Fish passage through a Deelder lock on the Murrumbidgee River, Australia

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October 2003

NSW Fisheries Final Report Series
No. 57
ISSN 1440-3544

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Authors: Lee J. Baumgartner
Published By: NSW Fisheries
Postal Address: PO Box 21, Cronulla NSW 2230
Internet: www.fisheries.nsw.gov.au

ISSN 1440-3544

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ACKNOWLEDGEMENTS

This study was funded by Agriculture Fisheries and Forestry Australia under the National Heritage Trust MD2001 Fishrehab program with supplementary funding provided by State Water.

I would like to thank Peter McLean, Cameron Lay, Joanna Williams and Ian Wooden for their enthusiastic assistance with field sampling. I would also like to thank Tom Davy of State Water for permitting access to Balranald Weir and for his assistance and interest in the project.

A steering committee comprising Dr Peter Gehrke, Dr John Harris, Cameron Lay, Lindsay White, Kumar Sathasivam and Robert Shuttle provided direction and guidance.

Helpful comments on various drafts were provided by Drs Dean Gilligan, Bob Creese and Tracey MacDonald.

The study was conducted under NSW Fisheries Animal care and ethics permit 99/15.

NON-TECHNICAL SUMMARY

Fish passage through a Deelder lock in the Murrumbidgee River, Australia

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OBJECTIVES:

To document the effectiveness of a Deelder fishlock at passing fish from a river within the Murray-Darling Basin.

NON TECHNICAL SUMMARY:

Of the 55 freshwater fish species that inhabit the rivers of New South Wales, at least 36 have a requirement to migrate at some stage of their life. Adult and juvenile Australian native fish previously have been observed undertaking large-scale upstream migrations of up to 1,400km. The presence of dams and weirs prevents successful migrations by blocking pathways to spawning habitats, recruitment areas or feeding grounds. Since 1913, over 70 fishways have been constructed in NSW to help mitigate the effects of instream barriers and restore longitudinal connectivity for migratory fish.

The fishway design that has been most comprehensively assessed in Australia has been the vertical slot fishway, which has proved effective at passing a wide range of species and size classes of fish in coastal and inland systems. More recently, fishway assessments have focused on alternative designs such as rock ramps and denils. Assessments of these designs have been far from conclusive, especially for large fish, and ongoing research is needed to determine if more of these fishways should be installed.

The success of fishways at passing Australian native fish over a range of flows is generally inversely proportional to the cost. Therefore, there is a constant need to refine existing fishway designs and develop new technology so that future fishway installations can be more cost efficient without compromising the passage of native fish.

A cost-effective design that has considerable potential for Australian systems is the Deelder fishlock, which was first constructed on the Muese River, Belgium, in 1958. The original fishway was decommissioned in 1976 and the design was not adopted anywhere else in the world.

Australia's first, and the world's only operational, Deelder fishlock was constructed at Balranald Weir on the Murrumbidgee River, NSW in December 2002. A detailed assessment was then initiated to determine its utility for wider application in the Murray-Darling Basin. This study assessed the effectiveness of the Deelder fishlock at providing passage for Australian native fish. In 18 paired entrance and exit samples, over 3 different cycle times, a total of 7,939 fish representing 9 different species were sampled passing through the fishlock. Australian smelt, bony bream and western carp gudgeon contributed 94% of the total catch. The maximum rate of daily fish passage was 854 fish at an average daily rate of 360 ± 58 fish (equivalent to 22 ± 3 per hour).

The fishlock was most successful at providing passage for Australian smelt, crimson-spotted rainbowfish, golden perch, the threatened silver perch and young-of-the-year Bony herring. However, higher abundances of flyspecked hardhead and carp gudgeon at the entrance of the fishlock than at the exit suggest that fish passage was inhibited for these species. Cycle time did not have a significant affect on the abundance or composition of fish using the fishlock, and sizes of fish sampled from the exit trap ranged from 12 – 540 mm fork length. Therefore, fish from a wide range of size classes were capable of utilising the fishlock. However, the catching efficiency of the fishtrap greatly influenced the results. Reducing the mesh size on the trap from 10 mm to 1 mm significantly increased the capture rates of Australian smelt, bony herring, flyspecked hardyhead, carp gudgeon and crimson spotted rainbowfish.

Movement of fish varied significantly with time of the day. The greatest movement occurred between 12:00 and 16:00 for Australian smelt, bony herring, crimson spotted rainbowfish and flyspecked hardyhead. Few fish migrated at dawn or at night.

Recommendations

- The Deelder fishlock at Balranald provided passage for a wide range of size classes and species of Australian native fish. This fishlock currently only has provision for manual operation, because of cost constraints at the time of construction. It is recommended that the fishlock be fully automated as soon as possible to enable fish passage at times when the fishlock is unmanned.
- Most fish sampled passing through the Deelder fishlock were either small or young-of-the-year native fish, suggesting that upstream passage is important for these species and size classes. It is recommended that further research be conducted into their migratory requirements and that future fishways be designed to provide passage for small fish as well as for large fish.
- Flows were constant, and relatively low, for the duration of this study. The results of this study, therefore, are only indicative of fish passage under low flow situations. It is recommended that the study be repeated during times of high flows to ensure that fish passage is equally efficient.
- More fish remained in the exit chamber following the 60-minute cycle than under 120 or 240 minute cycles. Therefore, it is recommended that future Deelder fishlocks operate on a 120-mintue cycle to maximise passage rates.
- Fish passage appeared to be inhibited for carp gudgeon and flyspecked hardyhead because these species were present in higher numbers from entrance samples than exit samples, possibly because of the presence of the vertical internal weir. Experiments using a sloping weir should be conducted to observe whether passage is improved as a result.
- Significantly higher numbers of small fish were sampled after reducing the mesh size of the trap from 10mm to 1mm. Therefore, it is recommended that future fishway studies consider using a small mesh size to ensure that small fish are also sampled during assessments of fishway efficiency.

1. INTRODUCTION

Of the 55 freshwater fish species that inhabit rivers in New South Wales Rivers, at least 36 have a requirement to migrate at some stage of their life history (Harris and Gehrke, 1997; Thorncraft and Harris, 2000). Adult Australian native fish have been previously observed undertaking large-scale migrations of up to 1,400km (Reynolds, 1983) and juvenile fish may undergo mass upstream migrations at a rate of up to 3,000 per day (Mallen-Cooper, 1996). The presence of instream barriers inhibits successful upstream migrations by blocking pathways to habitats that are important for spawning, rearing or feeding (Mallen-Cooper, 1989). Fishways are usually constructed to help mitigate these effects.

A total of 44 fishways were built in Australia between 1913 and 1985, although many were designed for Northern Hemisphere salmonids and failed to account for the reduced swimming abilities of Australian native fish (Eicher, 1982; Harris, 1984a; Mallen-Cooper; 1989, 1996; Thorncraft and Harris, 2000). Since 1985, a significant amount of research has been conducted on the biology of Australian native fish and the development of fishways has advanced significantly (Lay and Baumgartner, 2001).

The fishway design that has received most attention to date has been the vertical slot fishway which has proven effective at passing a wide range of species and size classes in coastal (Mallen-Cooper, 1992; Stuart and Mallen-Cooper, 1999; Stuart and Berghuis, 2002; Gilligan *et al*, 2003) and inland (Mallen-Cooper, 1994; Mallen-Cooper, 1996) systems. Recently, Australian fishway assessments have also focused on alternative designs such as rock ramps (Thorncraft and Harris, 1996; Harris *et al*, 1998; Baumgartner and Lay, 2001) and denil fishways (Mallen-Cooper and White, 1995). However, assessments of these designs have been far from conclusive, especially for large fish.

Lock type fishways are frequently constructed at high head installations around the world (Clay, 1995). A fishlock is best described as a device that assists the migration of fish over dams by filling a chamber with water that fish have entered at tailwater level (Clay, 1995). Once the chamber is filled to the level of water in the weirpool, fish are free to continue their upstream migration. Fishlocks generally require fish to continue their migrations via their own volition. However, if required, a herding device may be incorporated to force fish to exit the structure once it has filled. Fishlocks are still considered highly experimental in Australian systems and their assessment is limited to three studies, each of which has highlighted some operational problems.

Thorncraft and Harris (1997) identified operational problems with the fishlock at Yarrawonga Weir on the Murray River where a hydroelectric plant adjacent to the fishway created excessive velocities at the fishway exit. It was suggested that any fish successfully exiting the fishlock were forced downstream through the turbine. White and Keller (2001) assessed the same structure but added to the earlier work by describing optimal operating conditions within the fishlock itself. Although these two studies identified the potential of the fishlock at Yarrawonga, it is still not fully automated because the problems of the excessive exit velocities have not yet been resolved. A second fishlock, of Ardnacrusha design (described in Clay, 1995), was assessed on the Fitzroy River in Queensland. It passed a wide range of species and size classes of coastal fish (Stuart and Berghuis, 1997). However, the design was considered inefficient because of inappropriate entrance conditions that were failing to attract the full complement of migrating fish. These three studies suggest that fishlocks have significant potential to improve fish passage. However, problems specific to each design have limited their efficient operation.

The success of fishways at passing Australian native fish over a range of flows is generally inversely proportional to the cost (Mallen-Cooper, 2000). Therefore, there is a constant need to refine existing fishways and develop new technology so that future fishway installations can be more cost efficient without compromising the passage of native fish.

