The Goodga River Fishway

the first vertical-slot fishway in Western Australia: monitoring and evaluation

Report to

Department of Fisheries
Government of Western Australia

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Freshwater Fish Research

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Summary

The Goodga River Fishway was opened in April 2003 with the aim of increasing the habitat available to the trout minnow (*Galaxias truttaceus*), a highly restricted freshwater fish species in W.A. *Galaxias truttaceus* is now known only from the Goodga and Angove rivers in Western Australia and although it occurs in south-eastern Australia, there are considerable morphological and biological differences between eastern and western populations. Genetic examination may yet result in the W.A. population being granted species status.

Fish usage of the fishway was monitored in each season between April 2003 and February 2005. Prior to the opening of the fishway no fish was found above the Goodga River Gauging Station (weir) that is approximately 2 km upstream of the river's entrance to Moates Lake. During monitoring of upstream sites prior to and after the opening of the fishway, the abundances of both *G. truttaceus* and the spotted minnow (*Galaxias maculatus*) increased substantially on each sampling occasion over the first year before reaching an equilibrium (possibly a carrying capacity that was also influenced by mass migrations of both species in November 2004).

Galaxias truttaceus was found to utilise the fishway in all sampling periods including both immediately prior to it's known spawning period (i.e. April/May) and during spring (i.e. November). Adult fish migrated up the fishway prior to spawning while large numbers of new recruits (small juveniles) migrated up the fishway during sampling in November 2003 and 2004. Surprisingly, little usage of the fishway occurred during the winter months when river discharge was highest. This, and the fact that fishway utilisation by *G. maculatus* was consistent during all samples with new recruits migrating in February 2004 and 2005 and November 2004, demonstrates the importance of constructing fishways that function during periods of low flow, such as is the case for the Goodga River Fishway.

More *G. truttaceus* and *G. maculatus* were captured on the fishway during day-light hours compared to the night, however large *G. truttaceus* were more commonly captured at night whereas the mean size of *G. maculatus* on the fishway during the day was larger than during the night. All size classes of both species that are found in that part of the river were able to successfully negotiate the fishway.

The western pygmy perch (*Edelia vittata*) was only captured on the fishway during the day in November 2003 and 2004, a period that coincides with its spawning period. It is thus suggested that *E. vittata* moves upstream during day-light hours during this spawning period to offset the downstream movement of larvae. They were, however, not captured upstream of the fishway suggesting that had are yet to establish a population in this part of the river.

Although abundant in the downstream section of the Goodga River, including Moates Lake, the Swan River goby (*Pseudogobius olorum*) was not captured on or above the fishway. This is possibly a result of the species being benthic and that the fishway entrance is elevated above the substrate. The fishway entrance should be modified to enhance the upstream migration of *P. olorum*.

During May, August and November 2004 a trap was set immediately below the Goodga River Gauging Station to determine whether fish fall over the weir wall. In all months fish were found to fall over the wall, but numbers were highest during November and larger adults of both galaxiids were generally caught during the night, compared to juveniles which were more often caught in the trap during the day. A substantial proportion of these were deceased but it is not known whether being buffeted in the trap or the fall onto the concrete footing of the weir lead to their death. A simple plastic pool slide-like structure could be fitted to weir to minimise the impact of such a fall. This may be extremely important in terms of larval migrations (and survival), as the larvae of *G. truttaceus* are known to be swept downstream into Moates Lake (Morgan 2003).

Part of the upper Goodga River flows through agricultural land, and the catchment in this area has numerous small stock dams. There is thus the potential for exotic freshwater fish and crayfish to enter the Goodga River from these dams. It is recommended that land owners in the catchment are made aware of the rarity of *G. truttaceus* in the Goodga River and be advised not to stock their dams with exotic fish and crayfish. These dams could be stocked with *G. truttaceus* to gauge the efficacy of breeding the species in a 'closed' environment.

Similar to fish migrations in the Goodga River there was a large number of juvenile new recruits of *G. truttaceus* below the gauging station in the Angove River in November 2004. However, the modal length class of these fish was 60-65 mm TL, which was 10 mm longer than those captured on the Goodga River Fishway (50-55 mm TL) during the same period (see Figures 4 and 14). Furthermore, no fish smaller than 58 mm TL was recorded in the Angove River. This suggests that either growth is faster in the Angove River or that the spawning period is earlier in the Angove River. The latter argument would help to explain the absence of adult *G. truttaceus* below the Angove River Gauging Station during the May sample. For *G. maculatus* there was also a pronounced increase in the number captured below the Angove River Gauging Station during the November sample (Figure 14). The lengths of these fish ranged from 57-113 mm TL and are far larger that those found during the same period in the Goodga River (modal length 45-50 mm TL) (Figures 5 and 14). The distinct differences in population demographics of both *G. truttaceus* and *G. maculatus* in the Angove River compared to the Goodga River have important implications not only for future fishway designs in the Angove River but also in the conservation of the river's fishes, particularly in respect to *G. truttaceus*, which in Western Australia is restricted to these two systems. Similar to the Goodga River, *E. vittata* in the Angove River (below the gauging station) were most abundant during spring (i.e. November) when they undertake an upstream spawning migration. The Angove River is the most eastern extent of the western pygmy perch. The Angove River is also important in that it contains another rare fish species, i.e. Balston's pygmy perch (*Nannatherina balstoni*), which prior to this study was only known from streams and lakes west of the Goodga River. Thus, their capture in the Angove River represents a notable range extension for the species.

The population of *G. truttaceus* in the Angove River is apparently restricted to the approximate 2 km of river below the weirs and Angove Lake, a scenario similar to that which existed in the Goodga River prior to the construction of a fishway. This, together with the importance of the

Angove River to the conservation of the south-west's endemic pygmy perches, demonstrates the need to assess the suitability of the construction of fishways for the Angove River. Biological information regarding species migrations and spawning periods should be assessed to assist in ensuring that the fishway functions during important life history stages of the target species.

Acknowledgements

The construction and monitoring of the Goodga River Fishway would not have been possible without either the funding provided by the Natural Heritage Trust or the Fish and Fish Habitat section at the Department of Fisheries Western Australia and the Department of Environment (Albany). In particular we would like to thank both Jodie Oates and Steve Janicke for their excellent contributions in all phases of the construction of the fishway. Thanks also to Simon Visser, Michael Hammer and Jodie Oates for their help with sampling the fishway. Thanks to the Water Corporation of Western Australia for providing access to the Angove River. Special thanks to Sam and Larry James from the King River Tavern for providing accommodation and organising access through private property to the various rivers.

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Background

The trout minnow (*Galaxias truttaceus*) is endemic to streams and lakes of southern Australia including: Tasmania, Victoria and southern Western Australia (Allen *et al*. 2002, Morgan 2003). There are considerable morphological and biological differences between the Western Australian populations and those in south-eastern Australia (McDowall and Frankenberg 1981, Humphries 1989, Morgan 2003). Within Western Australia, *G. truttaceus* is reported to be restricted to the small catchments of the Goodga, Angove and Kalgan Rivers (see Morgan *et al*. 1998, Allen *et al*. 2002, Morgan 2003, Morgan and Beatty 2004), making the species probably the most restricted freshwater fish in Western Australia. While recent surveys failed to capture this species in the Kalgan River (Morgan *et al*. 1998, Morgan 2003, Morgan and Beatty 2004), within the Goodga River the species was restricted to a 2 km stretch of stream below a small gauging station (weir) prior to the opening of the fishway (see Figure 1). The recent ecological study on *G. truttaceus* by Morgan (2003) (see Appendix) identified the weir as a threat to the population, particularly during upstream spawning migrations and a proposal to construct a fishway on the Goodga River was subsequently submitted to the Natural Heritage Trust. A vertical-slot fishway, the first of its kind in Western Australia, was constructed by the Department of Fisheries Western Australia and the Water and Rivers Commission of Western Australia and was largely funded by the Natural Heritage Trust. The fishway was opened in April 2003 and this report describes fish utilisation in each season during the two years that the fishway has been operating. It also examines barriers to fish migration on the Angove River, which is immediately east of the Goodga River (see Figure 1).

Spawning period and fishway function

Adult *G. truttaceus* move upstream prior to spawning in autumn, with very few fish found in the lower sections of the river at that time, and aggregate below the impassable Goodga River weir in autumn (Morgan 2003). Here they are particularly vulnerable to predation from birds, especially if infected with the introduced cestode (tapeworm) *Ligula intestinalis* which reduces the fishes mobility and makes them more visible to predators (Morgan 2003). This upstream spawning migration probably occurs to offset any downstream movement of larvae, however, as the river is relatively short, all larvae are initially transported into Moates Lake where they spend a few months before re-entering the river. Since the upstream migration and spawning period occurs in autumn, a period when flows are historically low, the fishway was designed to function during this period (see Figure 3).

