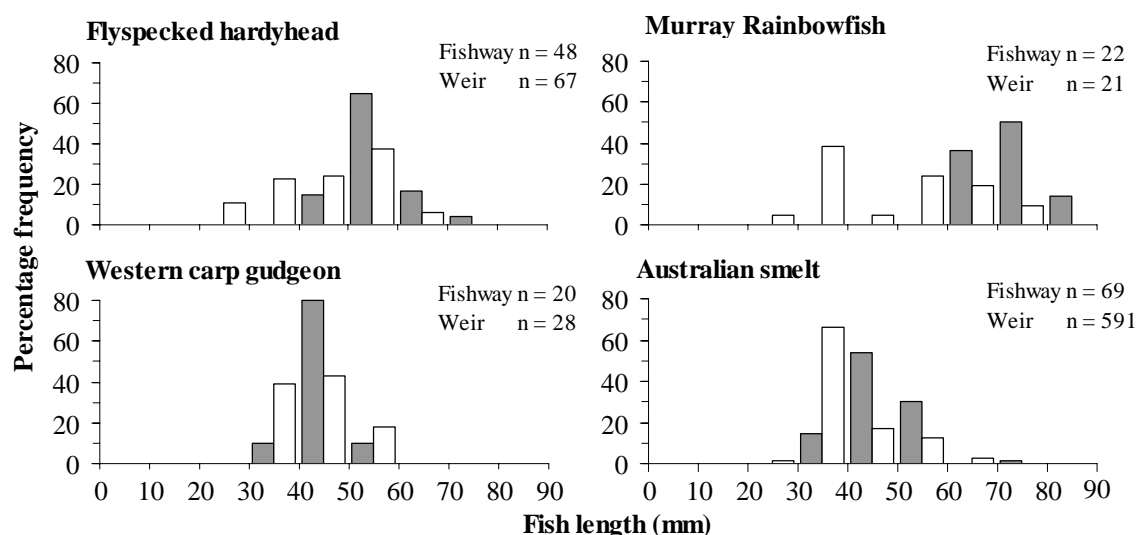


Figure 5. Length frequency distributions of the most commonly sampled fish within the Denil fishway (grey) and downstream of the regulator (white).

3.4. PIT tag summary

PIT tags were implanted into 154 fish over the duration of the study. Of these 57 were tagged downstream of the regulator, 57 in the upper Edward and Murray Rivers and 40 in Gulpa Creek. Up until April 2005, anglers had subsequently reported four recaptured fish. Two Murray cod (410mm and 450mm) tagged five kilometres downstream of the offtake regulator were caught from the same sites two and five weeks later respectively. A common carp (355mm) was tagged in Gulpa Creek and recaptured from the same location three days later. The final fish, a golden perch (400mm) was the only individual to demonstrate a substantial movement. This fish was tagged immediately downstream of the Gulpa Creek regulator and was recaptured in the Murray River, 20km downstream of the Gulpa Creek confluence, 13 days later.

Table 5. A summary of fish caught in Gulpa Creek downstream of the regulator. Abundances give total catch pooled for all replicates and all lengths are given in mm. Means are shown as the average \pm standard deviation.

Species	0km Downstream			5km Downstream		
	Abundance	Mean length	Length range	Abundance	Mean length	Length Range
Goldfish	2	64 \pm 11	56-72	5	142 \pm 97	84-254
Flyspecked hardyhead	31	38 \pm 11	18-71	42	34 \pm 9	20-57
Common carp	53	310 \pm 110	49-720	20	289 \pm 100	44-506
WC gudgeon	6	33 \pm 8	23-49	2	32 \pm 1	31-33
Golden perch	4	385 \pm 54	350-448	2	458	458-458
Trout cod	2	95 \pm 19	81-109	0	-	-
Murray cod	1	119	119-119	3	232 \pm 146	73-516
CS rainbowfish	16	45 \pm 15	24-65	14	41 \pm 12	26-64
Oriental weatherloach	1	73	73-73	0	-	-
Redfin perch	0	-	-	3	118 \pm 9	112-125
Australian smelt	179	34 \pm 9	18-65	484	32 \pm 8	13-58