A cost-effective lock design that has considerable potential for Australian systems is the Deelder fishlock (after Deelder, 1958) which was first constructed on the Muese River, in Belgium. The Deelder fishlock can best be described as an atmospheric lock incorporating two chambers divided by an internal weir (Figure 1). Deelder fishlocks are most suited to low head weirs and for conversions of existing but ineffective fishways that are too steep for native fish to negotiate (Thorncraft and Harris, 2000). Australia's first Deelder fishlock was constructed at Balranald Weir on the Murrumbidgee River, NSW in December 2002 and a detailed assessment was done to determine its utility for wider application in the Murray-Darling basin.

The aim of this study was to describe, for the first time, the ability of a Deelder fishlock to provide passage for Australian native inland fish and to fully describe its operating parameters and limitations.

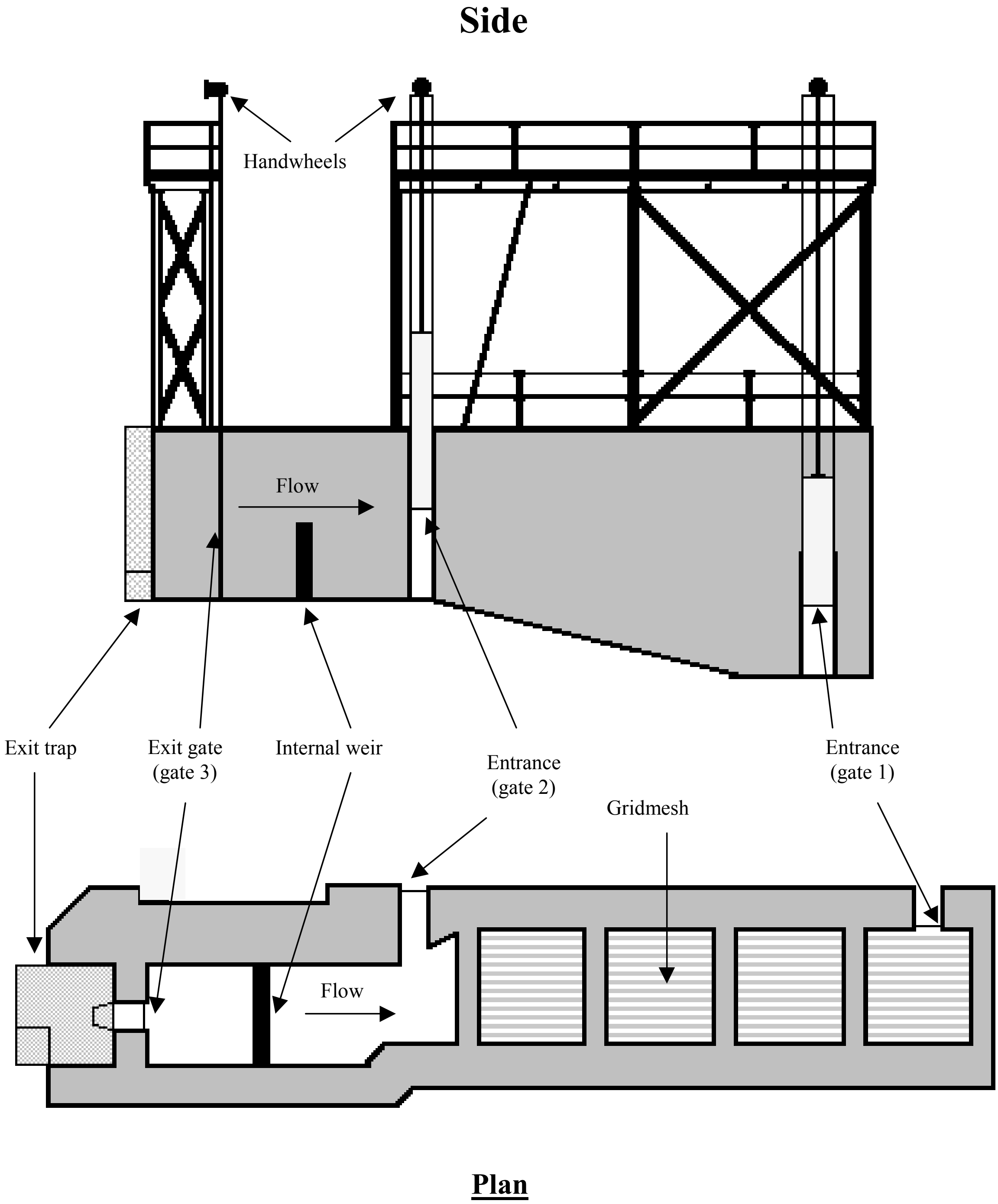

Figure 1. Side and plan view of the Deelder fishlock at Balranald Weir showing most mechanical elements. Handwheels are set at the 1:1000 year flood mark. Drawing is not to scale.

2. METHODS

2.1. Study site

The Murrumbidgee River is a highly regulated river draining 11,025 km^2 (Harris and Gehrke, 1997). It has six weirs along its length (Ebsary, 1992) which were constructed for domestic water supply, stock water supply, irrigation, diversion to irrigation areas and rediversion to effluent streams. Two storages, Burrinjuck and Blowering Dams, release water based on seasonal allocations with flows mostly released between September and March when irrigation demand is at its highest.

The Deelder fishlock was constructed within the channel of an existing submerged orifice fishway at Balranald Weir, approximately 6 km west of the township of Balranald (Figure 2). The weir is the most downstream structure on the Murrumbidgee River and is 40 m long by 3.7 m high with water levels regulated by drop boards (Figure 3). Its primary purpose is to supply water to the township of Balranald. The weir is a barrier to fish passage when flows are below 4,500 ML; above this, the drop boards are removed and free passage is restored.

2.2. Fishlock specifications

The fishlock is 14 m long x 1.5 m wide x 3 m deep and incorporates low flow and high flow entrance gates and one exit gate (Figure 1). The primary entrance gate (Gate 1) is 3 m downstream of the second and is operated only under low tailwater conditions. The secondary entrance gate (Gate 2) is much closer to the weir crest and is only used under high tailwater conditions. The exit gate (Gate 3) is located at the most upstream point in the lock chamber. All three gates have a width of 400 mm to allow passage of large individuals of Murray Cod (*Maccullochella peelii*). It is impossible to fully de-water the fishway because the floor of the structure is set at 0.8 m below the lowest tailwater level to allow sufficient depth for fish to enter under minimum flows.

The fishlock gates were operated manually via handwheels that drive a nut (fixed to the gate) up and down a non-rising spindle. Waterproof gearboxes were not available and therefore the control mechanisms were fixed above the projected 1 in 1,000 year flood line.

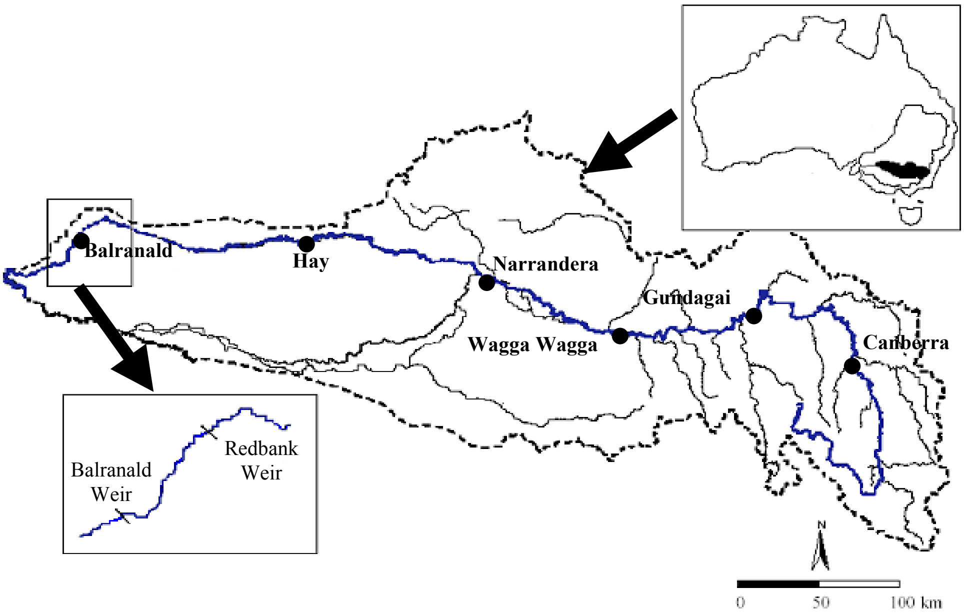

Figure 2. A map of the Murrumbidgee catchment showing the location of the Balranald Weir study site.

a)

b)

Figure 3. Balranald Weir showing a) the original submerged orifice fishway and b) the retrofitted Deelder fishlock.

2.3. Fishlock operation

The fishlock operates in a similar manner to a navigation lock for boats. The lock has four primary phases: an attraction phase, a filling phase, an exit phase and a transition phase (Figure 4). During the attraction phase, fish are attracted into the fishlock by maintaining a flow of 0.85 $m\ s^{-1}$ through the entrance gate. This velocity is controlled by opening the exit gate to a specified distance, which is dependent on the tailwater level. After a predetermined time, the filling phase begins by closing the entrance gate and allowing water levels in the chamber to slowly equilibrate with that of the weirpool. Once this is achieved the exit gate is lifted clear of the water and the exit phase begins by slightly opening one of the entrance gates to provide a velocity of 0.5 $m\ s^{-1}$ through the exit slot. Fish are then free to continue their upstream migration. After another predetermined time a transition phase occurs where the fishway is drained by partially closing the exit until the fishlock is returned to the attraction phase. The cycle is then repeated. The entrance and exit velocities were chosen to suit the swimming abilities of both the largest and smallest fish expected at the site, while also providing adequate conditions to attract fish into the fishlock.