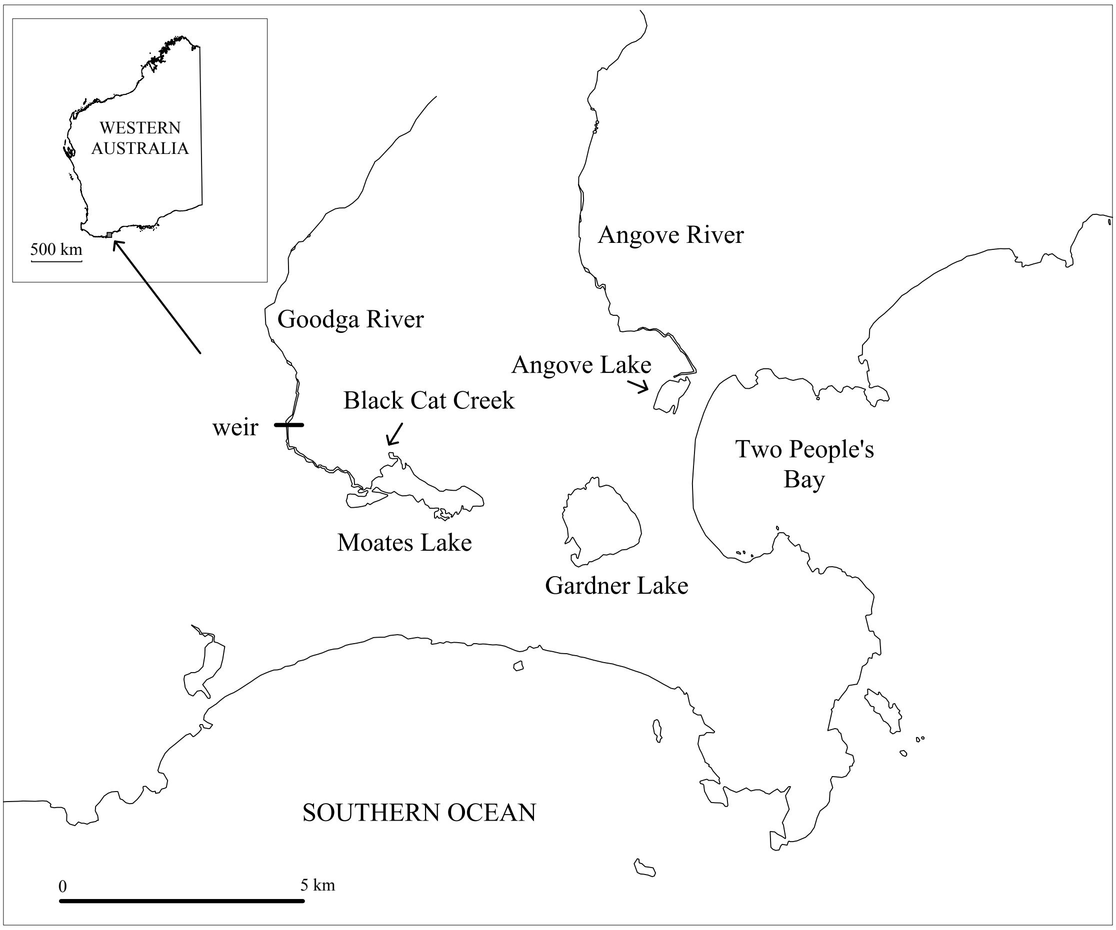

Figure 1 The Goodga River, weir (gauging station), Moates Lake and surrounding environs of Two People's Bay. The adult population of *Galaxias truttaceus* in the Goodga River was previously restricted to below the weir and Black Cat Creek.

Aims of the study

The primary aim of this study was to:

- Assess the effectiveness of the Goodga River fishway in providing fish passage to the trout minnow and sympatric species, such as the spotted minnow (*Galaxias maculatus*), western pygmy perch (*Edelia vittata*) and the Swan River goby (*Pseudogobius olorum*). As no fishes have previously been recorded upstream of the weir (or fishway), the abundance of fishes above the fishway was assessed on each sampling occasion.

Secondary aims included:

- Determine the peak seasonal movements of the different species.
- Determine if differences exist in the species movement during the day versus night.

- During the second year of study determine the downstream movements of fish over the weir.
- Assess the extent to which artificial barriers (weirs, gauging stations) on the Angove River impede the upstream migration of *G. truttaceus* and other species.

Fishway monitoring

The Goodga River Fishway (Plate 1) is a vertical-slot fishway that consists of a series of cells that are separated by aluminium baffles with a small slot designed to reduce flows and create eddies. From the fishway entrance, fish progress up four 'runs' with a resting pool at the terminus of each section (see Plates 1 and 2). The fishway was sampled during the peak spawning period of *G. truttaceus* (i.e. April/May) and again in July and November 2003, February, May, August and November 2004, and February 2005. In order to determine whether the different species were able to negotiate the entire length of the fishway, a series of funnels were inserted using clamps on the second, third and fourth run (see Plate 2). The funnels allow fish to move upstream but stop or minimise any downstream movement after the fish have passed through the funnel (see Plates 2 and 3) (see also Close *et al*. 1989). A mesh screen was placed at the fishway exit and, while still allowing the fishway to function, it stopped fish leaving the fishway after they had entered it.

To determine whether different species or their life history stages had preferences for migrating during the day or night the fishway was monitored for up to three days (dusk sample) and four nights (dawn sample) during each sampling period. For night samples (i.e. using the fishway at night), the traps were set after dusk and retrieved prior to dawn, and for day samples (i.e. using the fishway during the day), the traps were set at dawn and retrieved after dusk. During each sampling occasion the fishway was 'dewatered' by placing a board across the fishway exit (i.e. the mesh screen was removed) and for each species the number, total length (TL) (mm) and position of fish on the fishway was recorded. To prevent fish in the bottom run of the fishway escaping, a mesh screen was used to block the fishway entrance.

Prior to the opening of the fishway no fish were captured above the weir (see Morgan 2003). During each sampling trip a number of sites on the Goodga River, upstream of the fishway, were sampled using fine mesh seine nets and also on occasion an electrofisher. The abundances of fishes upstream of the fishway were then calculated and used to determine any change in abundances of fishes above the fishway.

Water velocity was measured on the fishway using a Current Meter Counter (model C.M.C. 20). The measurements were taken in front of the slots between each of the cell entrances. Water temperature and conductivity were recorded on each sampling occasion while rainfall data was provided by the Western Australian Bureau of Meteorology, discharge data was provided by the Department of Environment (Water and Rivers Commission), and monthly trends in conductivity, pH and water temperature data are from Morgan (2003) (see Appendix).

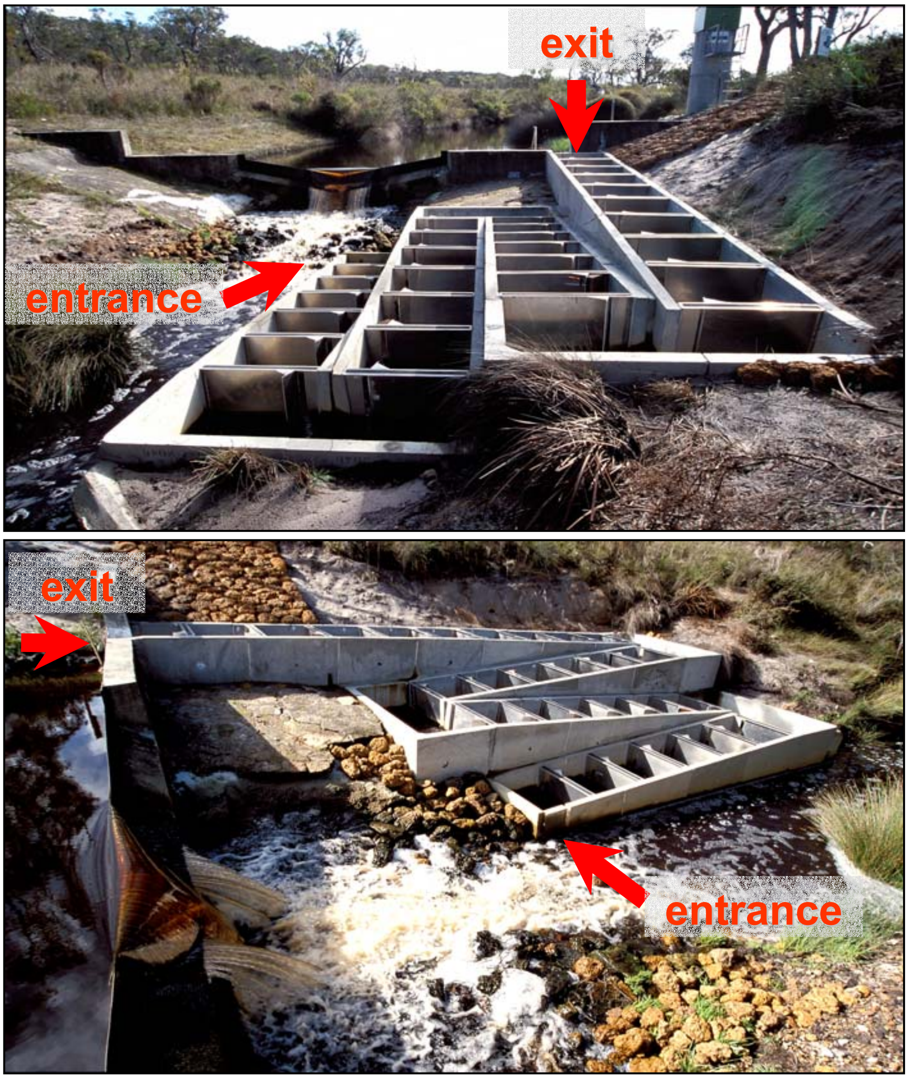

Plate 1 Downstream and lateral views of the Goodga River Fishway showing the entrance and exit.