4. DISCUSSION

This study provided important information that has ‘benchmarked’ the composition of fish assemblages from the Murray River, upper Edward River and Gulpa Creek in the Barmah-Millewa region. The surveys identified key species in the vicinity of each regulator and the potential size classes of fish requiring passage. Of interest was the high relative abundance of smaller bodied species and substantial numbers of freshwater prawns gaining passage through the fishway. Passage of large numbers of freshwater prawns is further evidence that macroinvertebrates should be considered when constructing fish passage facilities in Australia. Overseas, fishways are frequently constructed to accommodate migratory invertebrates (Rawer-Jost *et al*, 1998). Nevertheless, the passage of large numbers of freshwater prawns is rarely reported in Australian systems (Baumgartner, 2005). Although the ecological requirement for macroinvertebrate migrations remain to be defined, further research in this area would permit the development of suitable design criteria for incorporation into future fishways.

Electrofishing surveys identified substantially greater abundances of small-bodied species downstream of Edward River offtake than upstream. The dominance of smaller bodied species is consistent with accumulations downstream of barriers in other areas of the Murray-Darling Basin during autumn months (Stuart *et al*, 2004; Baumgartner, 2005). Most species accumulating downstream of the regulator successfully negotiated the fishway but substantial numbers of smaller Murray rainbowfish and fliespecked hardyhead were sampled downstream of the weir and not in the fishway. This observation suggests that the fishway was unable to provide passage for the very smallest size classes at the site.

The successful passage of adult fliespecked hardyhead, Murray rainbowfish and western carp gudgeon was unexpected given the poor swimming abilities of these species. Mean headloss across the regulator was relatively low (408mm) for the duration of the study and an elevated tailwater had submerged most of the fishway entrance. This situation can alter the internal hydraulics of Denil fishways by lowering turbulence and velocity thus enhancing opportunities for poorer-swimming species to negotiate the fishway (Larinier, 2002). Under normal operating conditions, these species may not be able to gain effective passage.

Entrance location is one of the single most important aspects of fishway design (Clay, 1995; Porcher and Travade, 2002). The entrance of the Edward River offtake fishway was fully inundated over the study period and most attraction flow was exiting via the resting pool. Some fish would be unable to effectively locate the entrance during such periods of inundation. An inability of Denil fishways to cope with large fluctuations in tailwater level and maintain optimal operating conditions is commonly reported (Schwalme *et al*, 1985; Clay, 1995; Bunt *et al*, 1999). At Edward River offtake the problem could be partly ameliorated by raising the entire fishway approximately 600mm. This would ensure all flow is directed through the entrance under high tailwater conditions and attract more migrating fish to this area. The probability of fish making a successful entry would subsequently increase.

The assessment period was outside the expected period of migration for larger bodied species such as golden perch, silver perch and Murray cod (Mallen-Cooper, 1996). Nevertheless, passage for larger individuals would prove difficult at this site, as a protective grating (150mm mesh) has been installed at the fishway entrance and exit. At the entrance, this mesh preclude the entry of large fish and at the exit, it regularly accumulates debris which alters the hydraulic performance of the fishway. A simple removal of this mesh may ameliorate these problems after which a repeat assessment during peak migration periods, would be required to determine any subsequent improvements in large fish passage.

The fishway also had problems with baffle instability. The current baffles are constructed out of fibreglass, are quite flexible and move freely within their guides. Optimal baffle configuration is critical to the effectiveness of Denil fishways, as even slight changes can create unsuitable hydraulic conditions (Odeh, 2003). Prior to each sampling occasion it was evident that flow through the fishway had dislodged some of the baffles, which frequently needed adjustment to restore optimal hydraulics. This problem could be easily rectified by securing the baffles with pins or bolts to prevent movement.