2.4. Cycle times

Fishlock efficiency was initially assessed over three different cycle times: 60 minutes, 120 minutes and 240 minutes. During a 60 minute cycle the fishlock was in attraction phase for 20 minutes, the gates were adjusted then left in exit phase for 20 minutes. During the 120 minute cycle, the fishlock was left in attraction and exit phase for 50 minutes each. The 240 minute cycle incorporated a 170 minute entrance phase with a 50 minute exit phase. A total of 20 minutes was required to operate the gates each cycle. More time was devoted to attracting fish rather than facilitating their exit in the 240 minute cycle because:

i) it is normally difficult for fish to locate the fishlock entrance as the discharge of the weir will always be greater than the discharge from the fishlock;

ii) the flow of 0.5 $m\ s^{-1}$ through the chamber during the exit phase should lead fish directly to the exit and so a shorter time is needed.

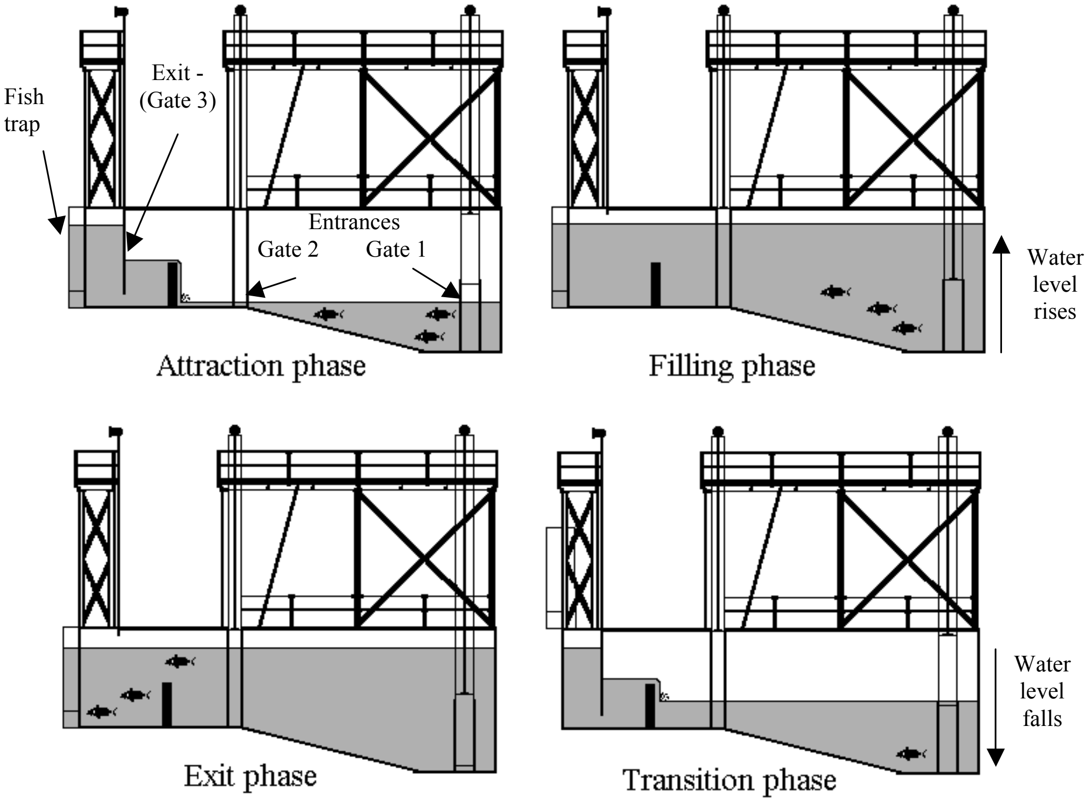

Figure 4. A diagrammatic representation of a full Deelder fishlock cycle showing all operating phases. The shaded areas refer to water levels within the lock chamber. In attraction phase, the entrance gate is fully open to permit entry of fish and the exit gate is opened slightly to provide an attraction flow of 0.75 ms^{-1} through the entrance. During the filling phase the entrance gate is closed, the exit gate is opened, and the water level equilibrates with that of the weirpool and inundating the internal weir. In exit phase, the entrance gate is opened slightly to create a flow of 0.5 ms^{-1}, which stimulates movement towards the exit. The transition phase is when fish traps are removed and the gates return to attraction phase configuration. The cycle is identical under high tailwater situations except that the upstream entrance gate (Gate 2) is used instead of the downstream entrance gate (gate 1).

2.5. Entrance and exit trapping

The Deelder fishlock was assessed through paired entrance and exit trapping on 18 occasions for each 60 minute, 120 minute and 240 minute cycle performed. Trapping occurred daily between 0700 hours and 2300 hours, and was fully randomised (between cycle time and location of the trap) over the study period between January and April 2003. This gave 108 replicates encompassing most diurnal and some nocturnal periods of fish passage.

The entrance trap was constructed from a modified fyke net. The net had a rectangular mouth with dimensions of 40 cm x 100 cm (4 mm mesh) and was placed into the guides of the entrance gate. The net was lowered via a rope and secured so that fish were unable to swim around or underneath the trap. The exit trap was constructed from a rectangular frame fitted with 10 mm bird-mesh which had three cones evenly spaced vertically to allow fish to enter. The maximum width of the cones (30 cm) was designed to match that of the entrance trap (Figure 1). The trap was lowered over the fishlock exit via a hand winch, positioned over the exit gate prior to the commencement of the exit phase, and raised during the transition phase.

Whenever the fishway entrance was trapped, a full cycle of the fishway was completed to offset any effects of draining the fishway upon the completion of the exit phase. This was seen as a major factor influencing fish attraction to the entrance prior to commencing the next cycle.

2.6. Trap efficiency

The exit trap's efficiency to capture small fish was assessed after reducing the mesh size from 10 mm to 1 mm by covering the trap with 90% UV protected shadecloth. This was considered the ideal material to exclude small fish because it was less susceptible to damage from floating debris than other types of fine mesh. It is possible that some fish did not exit the fishway because of the presence of the trap or because the timing of the exit phase did not allow enough time for fish to do so. Exit phase efficiency was therefore assessed during 12 cycles to determine whether fish were not effectively exiting the chamber. This was done by fully closing the exit gate to drain the exit chamber during 60 minute (N = 4), 120 minute (N = 4) and 240 minute (N = 4) cycles. Any fish remaining in the space between the internal weir and the exit gate were identified and recorded as not having successfully exited the fishway. If the reason for non-successful passage was cycle time, it was expected that numbers of fish not gaining passage would change with different exit times. However, if the reason were trap avoidance the number of fish remaining in the chamber would be relatively constant irrespective of cycle time.

2.7. Daily migration periods

Optimal daily fish passage periods were determined for the most common species sampled using a methodology similar to that described by Mallen-Cooper (1996). Each sampling day was divided into five distinct periods. Dawn (N = 5) represented any replicates that were completed before 800 hours, morning (N = 10) was between 0800 and 1200 hours, afternoon (N = 24) occurred between 1200 and 1600 hours, dusk (N = 18) encompassed 1600 to 2000 hours and night samples (N = 8) represented any replicates completed after 2000 hours. The sampling design was fully randomised and some trap sets overlapped these periods. Consequently, only samples completed within the set hours were included in subsequent analyses for this component of the study. Samples were standardised to catch per hour of cycle time to reduce any confounding effects of extended cycle times on catch rate.

2.8. Abiotic variables

Abiotic variables such as pH, dissolved oxygen, temperature and conductivity were measured twice daily using a Model U-10 Horiba water quality meter whenever entrance and exit trapping was conducted. Flow readings were obtained via a fixed station flow meter that was situated approximately 50 m downstream of Balranald Weir.

2.9. Data analysis

Analyses were done to determine whether similar species, absolute abundances (from direct trapping data) and length frequencies (based on fork length) of fish were gaining successful passage through the fishlock. In this study, ‘fish communities’ were defined by species counts (standardised to electrofishing time) that were converted to Bray-Curtis similarity values as described in Clarke and Warwick (1994).

Two-way analysis of similarities (ANOSIM) (as described in Clarke and Warwick, 1994) were used to determine differences in fish community composition depending on cycle time and to test whether similar species were entering and exiting the fishlock. The test was performed using 20,000 Monte-Carlo randomisations and data were fourth root transformed to increase the contributions of rare species. Similarity percentages (SIMPER) were used to determine species significantly contributing to observed differences. A one-way analysis of similarities was also used to determine if the fish community caught in the trap significantly differed when the trap mesh size was reduced from 10 mm to 1 mm.

The response of each individual species was likely to vary because of differing migratory requirements and swimming abilities. Therefore, differences in absolute abundance between cycle time and trap location (entrance or exit) were assessed for individual species using a randomised complete block paired comparison test as described in Sokal and Rohlf (2001). This was then analysed using the S-PLUS software package (Insightful, 2001). In both cases, it was assumed that the number of migrating fish might change over time. Therefore, for these two tests, the blocks were defined as time elapsed since the commencement of trapping. The response to both cycle time and entrance/exit trapping was determined by two-way ANOVA. Data were log x+1 transformed to stabilise variances and then statistically compared using an F-test (for paired trap comparisons) and an F-max test (for cycle times). Quantile-quantile plots of the residuals confirmed that log x+1 transformed data were approximately normally distributed (Insightful, 2001).

Two tailed Kolmogorov Smirnov tests (as described in Sokal and Rohlf, 2001) were used to determine significant differences in size frequency distributions of fish attempting to ascend the fishway and successfully ascending the fishway. These tests were also used to determine if fish of different sizes were caught after reducing the mesh size from 10 mm to 1 mm.

Differences in daily migration period for individual species were determined using the non-parametric Kruskal-Wallis test (as described in Sokal and Rohlf, 2001) because variances could not be stabilised due to small sample sizes in some species.