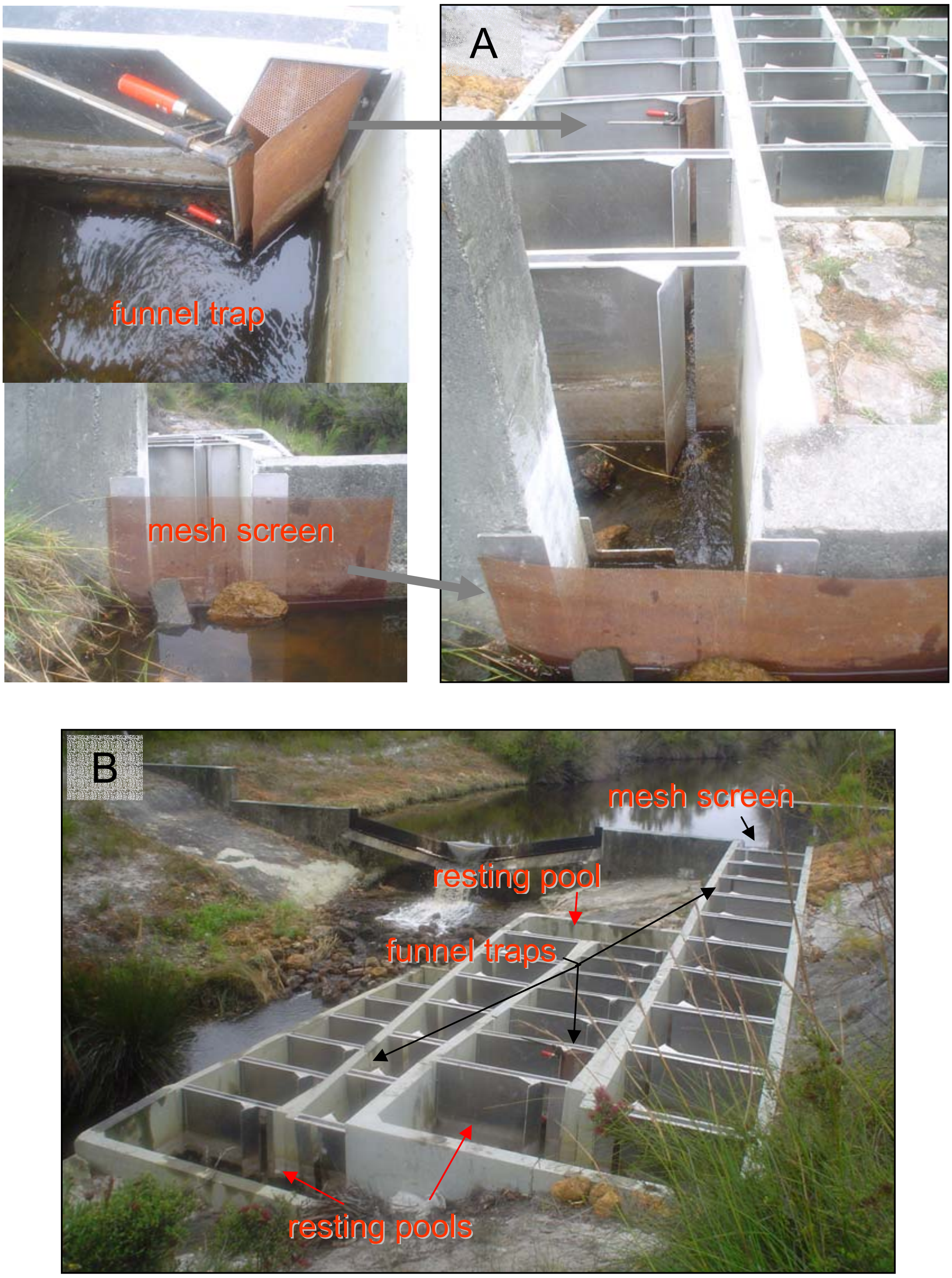

Plate 2 (A) Mesh screen and funnel trap set on the Goodga River Fishway during each sampling occasion and, (B) the location of the funnel traps, mesh screen and resting pools on the fishway.

Results & Discussion

Goodga River Fishway environmental variables, discharge and flow rates

The environmental variables for the Goodga River, Black Cat Creek and Moates Lake are discussed in Morgan (2003) (see Appendix). Rainfall follows a highly seasonal pattern with mean falls of 120-150 mm/month occurring during winter and only 12-30 mm/month falling during summer. Water temperatures are also seasonally affected with higher temperatures of between 20 and 23^{o}C occurring between November and March and lower temperatures recorded during winter (<12^{o}C during July). The Goodga River and Moates Lake are generally acidic, with mean pHs ranging from 4.2 to 6.5. Conductivity is also low and ranges from *ca* 300 to 1600 μS cm^{-1}.

The Goodga River flows year round but mean monthly discharge peaks in July and August at around 0.3 m^3S^{-1} and is lowest between December and April (<0.05 m^3S^{-1}) (Figure 2). Discharge and water levels rise marginally between April and May, the peak spawning period of *G. truttaceus* in the Goodga River (Figures 2A and 3) (Morgan 2003). It is possible that the onset of spawning is initiated by the small rise in discharge and water levels between March and May (Figures 2 and 3), thereby providing larval *G. truttaceus* with a habitat that is substantially larger than that during summer. The rise in discharge also results in the larvae being transported (due to poor swimming ability) into Moates Lake where they spend the first few months of life feeding on the abundant zooplankton, such as copepods, that occur in the lake (Morgan 2003).

The flow rates of the Goodga River Fishway, on the 2nd May 2003 (during the peak spawning period of *Galaxias truttaceus*) were generally <1mS^{-1} in each slot (Figure 2B), whereas directly in front of the fishway entrance the flow rates were marginally higher (*ca* 1mS^{-1}). The high flows at the fishway entrance act as a source of attraction for fishes. Although the data presented in Figure 2B suggest that fish in the resting pools are subjected to lower flows than experienced in the fishway baffles, flow rates are much less in the resting pools than those given in Figure 2B. This was due to the measurements being taken at the entrance to the resting pool and not from within the large body of water itself.

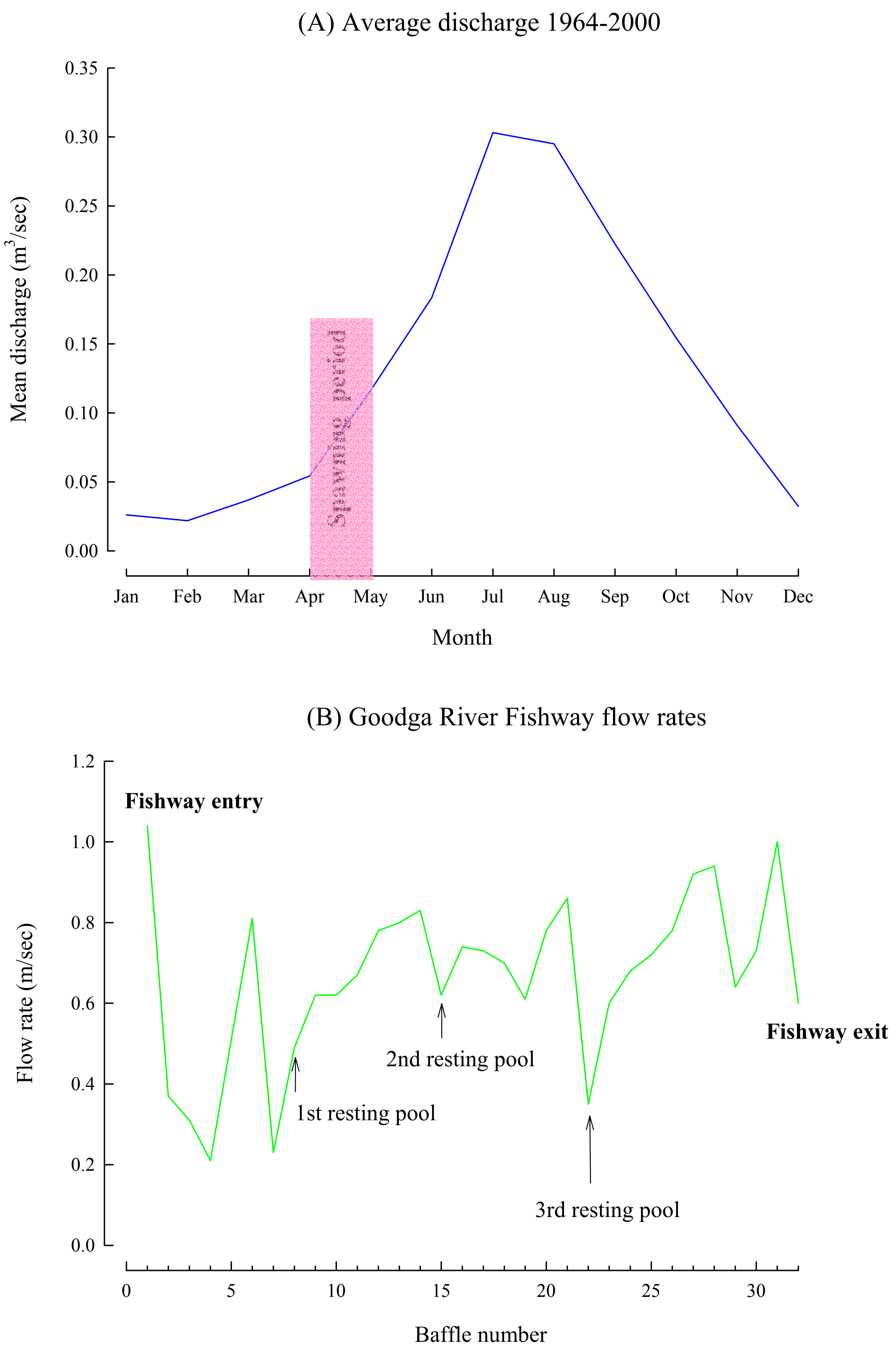

Figure 2 (A) The mean long-term monthly discharge (1964-2000) at the Goodga River Gauging Station and includes the spawning period of *Galaxias truttaceus*. (B) Flow rate within each concrete baffle (taken at the entrance to each baffle) of the Goodga River Fishway during May 2003.