PIT tag data demonstrated that some fish are able to migrate through the Gulpa Creek regulator and return to the Murray River. Although possibilities for this passage are likely to be limited, opportunities could arise when the regulator gates are fully removed or if migratory fish proceed downstream to the Edward River and then upstream through the Denil fishway. To enhance fish passage opportunities through the regulator, frequent removal of the gates may provide a useful interim solution prior to fishway construction. To be fully effective however, such actions must occur during peak migration periods and act for a sufficient period of time to allow passage for most individuals (Thorncraft and Harris, 2000; Gilligan *et al*, 2003). Given the diverse range of migratory requirements of accumulating fish, such a solution is unlikely to provide permanent passage at the regulator. The construction of a PIT reader system at the Edward River would permit a quantification of movements through the Gulpa Creek system and back into the Murray River. Although the construction of the PIT reader system was well beyond the scope of the current project, its future construction would generate new information on the migration of fish through the Barmah-Millewa region and also link in with other MDBC programs such as the Sea to Lake Hume project..

Electrofishing surveys determined that the construction of fish passage facilities on the Gulpa Creek regulator must accommodate a wide range of species and size classes. Such a task represents a substantial challenge due to the expected differences in swimming ability between large and small-bodied species (Stuart *et al*, 2004). In other areas of the Murray-Darling Basin, vertical slot fishways on conservative slopes (1:32) with low turbulence (43w.m^2) have proved successful at achieving passage, but have a large capital cost.

Significant cost savings may be achieved by pursuing alternative designs such as a Deelder lock (Baumgartner, 2005) or a father-son configuration incorporating two fishways (Mallen-Cooper, 2000), which independently accommodate fish of different size classes. Essentially, the structure of the fish assemblage requires a complex solution for fish passage that captures the swimming ability of all species and an operating range over a wide range of flows. Both outcomes require close co-operation between biologists and engineers to obtain a long-term solution for this site.

Table 6. A list of problems and solutions, identified during the study, which could substantially improve the operation of the Denil fishway at Edward River offtake.

Issue	Problem	Possible solution
Entrance inundation	Fish unable to locate entrance under high flows	Raise the fishway 600mm to improve entrance conditions under high flows or construct a second entrance to operate when the tailwater is elevated.
Baffle instability	Baffles frequently wash-out when fishway discharge is high	Each baffle should be fixed into the fishway channel by pinning or bolting
Grid over entrance	Physically prevents the entrance and exit of large-bodied fish	All grid should be removed from the entrance and exit
Debris in exit	Sticks and leaves accumulate at fishway exit and increase exit head differential.	Removal of gridmesh would prevent some fouling. The installation of a suitable trash rack could also exclude larger items from the fishway exit.

5. CONCLUSIONS AND RECOMMENDATIONS

Despite previous concerns regarding fishway operation and operational difficulties, some degree of fish passage was possible through the Denil fishway. Many small-bodied fish species and freshwater shrimp successfully negotiated the fishway, albeit this was likely facilitated by the relatively small head differential at the time of assessment. Replicating this study during peak migratory periods, and when the operating head is greater, is necessary to determine the operating efficacy of the fishway over a wider range of flows.

Despite the apparent success of the fishway during low-head periods, a number of issues currently prevent the effective operation of the Edward River offtake fishway (Table 6). These problems would be relatively inexpensive to ameliorate and would greatly enhance fish passage through the structure. It is subsequently recommended that the Denil fishway is repaired and modified to improve fish passage opportunities (Table 6). Following modification it is further recommended that a second assessment be undertaken to gauge the subsequent effectiveness of the modified installation. Ideally, this would also include the addition of a PIT reader system at both the Edward River offtake regulator and at Gulpa Creek to identify larger-scale fish movements in the Barmah-Millewa region. Should a subsequent assessment demonstrate similar operational problems, a new fishway may need to be considered.

The results also suggested that the construction of a fishway at Gulpa Creek could potentially provide passage for a number of species accumulating downstream of the regulator. Any such fishway should accommodate a large range of species and size classes given the composition of fish found to accumulate over the study period.

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