3. RESULTS

3.1. Abiotic variables

Flow over Balranald Weir averaged 226.72 ± 12.84 MLday^{-1} over the study period (Figure 5). Flow varied minimally, except for a five-day period in mid-March when a peak of 785 MLday^{-1} was experienced. End of system flows in the Murrumbidgee River are generally maintained at a minimum of 200 MLday^{-1}. Therefore, the discharge over the weir for the duration of this study is indicative of a low-flow situation.

Temperature ranged from 23.1°C to 29.2°C with an average of 24.90 ± 0.29°C. There was little variation on either a daily basis or over the 115 day study period. This is probably a reflection of the low flow conditions. There was also minimal variation in pH (mean ± one standard error 7.41 ± 0.06), dissolved oxygen (8.22 ± 0.32gL^{-1}) or conductivity (0.117 ± 0.005 microsiemens).

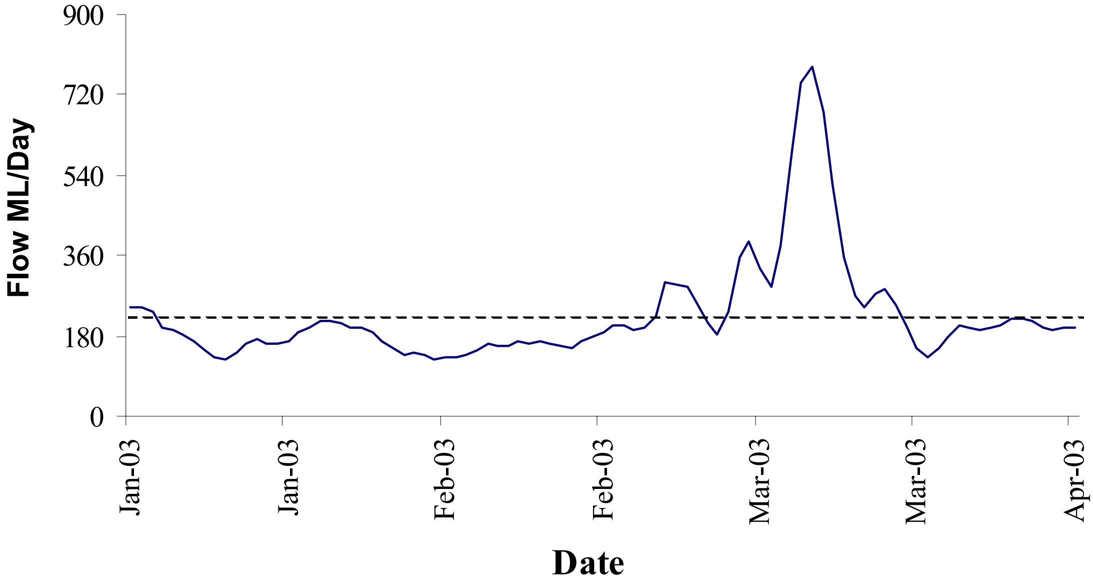

Figure 5. Flow (in Megalitres per day) over Balranald Weir over the duration of the study. Dotted line represents the mean daily flow rate.

3.2. General fish sampling

A total of 7,939 fish representing 9 species was trapped from the Deelder fishlock during the sampling period. The fishlock passed an average of 22.50 ± 3.64 fish hour^{-1}. Small fish species such as *R. semoni*, *N. erebi* and *Hypseleotris* spp contributed 94% of all fish sampled (Table 1). The only alien species sampled in the fishway was *C. carpio*. All species trapped at the entrance of the fishway were also trapped at the exit. The maximum number of fish to ascend the fishway in a single sampling day (7:00-11:00) was 854 fish, with an average of 360.86 ± 58.35 fish day^{-1} over the sampling period.

3.3. Cycle time and Entrance/Exit trapping

Two way ANOSIM determined no significant differences in fish community composition among cycle times (R = -0.019, p = 0.870), although a significant difference existed between fish communities captured from the entrance and exit of the fishlock (R = 0.120, $p < 0.001$). A subsequent SIMPER analysis revealed that *R. semoni*, *N. erebi* and *Hypseleotris* spp and *C. stercusmuscarum* contributed most to observed differences (Table 2).

R. semoni and *N. erebi* were sampled in greater numbers from the exit, but *Hypseleotris* spp and *C. stercusmuscarum* were sampled in greater numbers at the fishlock entrance. Other species exhibited low consistency ratios and hence contributed little to observed differences.

Two-Way ANOVA revealed significant differences between the absolute abundance of fish trapped at the entrance and the exit for a number of species, but there were no significant differences over time (blocks) (Table 3). *Bidyanus bidyanus* (p = 0.022) and *R. semoni* ($p < 0.001$) were sampled in significantly higher numbers from the exit but *C. stercusmuscarum* ($p < 0.001$) and *Hypseleotris* spp ($p < 0.001$) were sampled in greater numbers from the entrance. No significant differences were observed for *N. erebi* (p = 0.556) or *M. fluviatilis* (p = 0.052).

Two-Way ANOVA revealed no significant differences in abundance of any species due to cycle time ($p > 0.05$) but, in general, more fish were sampled from 60 minute cycles (Figure 6). Although, no individual species demonstrated a statistically significant difference among cycle times, more *B. bidyanus* successfully reached the exit during 240 minute cycles. Further, casual observations suggested that exit times of 50 minutes were more beneficial for passage of silver perch than 20 minutes.

Kolmogorov-Smirnov tests identified significant differences in size frequency distributions for *N. erebi* (ks = 0.112, p = 0.004) and *R. semoni* (ks = 0.127, p = 0.006) trapped from the entrance and the exit (Figure 7, Table 4). Larger individuals were sampled from the exit. However, in both species, smaller size classes of fish were well represented and there was little evidence to suggest that small fish were unable to gain passage through the fishlock. No significant differences in length frequency distribution were observed for *M. fluviatilis* (ks = 0.228, p = 0.343), *Hypseleotris* spp (ks = 0.100, p = 0.263), *C. stercusmuscarum* (ks = 0.199, p = 0.488) or *B. bidyanus* (ks = 0.393, p = 0.521) demonstrating that fish entering and exiting the fishway were of similar sizes (Figure 7).

Table 1. Total fish trapped from the entrance or exit of the Deelder fishlock over the study period at 3 cycle times.

	60 min		120 min		240 min	
Species	**Entrance**	**Exit**	**Entrance**	**Exit**	**Entrance**	**Exit**
Nematalosa erebi	447	873	525	319	318	476
Retropinna semoni	282	770	209	973	247	797
Hypseleotris spp	366	81	294	87	358	30
Craterocephalus stercusmuscarum	106	14	45	24	128	8
Melanotaenia fluviatilis	28	11	22	0	19	5
Bidyanus bidyanus	1	9	7	6	1	21
Phylipnodon grandiceps	3	0	3	0	12	2
Cyprinus carpio	0	0	2	3	4	0
Macquaria ambigua	0	0	0	3	0	0
Grand Total	**1233**	**1758**	**1107**	**1415**	**1087**	**1339**

Table 2. SIMPER results showing species significantly contributing to differences between entrance and exit traps of the Deelder fishlock. Analysis is based on fourth root-transformed data. Mean dissimilarity is the measure of similarity between the two groups ranging from 0% (identical) to 100% (totally dissimilar). CR is the degree to which species are contributing to observed differences with higher values indicating a greater contribution.

Species	**Mean abundance**		**CR**	**% contribution**
Entrance vs Exit mean dissimilarity = 53.22				
	Entrance	Exit		
Retropinna semoni	13.92	46.18	1.17	23.75
Nematalosa erebi	24.34	30.33	1.20	22.19
Hypseleotris spp	19.21	3.60	1.22	20.06
Craterocephalus stercusmuscarum	5.26	0.84	1.03	13.48
Melanotaenia fluviatilis	1.30	0.29	0.72	6.64
Bidyanus bidyanus	0.17	0.65	0.58	6.08
Phylipnodon grandiceps	0.34	0.04	0.45	3.74
Cyprinus carpio	0.11	0.05	0.33	2.87
Macquaria ambigua	0.00	0.05	0.21	1.19

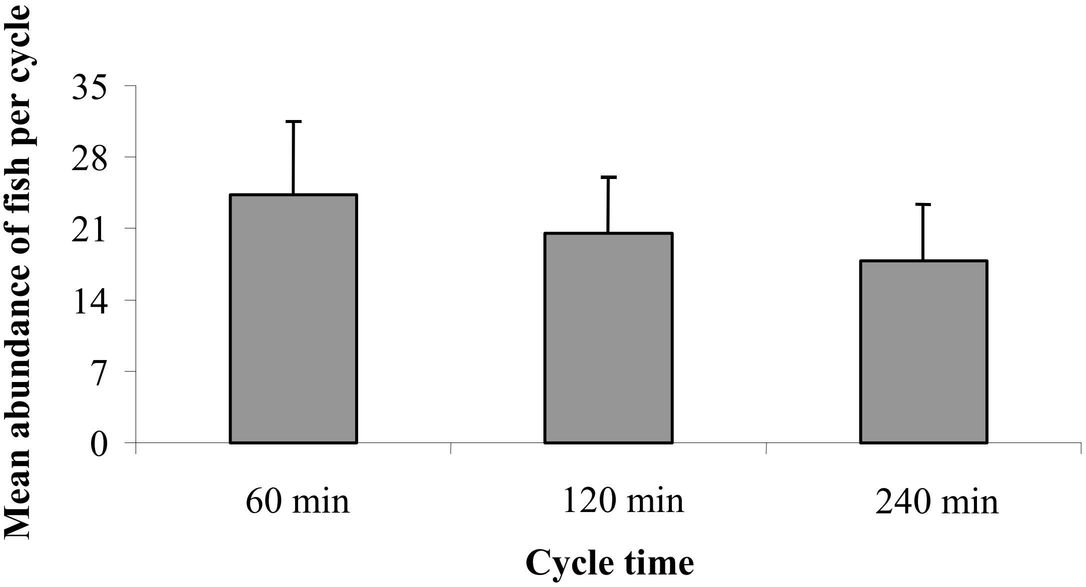

Figure 6. Mean absolute abundance (pooled for all fish species) caught migrating through the Deelder fishlock (± one standard error). Data from the 18 paired entrance and exit samples have been pooled.