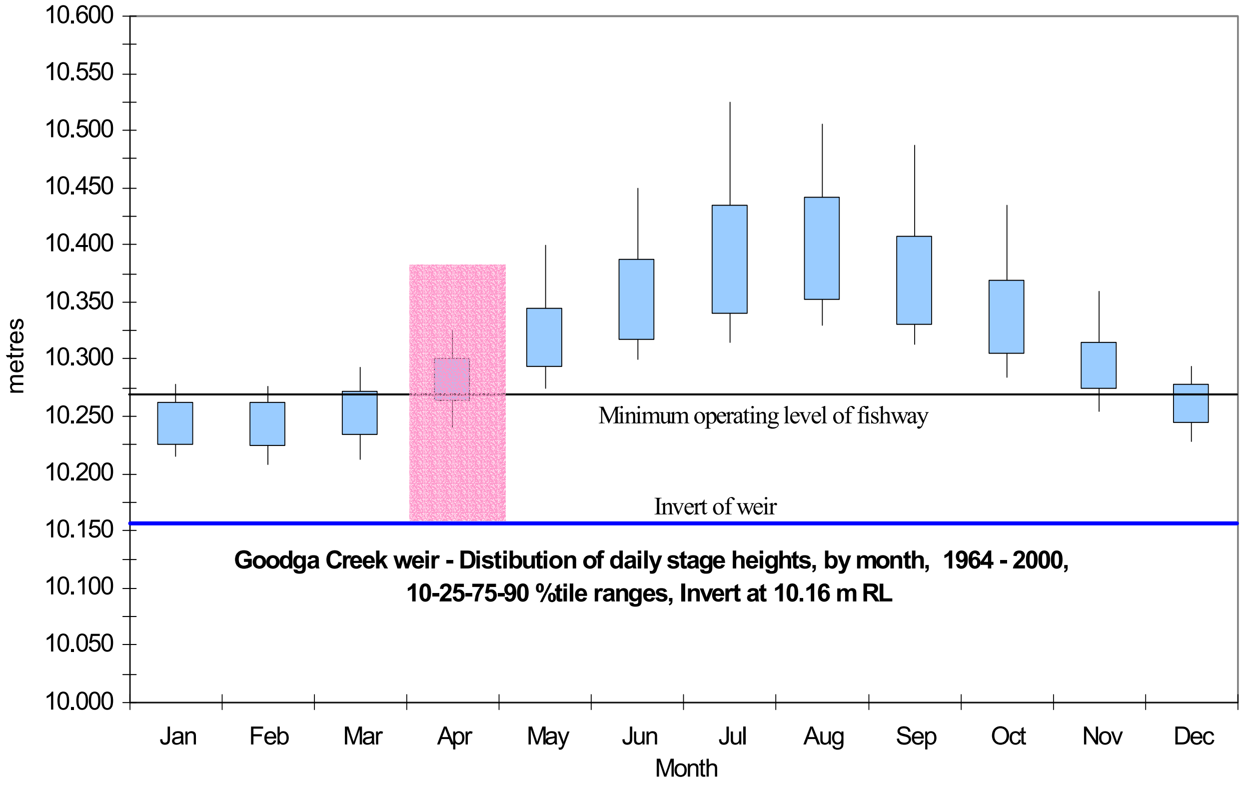

Figure 3 Annual flow pattern of the Goodga River at Goodga River Gauging Station (data provided by the Western Australian Water & Rivers Commission). Pink shading denotes the spawning period of *Galaxias truttaceus* (Morgan 2003).

Fish captured on the Goodga River Fishway

Three species of fish were captured on the Goodga River Fishway, the trout minnow (*G. truttaceus*), the spotted minnow or common jollytail (*G. maculatus*) and the western pygmy perch (*Edelia vittata*) (Table 1, Plate 3). A further species, the Swan River goby (*Pseudogobius olorum*) was abundant below the fishway in the Goodga River and Moates Lake. Its absence from the fishway may be a reflection of it being benthic and that the fishway entrance is positioned well above (~20 cm) the river bed.

In total, 2405 *G. truttaceus*, 1649 *G. maculatus* and 15 *E. vittata* were captured on the fishway during this study (Table 1). Fishway utilisation was highest by all species in spring (November) with ~95, 70 and 100% of *G. truttaceus*, *G. maculatus* and *E. vittata*, respectively, being captured on the fishway in this season. Fishway utilisation was lowest during winter.

Table 1 Total (and mean number) of each species captured on the Goodga River Fishway at dawn (night movement) and dusk (day movement) in the different months between April/May 2003 (when the fishway was opened) and February 2005. The number of samples (on different days) is given. N.B. *Gt* = trout minnow (*Galaxias truttaceus*), *Gm* = spotted minnow or common jollytail (*Galaxias maculatus*) and *Ev* = western pygmy perch (*Edelia vittata*). The number (and density (fish/m^2)) of each species captured above the fishway is also given.

		Fishes on fishway			Above fishway		
Month	**Time (# samples)**	*Gt*	*Gm*	*Ev*	*Gt*	*Gm*	*Ev*
2003							
April/May	Day (3)	8 (2.67)	65 (21.7)	-	-	-	-
	Night (4)	9 (2.25)	26 (6.5)	-			
July	Day (2)	4 (2)	26 (13)	-	63 (0.14)	10 (0.02)	-
	Night (3)	4 (1.3)	4 (1.3)	-			
November	Day (3)	1374 (458)	72 (24)	4 (1.3)	45 (0.33)	23 (0.17)	-
	Night (3)	90 (30)	9 (3)	-			
2004							
February	Day (2)	4 (2)	62 (31)	-	46 (0.61)	127 (1.69)	-
	Night (2)	-	10 (5)	-			
May	Day (3)	15 (5)	31 (10.3)	-	33 (0.37)	151 (1.68)	-
	Night (3)	39 (13)	30 (10)	-			
Aug	Day (3)	1 (0.33)	6 (2)	-	29 (0.38)	39 (0.51)	-
	Night (2)	2 (1)	1 (0.5)	-			
November	Day (3)	775 (258.3)	919 (306.6)	11 (3.67)	321 (2.68)	330 (2.75)	-
	Night (3)	56 (18.7)	154 (51.3)	-			
2005							
February	Day (2)	10 (5)	130 (65)	-	69 (0.46)	129 (0.85)	-
	Night (2)	14 (7)	104 (52)	-			
TOTAL		2405	1649	15	606	809	-

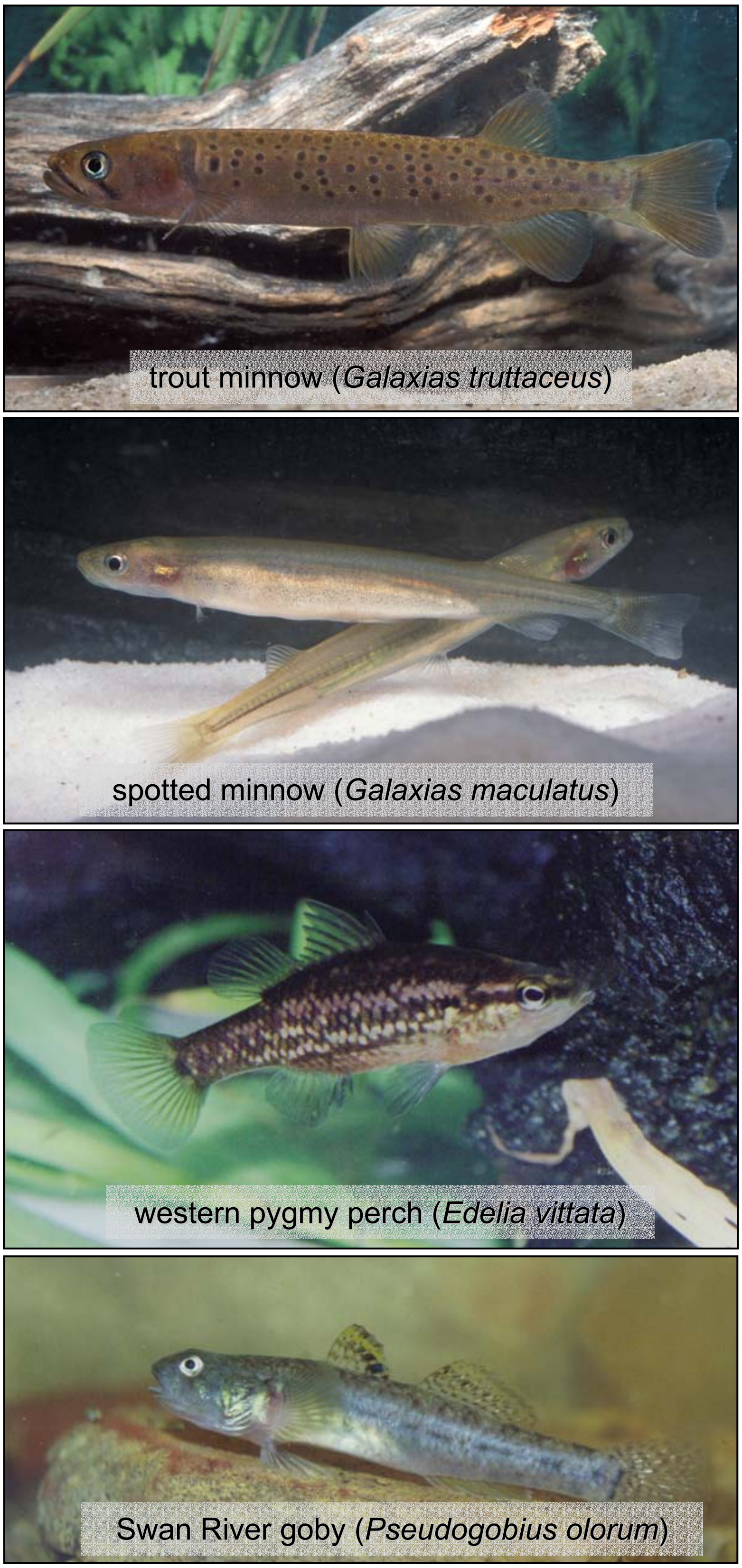

Plate 3 Fishes captured at, or on, the Goodga River Fishway.

Trout minnow (*Galaxias truttaceus*)

Although the spawning period is during April/May, only 17, mostly large (length range 56-92 mm TL) *G. truttaceus* were captured, over four nights and three days, on the fishway during this period in 2003 when the fishway opened (Table 1, Figure 4). During the spawning period in 2004 a further 54 large fish were captured over three nights and three days on the fishway. Many of these individuals were mature and in either early or late spawning condition, with the females having ovaries that were clearly visible through their ventral surface and the males running ripe, i.e. being easily 'milked' of sperm when pressure was gently applied to their ventral surface. Surprisingly, when discharge was highest, i.e. during winter samples (July 2003 and August 2004), utilisation of the fishway was low with a total of only 11 mostly large fish captured over six nights and four days. During February 2004 only four *G. truttaceus* (63-102 mm TL) were captured on the fishway during two day samples, with none captured at night (Figure 4). In February 2005 a total of 10 were captured during two day samples while a further 14 were found on the fishway at night.

The mean abundances of *G. truttaceus* captured on the fishway during both November 2003 and 2004 were significantly different (ANOVA, $p<0.05$) to the mean abundances during all other months sampled (Table 1). Furthermore, there was no significant difference in the mean abundances of *G. truttaceus* captured on the fishway between November 2003 and 2004 ($p=0.989$). The bulk of fish were therefore captured in November 2003 and 2004 and consisted largely of small fish <60 mm TL but ranged in length from 32-142 mm TL (Figure 3). These smaller fish were those that were recruited (hatched) after the fishway opened and were approximately seven months old, i.e. hatched in May 2003 or May 2004. Thus, while they spend the first few months of their life (as larvae and then small juveniles) within Moates Lake, they then migrate upstream where they would previously have congregated below the Goodga River Gauging Station (see Figure 1) (Morgan 2003). There were no significant differences in the mean abundances of *G. truttaceus* captured on the fishway between any other months sampled, again highlighting the significant utilisation of the fishway during the recruitment of juveniles into the population in spring (November).

Although there was an overall significant difference between the mean abundances of *G. truttaceus* captured on the fishway during the day (mean = 104.3) compared to the night (mean = 8.9) ($p<0.05$), these data were heteroscedastic and when they were log transformed, this difference was no longer significant ($p=0.25$). However, there were considerably higher numbers of fish captured during the day during both November 2003 and 2004 (Table 1, Figure 5) with approximately 94% of *G. truttaceus* recorded on the fishway in both November 2003 and 2004 captured during the day. The length ranges of the *G. truttaceus* during the night versus day in November were similar with fish captured on the fishway during the day ranging in length from 41-130 mm TL and those in the night ranging from 32-142 mm TL (Figure 5).

In contrast to day samples that were dominated by the 0+ age class in most months, examination of the length-frequency histograms demonstrated that the larger, older fish generally negotiated the fishway at night. Overall, the mean length of *G. truttaceus* using the fishway during the night was significantly larger (72.55 $\pm$ 1.67 S.E. mm TL) than those captured during the night (57.15 $\pm$ 0.399 S.E. mm TL) (ANOVA, p<0.001). For example during February 2005, all fish captured during the day consisted of 0+ fish whereas during the night, captures consisted of those fish >0+ (Figure 5). During May 2004 two fish measuring 151 mm TL fish were captured on the fishway at night. These are the largest fish captured during this study and are the largest recorded from the Goodga River, the previous record being a 144 mm TL female captured during the ecological study by Morgan (2003). This large female was seven years old and weighed 17.05 g. On average, females in the Goodga River attain lengths of 63, 89, 103 and 111 mm TL at the end of their 1st, 2nd, 3rd and 4th year of life, respectively, while males attain approximately 60, 84, 95 and 101 mm TL at these respective ages (Morgan 2003). Maturity is reached by approximately 34% and 8% of males and females, respectively, at the end of their first year of life while the majority of fish mature by the end of their second year.

Moates Lake – the Goodga River flows in from the far right

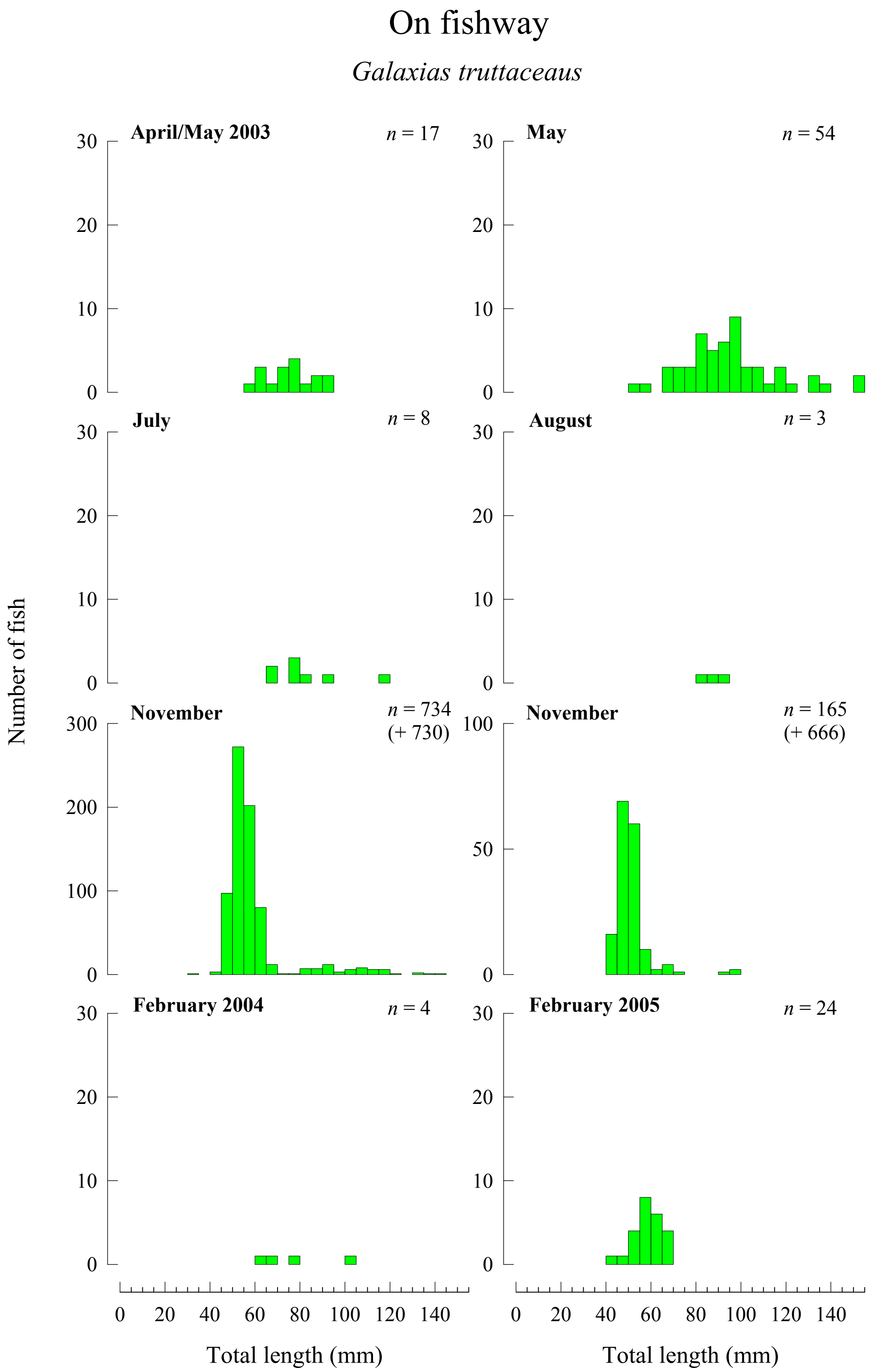

Figure 4 Length-frequency histograms of the trout minnow (*Galaxias truttaceus*) captured on the Goodga River Fishway during the different sampling periods (i.e. April/May, July and November 2003; February, May, August and November 2004; and February 2005). *n* = number of fish, while the +730 and + 666 for *G. truttaceus* in November 2003 and 2004 represent additional 0+ fish that were captured but not measured so as to reduce stress to the animals.