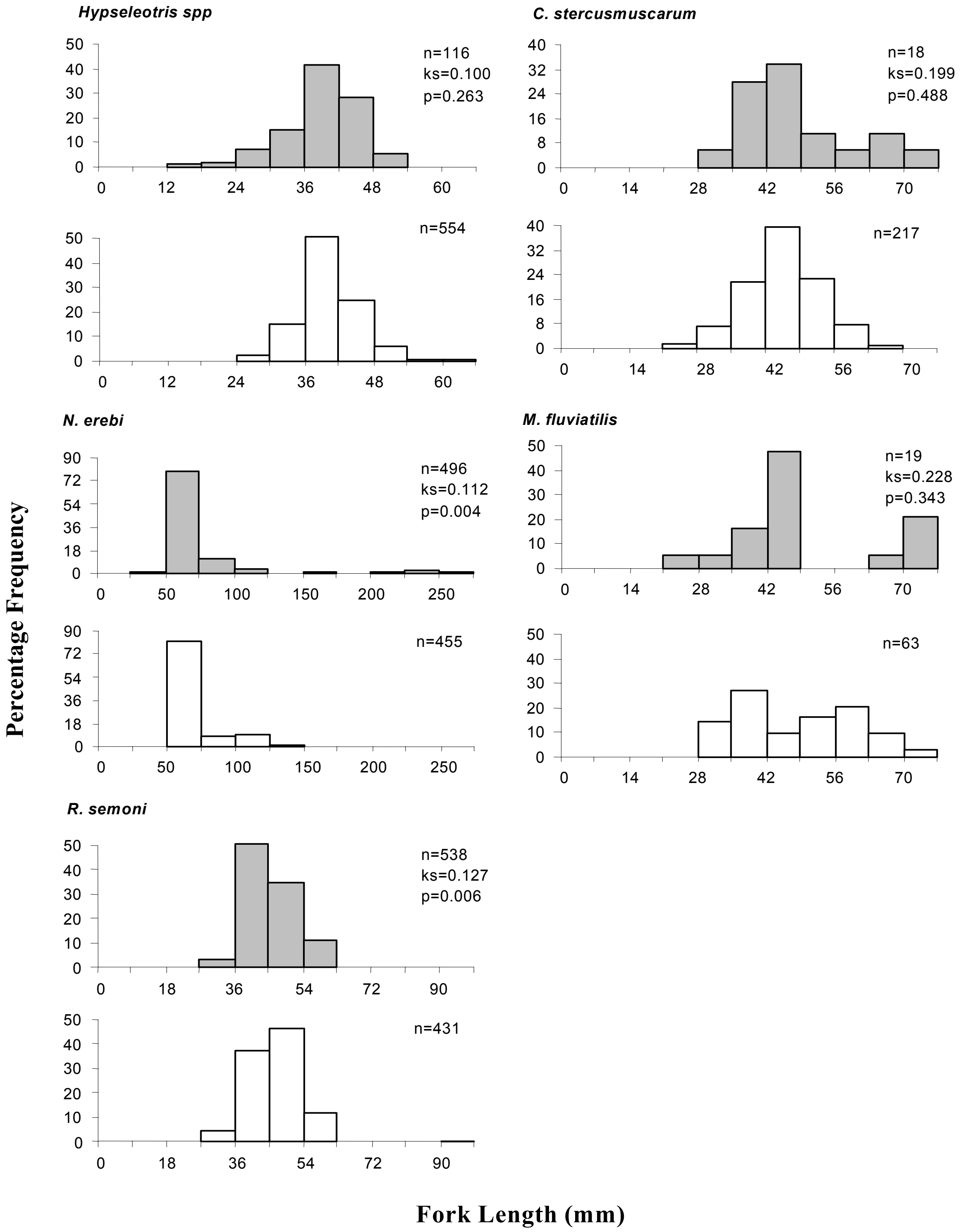

Figure 7. Length frequency distributions and Kolmogorov-Smirnov statistics for the most frequently sampled species from the entrance and exit of the Deelder fishlock at Balranald Weir. n represents the total number of fish used in the analysis, ks is the Kolmogorov-Smirnov critical value and p is the significance level of the test. Exit samples are shaded and shown above the unshaded entrance samples.

Table 3. Summary of Two-Way analysis of variance results for randomised blocks testing differences among cycle times and between entrance and exit trapping. Df is the degrees of freedom for the test. F represents the calculated *F*-ratio of the test and probabilities are listed as ns, not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Species	**Cycle time (*df* = 2) F**	**Block (*df* = 17) F**	**Entrance/Exit (*df* = 1) F**	**Block (*df* = 17) F**
B. bidyanus	0.21 ns	1.46 ns	6.30 **	1.45 ns
C. stercusmuscarum	1.03 ns	2.05 ns	16.35 ***	1.19 ns
Hypseleotris spp	0.01 ns	1.07 ns	30.95 ***	1.65 ns
M. fluviatilis	0.26 ns	1.77 ns	4.34 ns	1.78 ns
N. erebi	0.01 ns	1.05 ns	0.35 ns	1.02 ns
R. semoni	0.03 ns	1.87 ns	16.92 ***	0.84 ns

Table 4. Summary of length statistics for all species sampled from the entrance and exit of the Deelder fishlock at Balranald Weir. **n** represents the total number of fish measured, **mean** is the average fork length (mm), **SD** represents one standard deviation of the mean, **min** is the smallest individual measured (mm) and **max** is the longest individual measured (mm).

	Entrance					**Exit**				
Species Name	**n**	**mean**	**SD**	**min**	**max**	**n**	**mean**	**SD**	**min**	**max**
B. bidyanus	4	140.25	13.52	128	156	33	138.67	40.33	68	271
C. stercusmuscarum	217	38.95	7.46	21	60	18	41.72	11.39	27	65
C. carpio	5	492.80	42.56	442	540	4	480.00	27.33	444	508
Hypseleotris spp	554	34.62	5.32	17	56	116	33.31	6.22	12	44
M. ambigua	0	-	-	-	-	3	150.67	209.00	29	392
M. fluviatilis	63	42.22	12.15	22	70	19	43.95	14.83	21	69
N. erebi	455	46.95	21.97	24	237	496	53.17	37.97	22	248
P. grandiceps	17	38.29	7.02	29	58	1	42.00	-	42	42
R. semoni	431	38.01	6.99	21	88	538	37.14	6.01	21	54

3.4. Exit phase efficiency

On one occasion during the exit efficiency trial, eight *N. erebi* remained in the exit chamber during a 60-minute cycle but no fish remained in any other replicate. This suggests that the 20-minute exit phase may not have been sufficient to permit the passage of these fish on at least one occasion. Further, that more fish were present within that exit trap rather than within the fishlock chamber suggests that trap avoidance was low.

In contrast to finfish, large numbers of freshwater prawns (*Macrobrachium australiense*) were observed on each occasion. Unfortunately, these were not counted because they were not considered a migratory species at the commencement of the study. *Macrobrachium australiense* were also present in high numbers from standard entrance and exit trapping, but they were not included in any analysis. Further, in the days following a minor river rise, an estimated 3,000 *M. australiense* were observed to actively climb the fishlock walls and the weir crest in what appeared to be an attempted mass upstream migration.

3.5. Daily migration periods

Kruskal-Wallis tests identified significant differences between daily passage periods for *C. carpio* ($X^2 = 13.78$, $p = 0.008$), *Hypseleotris* spp ($X^2 = 9.87$, $p = 0.042$), *M. fluviatilis* ($X^2 = 10.01$, $p = 0.040$), *N. erebi* ($X^2 = 16.24$, $p = 0.002$) and *R. semoni* ($X^2 = 19.32$, $p < 0.001$), indicating that levels of movement varied between daily time periods. No significant differences were observed for *B. bidyanus* ($X^2 = 6.78$, $p = 0.147$) or *C. stercusmuscarum* ($X^2 = 8.35$, $p = 0.079$), although some patterns were evident for these two species (Figure 8).

Levels of passage were highest from afternoon samples for *C. stercusmuscarum, M. fluviatilis, N. erebi* and *R. semoni* and from dusk samples for *B. bidyanus* and *Hypseleotris* spp (Figure 8). For all species, passage was lowest during the dawn and night periods, except for *C. carpio* which were most active at night.

Numbers of *R. semoni* gradually increased throughout the day and peaked in the afternoon before falling again. This species was virtually never caught in night samples. *B. bidyanus, M. fluviatilis* and *C. stercusmuscarum* showed no movement during dawn samples (Figure 8). No migration occurred for *M. fluviatilis* until after 12:00 hours and for *C. carpio* until after 16:00 hours.

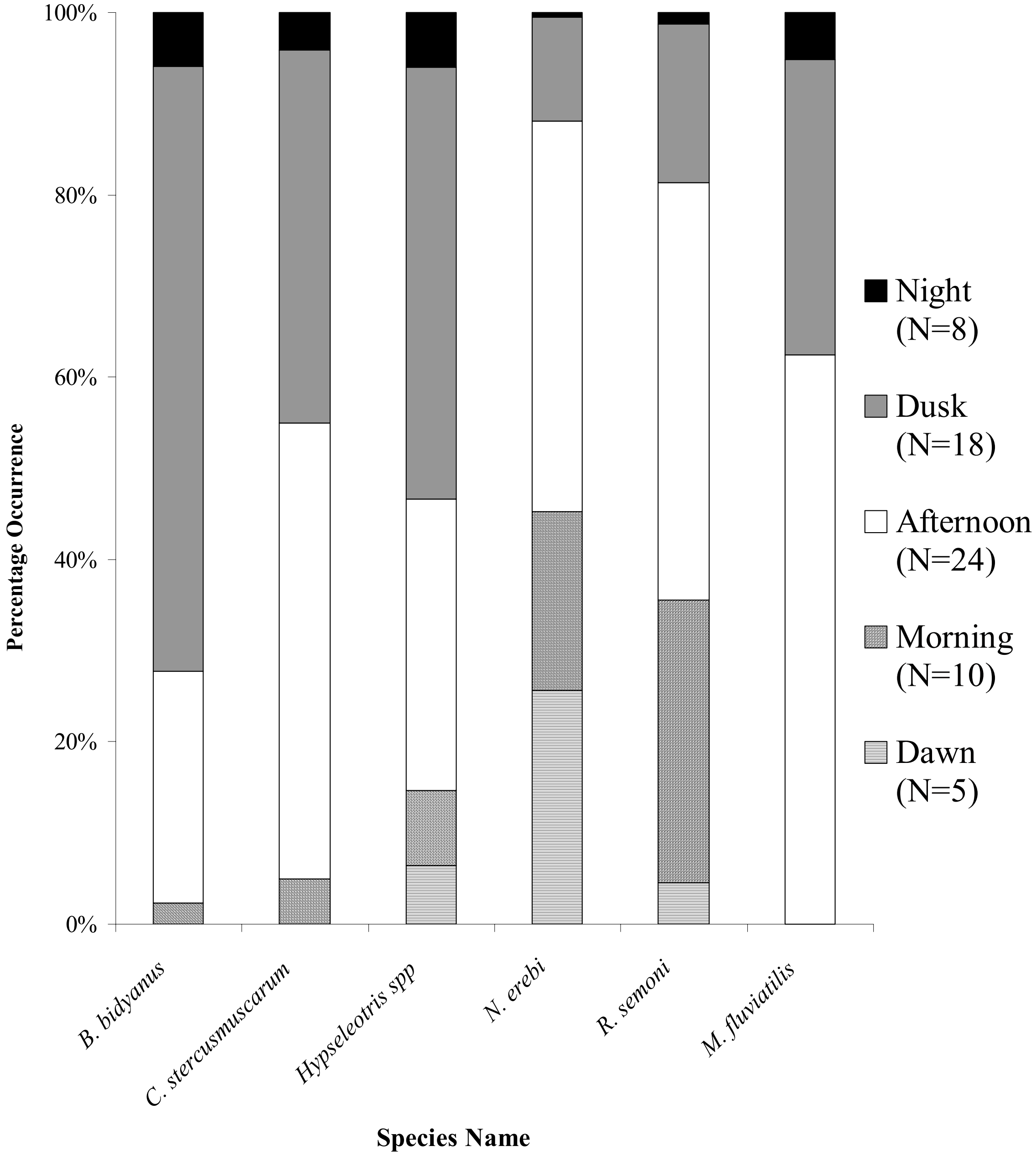

Figure 8. Percentage occurrence of common fish species sampled over different trapping periods of the Deelder fishlock. N represents the number of replicates completed per time period.

3.6. Trap efficiency

To determine relative efficiencies of different fishtrap mesh size, a one-way ANOSIM compared fish community composition before and after the reduction in mesh size. ANOSIM detected significant differences (R = 0.278, p = 0.004) indicating that mesh size did influence the types of species caught. SIMPER analysis revealed that three species consistently contributed to observed differences: *R. semoni*, *N. erebi* and *Hypseleotris* spp (Figure 9, Table 5). All species except for *M. ambigua* were sampled in greater numbers after the mesh size was reduced. In the case of *R. semoni*, the mean catch rate was doubled and the catch rate of *N. erebi* was almost 8 times that of the pre-mesh reduction rate (Figure 9). For *M. fluviatilis* and *C. stercusmuscarum*, no individuals were captured before the reduction in mesh size, indicating that escape may have been high for these species when using larger mesh.

Kolmogorov-Smirnov tests indicated significant differences in the sizes of *B. bidyanus* (*ks* = 0.722, p = 0.005), *Hypseleotris* spp (*ks* = 0.520, p = 0.009), *N. erebi* (*ks* = 0.382, p < 0.001) and *R. semoni* (ks=0.472, p<0.001) caught from traps with different mesh size. These significant differences arose because more fish from larger size classes were sampled after the mesh size was reduced.

Table 5. SIMPER results showing species that significantly contributed to differences in fish communities before and after mesh size was reduced from 10mm to 1mm. Analysis is based on fourth root transformed data. Mean dissimilarity is the measure of similarity between the two groups, ranging from 0% (identical) to 100% (totally dissimilar). CR is the degree to which species are contributing to observed differences, with higher values indicating a greater contribution.

Species	**Mean abundance**		**CR**	**% contribution**
Before vs After mean dissimilarity = 62.44				
	Before	After		
Retropinna semoni	30.50	61.30	1.27	32.56
Nematalosa erebi	7.33	50.56	1.30	26.27
Hypseleotris spp	3.08	4.96	1.05	15.59
Bidyanus bidyanus	0.25	0.96	0.63	9.06
Craterocephalus stercusmuscarum	0.00	1.56	0.57	4.50
Melanotaenia fluviatilis	0.00	0.52	0.61	4.49
Macquaria ambigua	0.17	0.01	0.38	3.83
Cyprinus carpio	0.08	0.07	0.30	3.70

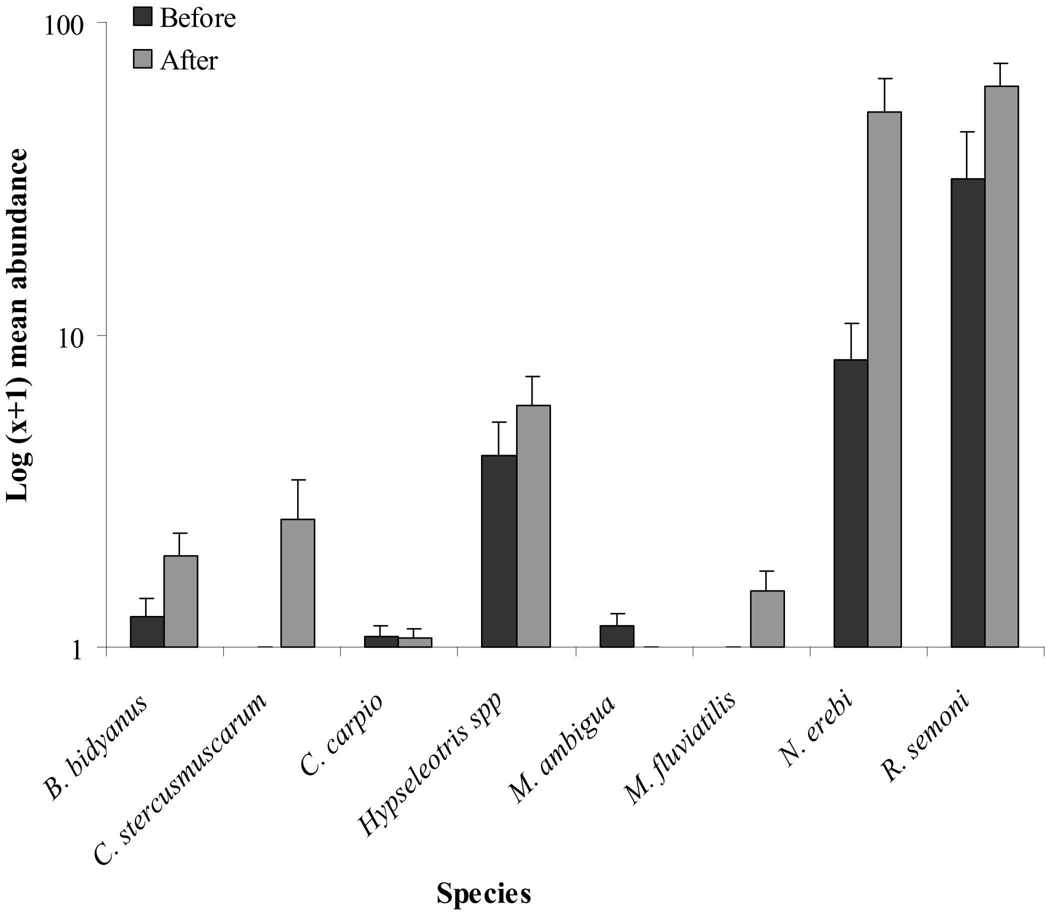

Figure 9. Comparison of exit trap catches, expressed as log (x+1) mean abundance(± one SE), before and after reducing the mesh size from 10mm to 1mm.

4. DISCUSSION

4.1. Fishlock performance

This study demonstrated that a Deelder fishlock was very successful at providing passage for Australian inland native fish for a variety of species and size classes. The average fish passage rate of 22.50 ± 3.64 fish per hour is an order of magnitude greater than that reported for other fishlocks in Australia. Maximum passage rates of native fish peaked at 2.20 fish per hour from a fishlock at Yarrawonga Weir on the Murray River (Thorncraft and Harris, 1997) and over 2.00 fish per hour were reported from the coastal Eden Bann fishlock on the Fitzroy River, Queensland (Stuart and Berghuis, 1997).