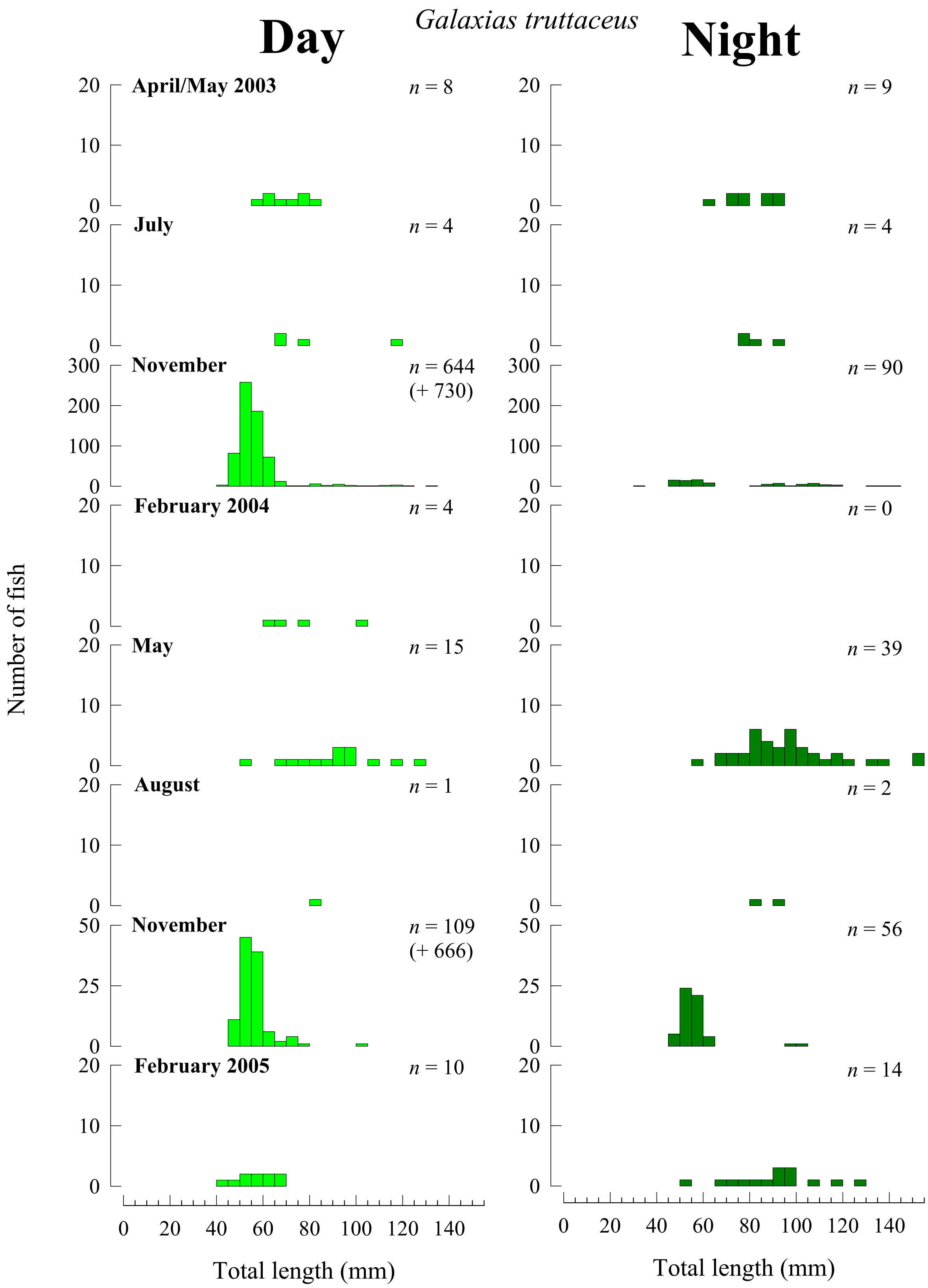

Figure 5 Length-frequency histograms of the trout minnow (*Galaxias truttaceus*) captured on the Goodga River Fishway either during the day or night in the different sampling periods (i.e. April/May, July, November 2003; February, May, August and November 2004; and February 2005). n = number of fish, while the +730 and +666 for *G. truttaceus* in November 2003 and 2004, respectively, represent an additional 730 and 666 0+ fish that were captured but not measured.

Spotted minnow (*Galaxias maculatus*)

Of the 1649 *G. maculatus* captured on the fishway, 91, 30, 81, 72, 61, 7, 1073 and 234 were captured in April/May (2003), July (2003), November (2003), February (2004), May (2004), August (2004), November (2004) and February (2005), respectively (Table 1, Figure 6). There were no significant differences in the utilisation of the fishway by *G. maculatus* in the different months, with the notable exception of November 2004, which was different to all other months (ANOVA, $p<0.05$) apart from February 2005. The utilisation of the fishway by *G. maculatus* in all months demonstrates the importance of maximising the duration that a fishway functions.

The length range of *G. maculatus* captured in April/May 2003 was 43-101 mm TL, and this was similar in July and November 2003 with length ranges being 43-99 and 44-110 mm TL, respectively in these months (Figure 6). The modal length of fish increased during these months from 55 mm TL in April/May to 60 mm TL in July and 80 mm TL in November 2003. During February 2004, the modal length of fish captured on the fishway was smaller at 40-45 mm TL and this was largely due to a group of small fish utilising the fishway (Figure 6). Similarly, in November 2004 and February 2005 a group of small fish were found on the fishway (modal length-class of both months 45-50 mm TL). A recent study by Chapman (2004), utilising fish collected monthly by the senior author over a 12 month period, found that *G. maculatus* in Moates Lake and the Goodga River are potentially capable of spawning year round, consistent with the presence of larvae in the lake throughout the year (see Figure 8). This would account for the recruitment of the 0+ fish into the river from Moates Lake that were captured on the fishway during the different months. At the end of their 1st, 2nd and 3rd years of life males had, on average, reached 56, 74 and 80 mm TL and females had reached 61, 81 and 88 mm TL (Chapman 2004). The peak spawning period however is mid-winter and the large group of small fish using the fishway in November were, based on length at age data, most likely from the peak winter spawning period. Utilisation of the fishway was low in winter when discharge was high, and may have been a response to fish breeding in the lake during this period (see Figures 6 and 8).

A logistic curve, fitted to the proportion of fish with mature gonads in sequential 5 mm increments during the main spawning period, indicated that the total lengths at which 50% of fish reached maturity (L_{50}) was 56.4 mm for females and 51.4 mm for males (Chapman 2004). The total lengths at which 95% of females and males attained maturity (L_{95}) were 88.0 mm and 59.8 mm, respectively. Approximately 75% of males and 62% of females attained sexual maturity at the end of their first year.

The overall mean number of *G. maculatus* captured on the fishway during the day was ~66 fish/day, whereas during night samples the mean number of fish captured on the fishway was ~10 fish/night (Table 1, Figure 7). ANOVA suggested that overall there were highly significant differences in the diurnal movements of *G. maculatus* ($p=0.004$) with clearly more fish moving during the day than at night (Table 1, Figure 7). Furthermore, these differences were evident during each sampling occasion, however ANOVA suggested that these differences were only significant during November ($p<0.001$). The overall mean length of fish moving up the fishway during the day was significantly larger than those captured during the night (ANOVA, $p<0.001$) (Figure 7), with the mean length of fish captured during the day measuring 56.15 ($\pm$ 0.629 SE) mm TL and those captured at night being 51.05 ($\pm$ 0.529) mm TL.

Galaxias maculatus infected with the introduced cestode *Ligula intestinalis* (see Morgan 2003, Chapman 2004).

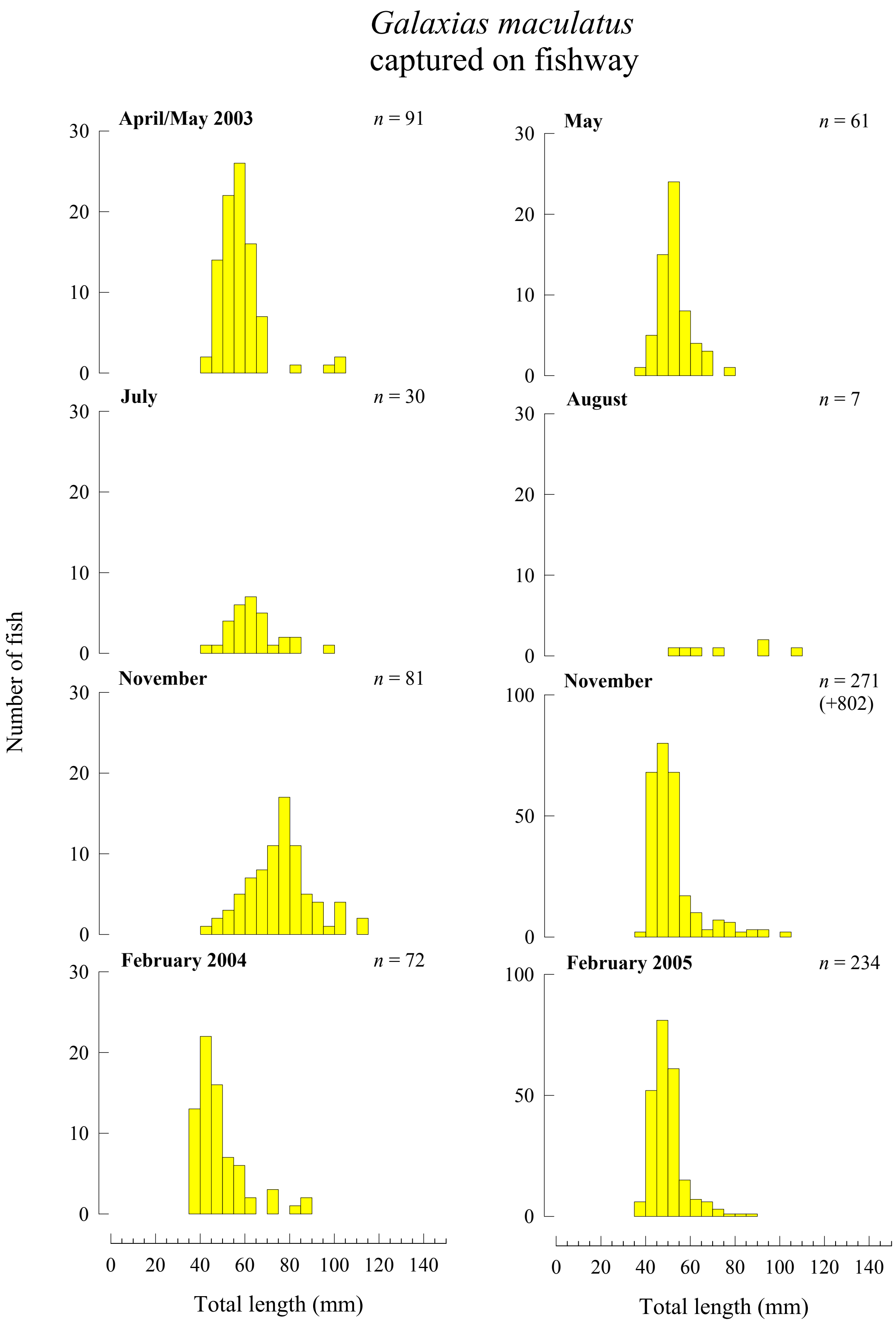

Figure 6 Length-frequency histograms of the spotted minnow (*Galaxias maculatus*) captured on the Goodga River Fishway during the different sampling periods (i.e. April/May, July, November 2003; February, May, August and November 2004; and February 2005). *n* = number of fish, while the +802 in November 2004 represents an additional 802 0+ fish that were captured on the fishway but not measured so as to reduce stress to the animals.

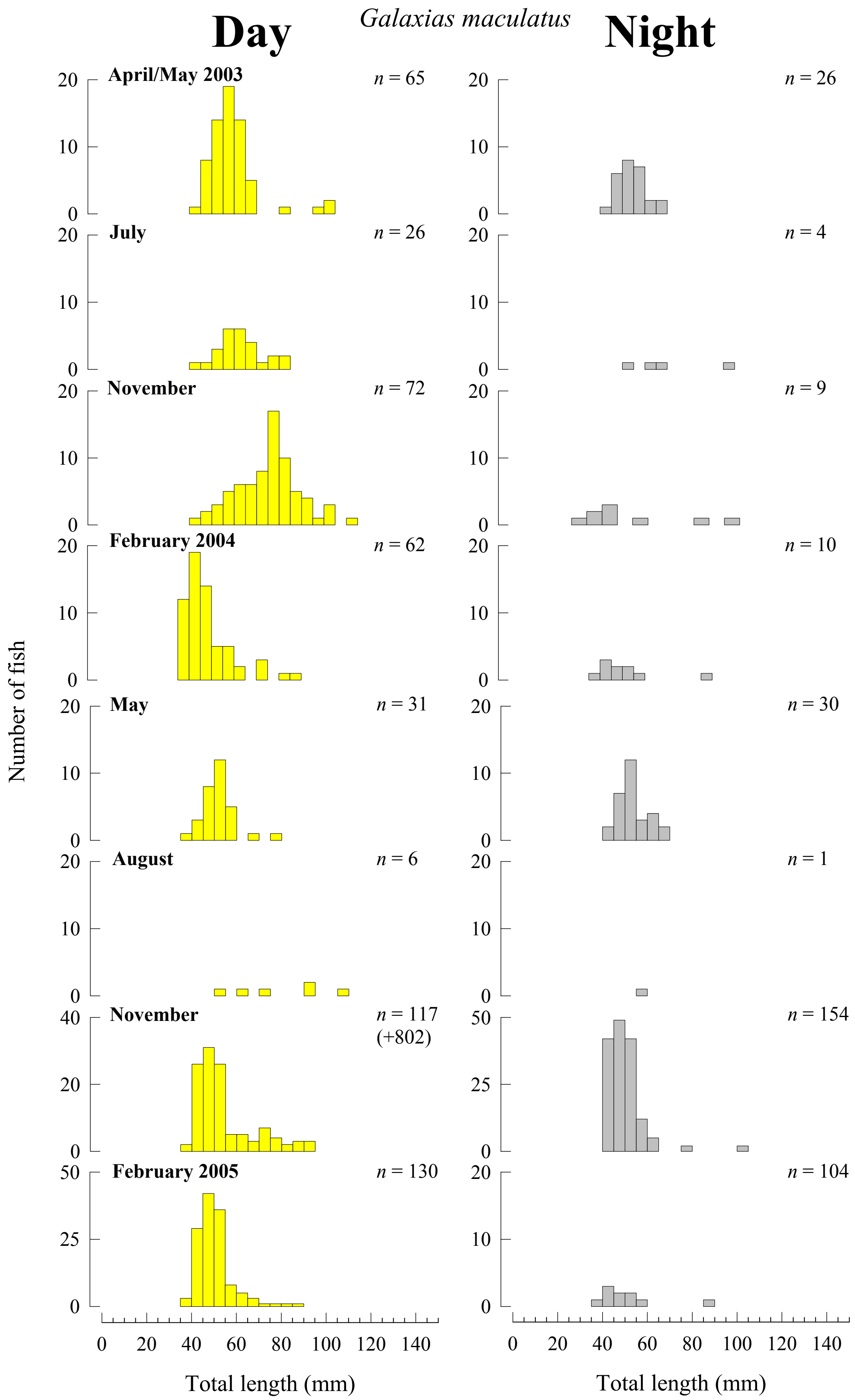

Figure 7 Length-frequency histograms of the spotted minnow (*Galaxias maculatus*) captured on the Goodga River Fishway either during the day or night in the sampling periods (i.e. April/May, July, November 2003; February, May, August and November 2004; and February 2005). *n* = number of fish, while the +802 in November 2004 represents an additional 802 0+ fish that were captured on the fishway but not measured so as to reduce stress to the animals.

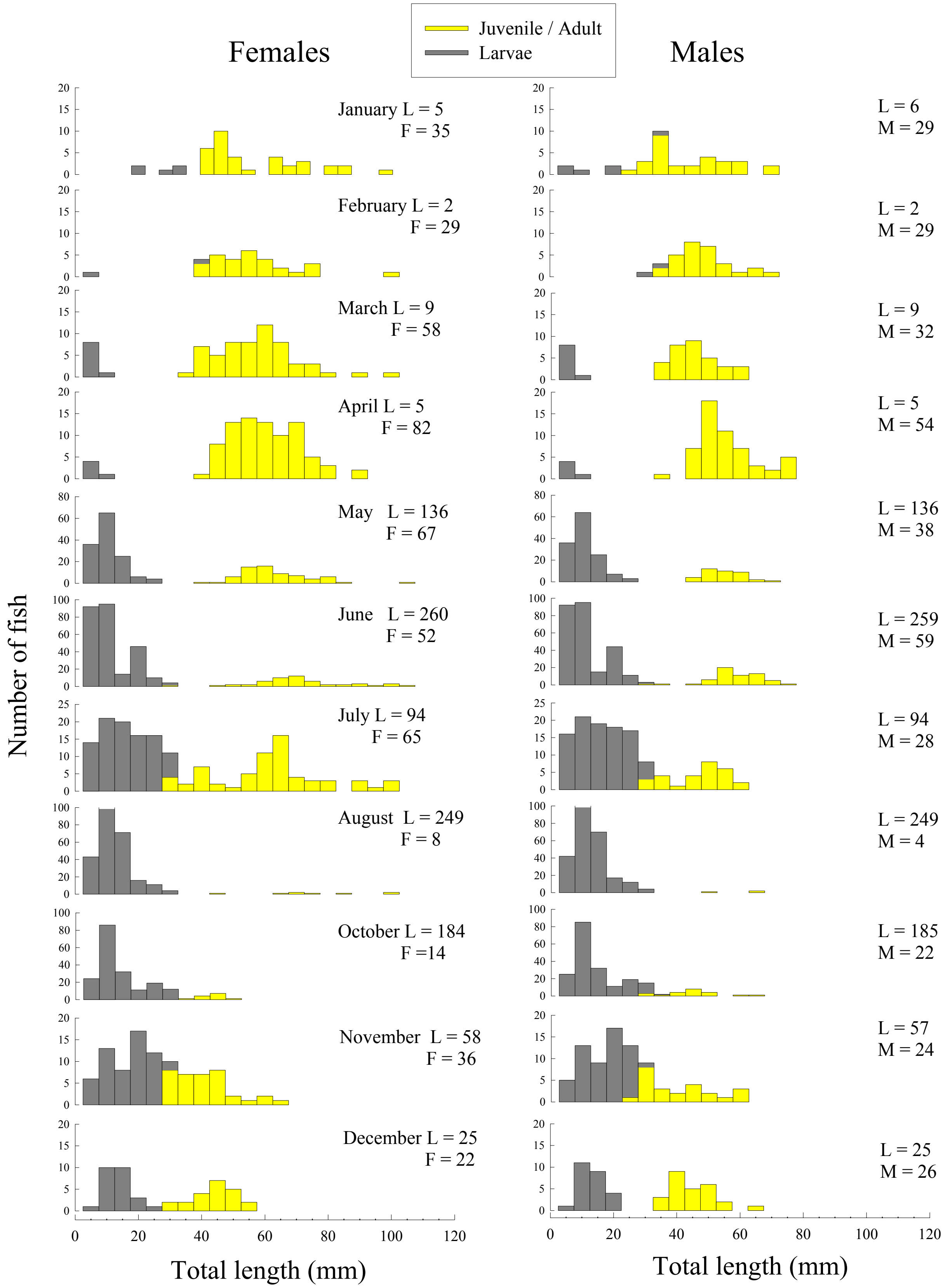

Figure 8 Monthly length-frequency histograms of the spotted minnow (*Galaxias maculatus*) captured in the Goodga River and Moates Lake. *n* = number of fish, L = larvae, F = females and M = males. The larval fish were captured using plankton nets primarily in Moates Lake while the juveniles/adults were captured using seine nets either in Moates Lake or the Goodga River.

Western pygmy perch (*Edelia vittata*)

The 15 *E. vittata* that were captured on the fishway were caught in either November 2003 or November 2004 (Table 1), a peak spawning period for this species (Pen and Potter 1991). Ten of these were mature spawning males (sperm was exuded from the fish after gently squeezing the body). It is plausible that their presence on the fishway during November is the result of an upstream spawning migration. They were only captured on the fishway during day-light hours suggesting that movements are restricted to the day.

No *E. vittata* were captured upstream of this structure (see section on *Fish species captured upstream of the Goodga River Fishway*) suggesting that they are yet to establish a above the fishway.

Swan River goby (*Pseudogobius olorum*)

The Swan River goby was not captured on or above the Goodga River Fishway, even though it is an abundant species downstream of the fishway and in Moates Lake. Its absence from the fishway is probably a consequence of the benthic nature of the species and that the fishway entrance is well above (~20 cm) the substrate.