The Deelder fishlock provided passage for a total of nine species of fish which could be considered relatively low given that 13 species were sampled from a recent survey downstream of Balranald Weir (Baumgartner, in prep). However, the fact that *R. semoni*, *N. erebi, M. fluviatilis* and *B. bidyanus* were all sampled in equal or greater numbers from the fishlock exit indicates that passage was highly successful for these species. Few *M. ambigua* or *C. carpio* were caught, possibly because these species were not migrating at the time of sampling. *Macquaria ambigua* has been observed migrating upstream in large numbers under high flow conditions and may not migrate under the low flows experienced during this study (Reynolds, 1983; Mallen-Cooper, 1996). Further sampling of the Deelder fishlock during periods of high flow would possibly allow a better assessment of the effectiveness of this design in providing passage for this species.

One species not caught was *Maccullochella peelii,* which was previously sampled migrating through fishways at Torrumbarry Weir and Euston Weir on the Murray River (Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996). *Maccullochella peelii* are thought to migrate upstream early in the migratory season during periods of increased flow (Koehn *et al*, 1998). Drought conditions during the present study may not have provided the necessary cues for upstream movement of this species. Introduced *G. holbrooki* and *C. auratus* are generally considered non-migratory (McDowall, 1996; Harris and Gehrke, 1997; Allen, 2002) and their absence from fishlock trapping is not surprising.

Despite the success of this study, inefficient provision of passage by fishlocks is frequently reported in the literature. In Latin America, Australia and the USSR, the single most noticeable problem is poor attraction conditions (Quiros, 1989; Pavlov, 1989; Stuart and Berghuis, 1997; Thorncraft and Harris, 1997). Pavlov (1989) further noted that few fishlocks have the ability to operate over high tailwater ranges. The Deelder fishlock overcame these problems by having two entrances that are optimally placed and designed to operate over the full range of tailwater levels up until the weir is inundated.

Lock fishways may have a reduced capacity to cope with large influxes of fish compared to other fishway designs (Clay, 1995). Fishways in Northern Hemisphere systems are usually designed for migrating salmonid fish (Trefethen, 1968; Collins, 1976; Clay, 1995; Mallen-Cooper, 1996; Ferguson *et al*, 1998; Thorncraft and Harris, 2000) and it is not uncommon for 200,000 - 700,000 fish to approach any weir over a small space of time (Pavlov, 1989). The capacity of any fishway design could be questioned under such conditions. However, Quiros (1989) further observed that schools of over 100 - 200 individuals passed through fishlocks in only 5% of cycles, despite high numbers of fish attempting to gain passage.

The capacity for Australian fishways need not be as large as required in the Northern Hemisphere because expected numbers of migrating fish are much lower. The maximum number of individuals to pass an Australian inland fishway in a 24-hour period was reported as 3,000 (Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996). The maximum that moved through the Deelder fishlock was 854. Although this is below the largest reported maximum, it is still a good indication that a Deelder fishlock can effectively pass large numbers of fish (in Australian terms) over a 24-hour period.

4.2. Diel migration and passage times

Passage through the fishlock varied significantly over different diel scales, with passage generally highest during the afternoon and lowest at night. *Cyprinus carpio*, *N. erebi*, *R. semoni* and *B. bidyanus* were previously reported to seek passage predominantly during daylight hours, with passage rates peaking during morning samples (Mallen-Cooper, 1996). These published observations are in contrast to the results of the present study, where most species sought passage after 1200 hours. Further, Mallen-Cooper (1996) observed that any *N. erebi* that did not fully ascend a vertical slot fishway during daylight hours would return downstream to the river before dark. It is not known whether this behaviour is displayed by other species, but it highlights an important advantage of lock fishways over other fishway designs that have longer mean fish passage times.

In Australia, pool-type fishways are generally constructed on conservative slopes to provide passage for fish with weaker swimming abilities (Harris 1983; Mallen-Cooper, 1996; Thorncraft and Harris, 2000), resulting in fishways that can be quite long. After a 28-hour period, 20% of blue catfish had not successfully ascended a 40.85 m coastal vertical slot fishway (Stuart and Berghuis, 1999). A minimum of 2.5 to 3 hours was required for fish to negotiate a 131m vertical slot fishway successfully at Torrumbarry Weir on the Murray River (Mallen-Cooper, 1996). If peak movement rates are during the afternoon, as results of this study suggest, species that only migrate during daylight hours would not be able to fully ascend a vertical slot fishway before dark.

This study demonstrated that large numbers of fish could successfully negotiate a Deelder fishlock in a 60 minute cycle time. This is probably a function of both the reduced fishway length and reduced velocities within the fishlock. If fish passage is consistently higher during the afternoon, frequent short (60 minute) cycles could be performed to maximise passage rates of species that will not migrate after dark. Such operational manipulations are not possible with other fishway designs because they operate at the same rate over a 24-hour period.

4.3. Entrance and Exit trapping

Trapping the entrance and exit of the fishway provides a better indication of fishway success than only trapping the exit, because it allows a comparison of fish than can successfully ascend the fishway to those attempting to ascend but failing to do so (Mallen-Cooper, 1996; Stuart and Mallen-Cooper, 1999; Stuart and Berghuis, 2002). In the present study, the Deelder fishlock effectively provided passage for *R. semoni*, *B. bidyanus, N. erebi* and *M. fluviatilis*. Either equal or significantly larger absolute abundances and size classes of individuals from these four species were trapped at the exit.

Interestingly, although no differences in size class were evident, significantly larger numbers of *C. stercusmuscarum* and *Hypseleotris* spp were sampled at the entrance of the fishway, suggesting inefficient provision of passage for these species. Both species are typically benthic (McDowall, 1996; Allen 2002) and low numbers caught at the entrance are possibly a function of the fishlock's internal weir. The original Deelder fishlock in Belgium was constructed so that the internal weir had a sloping face (Deelder, 1958). However, the internal weir at Balranald is vertical and benthic species may have difficulty surmounting this structure even though it was still submerged. Further sampling with a sloping weir face is required to determine if passage for benthic species can be improved.

The Deelder fishlock was very successful at passing small and juvenile fish. Such high catches have previously not been reported from other fishway studies, which could be a function of fishtrap mesh size. The original mesh size of 10 mm was comparable to that used for previous fishway assessments (Mallen-Cooper, 1996; Thorncraft and Harris, 1997; Stuart and Mallen-Cooper, 1999; Stuart and Berghuis, 2002). When using a larger (20 mm) mesh, the smallest fish sampled from a fishway at Euston Weir was 60-80 mm (Mallen-Cooper and Brand, 1992) and no fish smaller than 40-50 mm were sampled using 15 mm mesh (Mallen Cooper, 1996).

After reducing the mesh size in this study, the minimum length of an individual fish sampled was 12 mm, suggesting that the smaller mesh may have been significantly increased the numbers of smaller fish caught. The observed differences may have been attributed to a change in fish populations over time. However, most studies reporting changes in fish migration rates attributed such changes to rises in temperature or flow (Mallen-Cooper and Brand, 1992; Mallen-Cooper, 1996) and during the present study these factors varied little. A lack of variation in these factors, combined with the relatively short study period, suggest that major changes in the composition of the migrating fish community should not have occurred.

It is also important to note that previous studies did not record *M. fluviatilis*, *C. stercusmuscarum*, *Hypseleotris* spp as attempting to gain passage. This is despite the fact that these species could have been expected based on known distribution limits (McDowall, 1996; Allen, 2002). Another possible reason that small fish have not previously been sampled is that other fishways are inefficient at passing fish of this size. The maximum velocity of 0.85 m s^{-1} within the Deelder fishlock is much lower than the reported 1.81 m s^{-1} within vertical slot fishways (Mallen-Cooper, 1996). It is quite possible that such a reduction in velocity has allowed small fish to use the Deelder fishlock.

There is a general lack of information on specific aspects of the life history of small species and further research is required to determine the extent and purpose of upstream passage requirements. The results of this study are an indication that small native species must be considered when designing fish passage facilities.

4.4. Enhancing entrance conditions

The entrance of a fishway is the single most critical design element governing its success at passing fish (Clay, 1995). It should be located at the upstream limit of migration for fish to enter efficiently (Pavlov, 1989; Clay, 1995; Mallen-Cooper, 1996). If migrating fish are unable to locate the entrance, or are delayed in doing so, then fish passage will be compromised. To cope with different conditions under a range of flows, the Deelder fishlock is equipped with two entrances, one for operation during low tailwater periods and the other for high tailwater conditions. Although only the low tailwater entrance was used during this study, high catches of fish strongly indicate that entrance conditions were suitable for the range of flows experienced over the study period.

Flows at Balranald Weir generally fluctuate from approximately 200 MLday^{-1} to 4,500 MLday^{-1} (Ebsary, 1992) and, as such, downstream hydraulic conditions are very different between these two extremes. To maximise entrance efficiency, attraction flow from a fishway must be at least 5% of the median total discharge over the weir crest (Larinier, 1990). The maximum discharge from the Deelder fishlock is approximately 55 MLday^{-1} and was therefore an adequate 28.03% of the median daily flow during the study (196.16 ± 12.84 MLday^{-1}). Movements of Australian inland fish have been shown to increase under higher flow conditions (Reynolds, 1983; Battaglene, 1991;

Mallen-Cooper, 1996; Mallen-Cooper and Stuart, 2003) and the efficiency of any fishlock at attracting fish will decrease as competing flow increases.

Under maximum flow conditions of 4,500 MLday^{-1} the attraction flow is only 1.22% of the weir's competing flow and is exactly 5% when discharge over Balranald Weir is 1,100 MLday^{-1} (Appendix 1; Figure 10). When flow exceeds this critical point it will be necessary to alter weir operations to enhance entrance attraction, because fish are generally attracted to areas of greatest discharge (Pavlov, 1989; Clay, 1995; Mallen-Cooper, 1996; Marsden and McGill, 2001). This was directly observed at the Dumbleton Weir fishlock, where the number of fish accumulating at the high flow section of the weir crest was more than double the fish concentration at the fishlock entrance (Marsden and McGill, 2001).

Therefore, under high flows at Balranald Weir, it will be necessary to enhance entrance attraction by increasing discharge over the weir near the fishway entrance (Thorncraft and Harris, 2000), dubbed 'auxiliary flow' by Clay (1995). This could possibly be achieved via the removal of dropboards adjacent to the fishway entrance. Although this will not increase the flow through the fishway entrance, it will increase discharge in its vicinity. This will attract migrating fish and increase the chances of fish successfully gaining passage during high flow conditions.

4.5. Optimising cycle time

An optimal cycle time should allow fish enough time to locate and enter the fishway while permitting an optimal number of cycles to be completed per day. The optimal number of cycles primarily depends on ensuring fish passage is maximised. However, it should also consider maintenance requirements because lock fishways have moving parts that are prone to wear under frequent use. The results of this study suggested that 120-minute cycle times are most appropriate for a Deelder fishlock because it permitted the passage of a wide range of size classes and species of native fish. In addition, using only 120-minute cycles would allow 10 hours per day to actively passing fish (Appendix 1; Table 6). For 60 and 240-minute cycles, this is reduced to eight and five hours respectively and such situations could seriously compromise passage under peak periods of upstream fish migration. Although 60-minute cycles passed higher numbers of fish during this study, this was not statistically significant. If used as a permanent operating protocol, the large number of cycles per day would increase wear on mechanical components and subsequently increase maintenance requirements.

That cycle time did not significantly influence the total abundance of fish gaining passage is consistent with the findings of other Australian fishlock studies at Eden Bann (Stuart and Berghuis, 1997) and Yarrawonga Weirs (Thorncraft and Harris, 1997). In South America, Borland style fishlocks are generally operated over 60 minute cycles (Quiros, 1989) but only 30 minutes are required in Ireland (Clay, 1995). A fishlock situated at the Ardnacrusha Dam (Shannon River, Ireland) is one of the few reported cases where fishlock operation is temporally altered to suit fish migrating at different times of the year (Clay, 1995). The fishlock usually operates over a four hour cycle but, at times of the year when eel migration is heavy, the cycle time is deliberately shortened to two hours to increase the passage of these fish.

These examples highlight a critical issue with respect to fishlock operation, namely how much time to devote to attracting fish at the downstream end and then releasing them upstream. Longer attraction times can potentially attract more fish, but if the capacity of the entrance chamber to hold fish is limited, there is little point extending the attraction period once this limit is reached. Ideally, the exit phase should be long enough to allow all migrating fish to leave the chamber. To maximise fish passage, both attraction and exit phases need to be optimised at each specific installation.

Methods of enhancing attraction efficiency are implemented at Orrin Dam in Scotland where four fishlocks were constructed (Clay, 1995) and at Salto Grande Dam in Uruguay where two were constructed (Quiros, 1989). By constructing multiple fishlocks there is the added advantage of maximising fish passage by having each fishlock at a different cyclic phase. This could increase both capacity and cycle time (in a relative sense) but has the major disadvantage of greatly increasing the capital cost. Multiple fishlocks are not feasible as Balranald Weir and attraction times will need to be optimised based on flow. Under low flow conditions, shorter attraction times will be required because a high proportion of total discharge is through the fishway. Under high flow events, a longer attraction phase will allow fish more time to successfully locate the entrance when competing flow is greater.

The exit phase of the fishlock cycle is probably less critical than the attraction phase for three reasons. First, fish must enter the fishlock before they can exit. Second, if fish are using flow direction as a cue for migration they will be led directly to the exit gate. Third, if fish enter the fishway and do not exit in the specified time frame, another chance to pass the weir will be present in the following cycle, provided the individual remains within the structure. Clay (1995) suggests that repeated filling of the fishway may inhibit some fish from migrating but there have been no reported cases of this occurring.

It is highly likely that longer exit times would benefit some fish more than others, particularly small species with poor swimming abilities. Small fish species were observed to easily negotiate the $0.5ms^{-1}$ exit velocity at Balranald Weir. However, a school of eight *N. erebi* was observed within the lock chamber after one 60-minute cycle. This could occur either because the fish did not have sufficient time to leave the chamber or that the chamber offered suitable habitat for the fish to remain where they were. It is highly unlikely, however, that habitat preference is the likely explanation because, over the study period, many more fish (including *N. erebi*) were observed to exit the fishway than remain within it. It is therefore recommended that, under conditions where small fish species are expected to migrate, an exit period longer than 20 minutes be considered to maximise the passage of these fish.

5. SUMMARY AND RECOMMENDATIONS

- Deelder fishlocks provide passage for a wide range of size classes and species of Australian native fish. The Deelder fishlock at Balranald currently only has provision for manual operation. It is important that the fishlock be fully automated as soon as possible to enable fish passage times when the fishlock is unmanned.
- Most fish sampled passing through the Deelder fishlock were either small or young-of the-year native fish suggesting that upstream passage is important for these species and size classes. It is recommended that further research be conducted into their migratory requirements and that fishways are designed to provide passage for small fish.
- Flows were constant for the duration of this study and therefore the results of this study are only indicative of fish passage under low flow situations. It is recommended that the study be replicated during high flows to ensure that attraction conditions are still adequate.
- More fish were observed to remain in the exit chamber following the 60-minute cycle than under 120 or 240 minute cycles. Therefore it is recommended that future Deelder fishlocks operate on a 120-mintue cycle to maximise passage rates.
- Fish passage appeared to be inhibited for *Hypseleotris spp* and *Craterocephalus stercusmuscarum* because these were present in greater numbers from entrance samples than exit samples. This is possibly because of the presence of a vertical internal weir. It is recommended that experimentation with a sloping weir should be done to observe whether these species gain improved passage.
- Significantly higher numbers of small fish were sampled after reducing the mesh size of the trap from 10mm to 1mm. Therefore, it is recommended that future fishway studies consider using a reduced mesh size to ensure that small fish are also sampled during assessments of fishway efficiency.

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APPENDIX 1 – FLOW AND CYCLE TIME DATA

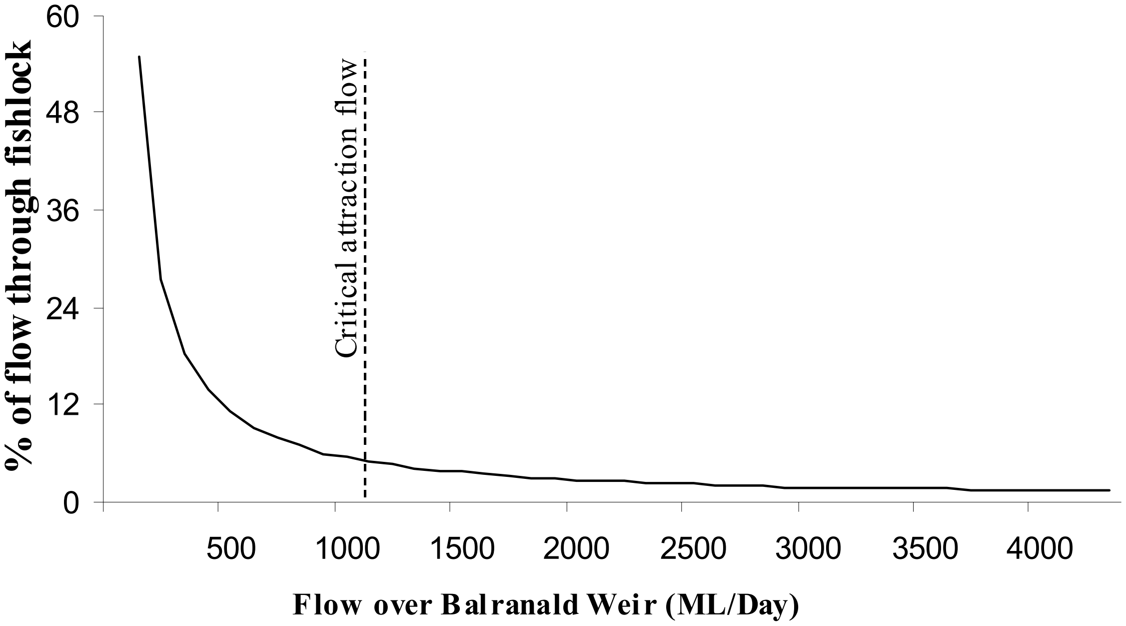

Figure 10. Relationship between Deelder fishlock attraction flow and daily flow over Balranald weir. Dotted line represents the critical attraction flow where attraction flow from the fishway equals 5% of total daily flow over Balranald Weir.

Table 6. Time allocations to each phase of different Deelder fishlock cycle times. Transitional phase refers to time manipulating gates and altering water levels within the lock chamber. The attraction phase is where fish are being attracted into the lock chamber. The exit phase denotes the period where fish exit the lock chamber into the adjoining weirpool.

	Cycle time		
	60 min	**120 min**	**240 min**
Transition phase			
Minutes Per cycle	20	20	20
Hours Per day	8	4	2
Attraction phase			
Minutes per cycle	20	50	170
Hours Per day	8	10	17
Exit phase			
Minutes Per cycle	20	50	50
Hours Per day	8	10	5
Max cycles per day	**24**	**12**	**6**

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