Other fauna

Oblong turtles (*Chelodina oblonga*) were captured on the fishway on several occasions, two of which were deceased. Freshwater shrimp (*Palaemonetes australis*), gilgies (*Cherax quinquecarinatus*), koonacs (*Cherax preissii*) and marron (*Cherax cainii*) were also captured during most samples.

Distribution of fishes within the fishway

The data presented in Figure 9 demonstrates that a high proportion of both *G. truttaceus* and *G. maculatus* were captured above the top trap set on the Goodga River Fishway, i.e, they were captured in the top three cells, suggesting that they readily climb the fishway (see also Plate 3). Thus, of the 2405 *G. truttaceus* captured, 1262 or ~52.5% were found at the top of the fishway while a further 555 were captured in the top resting pool. Similarly, for *G. maculatus* over 60% of those captured on the fishway were in the top three baffles (Figure 9). The fact that the middle (second) and top (third) resting pools (2nd and 3rd turnaround) on the fishway had the next most number of fish suggests that these pools provide refuge for fish while negotiating the fishway. Very few fish were captured immediately above the first and second trap or in the first resting pool however, a number of fish were captured in the bottom section of the fishway. The water levels in the lower section are generally deeper and have lower flows than that experienced in the other parts of the fishway.

The size range of both *G. truttaceus* and *G. maculatus* in the top of the fishway (i.e. in the top three cells above the top trap) did not differ from the lengths of the other fish captured throughout the fishway. This suggested that the fishway was able to be negotiated by all sizes of fish that attempted to utilise it.

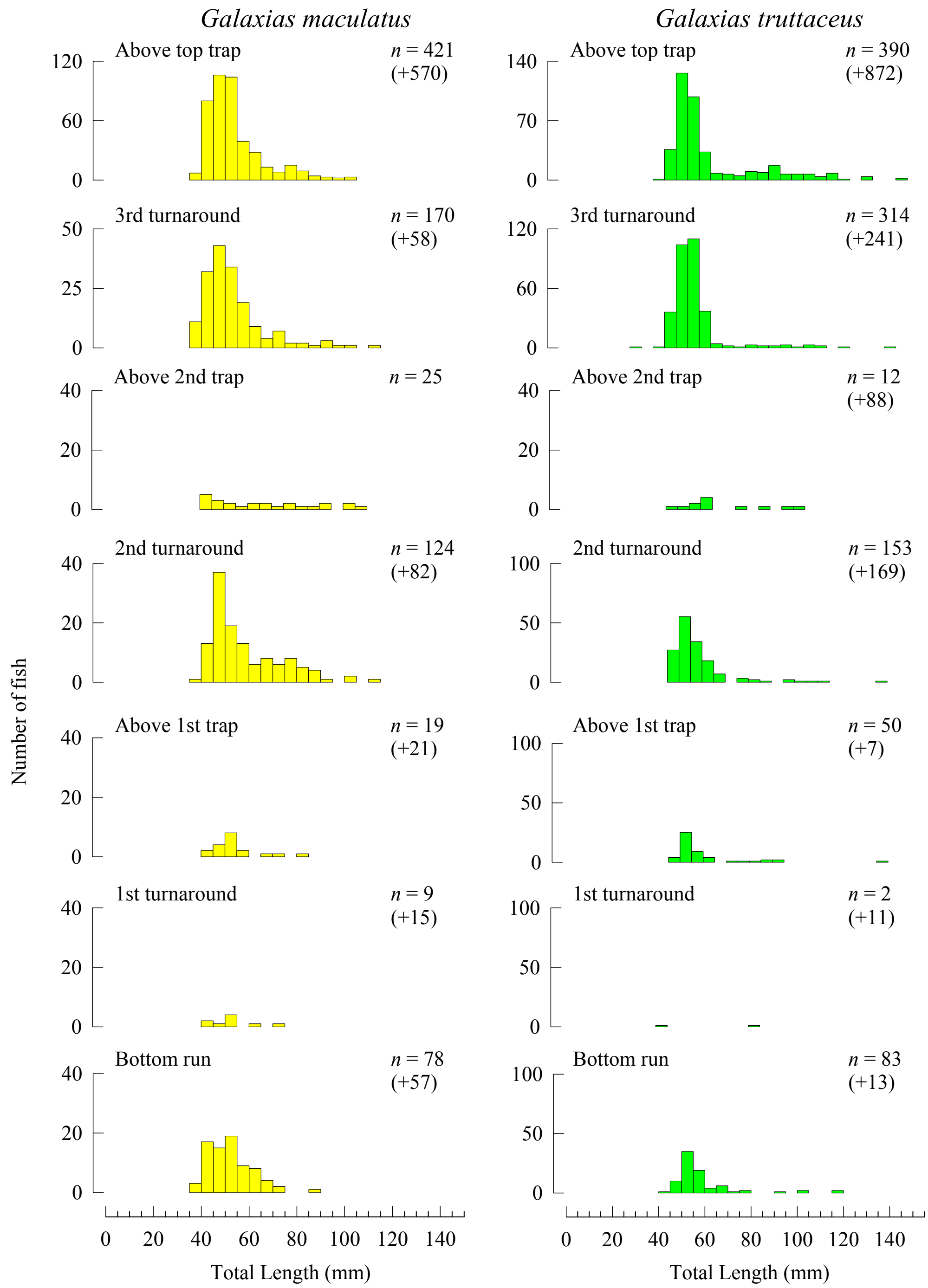

Figure 9 Length-frequency histograms of the spotted minnow (*Galaxias maculatus*) and trout minnow (*Galaxias truttaceus*) captured in the various sections of the Goodga River Fishway. *n* = number of fish. See Plate 2 for fishway sections.

Plate 3 A large school of *Galaxias truttaceus* caught above a funnel trap set at the top of the Goodga River Fishway in November 2003.

Fish species captured upstream of the Goodga River Fishway

Prior to the opening of the fishway in April 2003, no fish were captured above the fishway (Table 1, Figure 10, and see Morgan (2003)). However, during July 2003 both *G. truttaceus* and *G. maculatus* were captured above the fishway for the first time with densities of 0.14 and 0.02 fish/m^2, respectively. The density of both species increased substantially in November to 0.33 and 0.17 fish/m^2 for *G. truttaceus* and *G. maculatus*, respectively. During sampling in February the density of both species increased further to 0.61 fish/m^2 for *G. truttaceus* and 1.69 fish/m^2 for *G. maculatus*. The pronounced increase in abundance over the first year of sampling was most likely a reflection of increased migrations of small *G. truttaceus* in November and small *G. maculatus* in February (see Figures 4, 6 and 11), rather than as a consequence of habitat becoming reduced through lower discharge. While water levels in some of the upstream pools fell by approximately 30-50 cm during summer, the pools are still deep (up to 2 m depth) and offer excellent habitat for fishes. The population of *G. truttaceus* appeared to reach a carrying capacity over the next few months until November 2004 when it was influenced again by the massive juvenile upstream migration (Figures 4, 10 and 11). The density of the population upstream of the fishway then returned to its previous levels in February 2005. The population of *G. maculatus* remained steady between February and May 2004 before declining dramatically in August 2004, a period when little movement of fish was recorded on the fishway (Figures 6, 10 and 11). The abundance peaked again in November 2004, as a result of massive juvenile recruitment before decreasing in February 2005, despite continued recruitment of juveniles.

The increase in abundances of fishes since the fishway was opened demonstrates that fish are continually recruited to the upstream sections of the Goodga River as a result of the fishway being constructed. This steady recruitment in most months and high fishway usage in November (and possibly spring in general) highlights the importance of ensuring that the fishway functions when discharge is typically low.

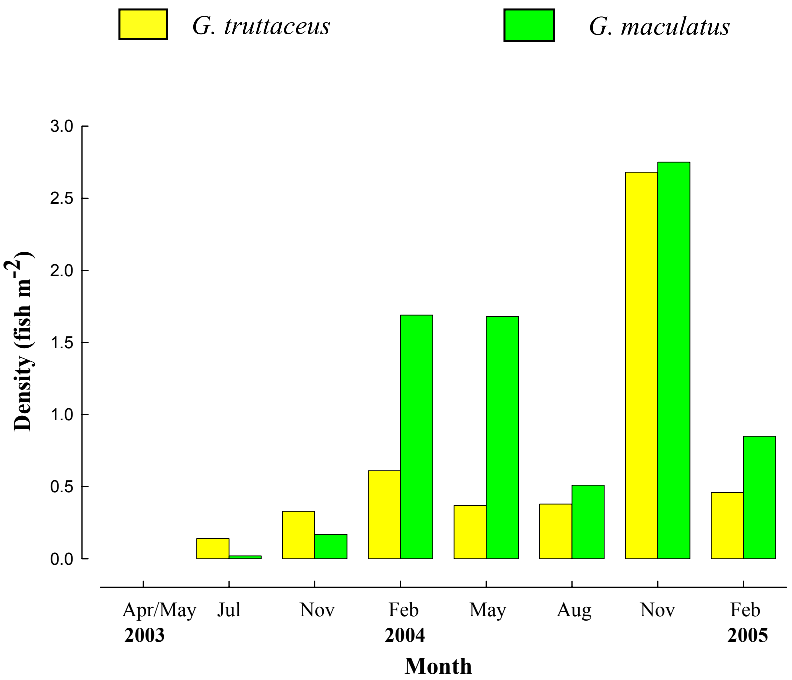

Figure 10 Abundances (density = fish/m^2) of the trout minnow (*Galaxias truttaceus*) and spotted minnow (*Galaxias maculatus*) captured upstream of the Goodga River Fishway: prior to the fishway opening in April/May, and after the fishway had opened in July and November 2003; in February, May, August and November 2004; and in February 2005.

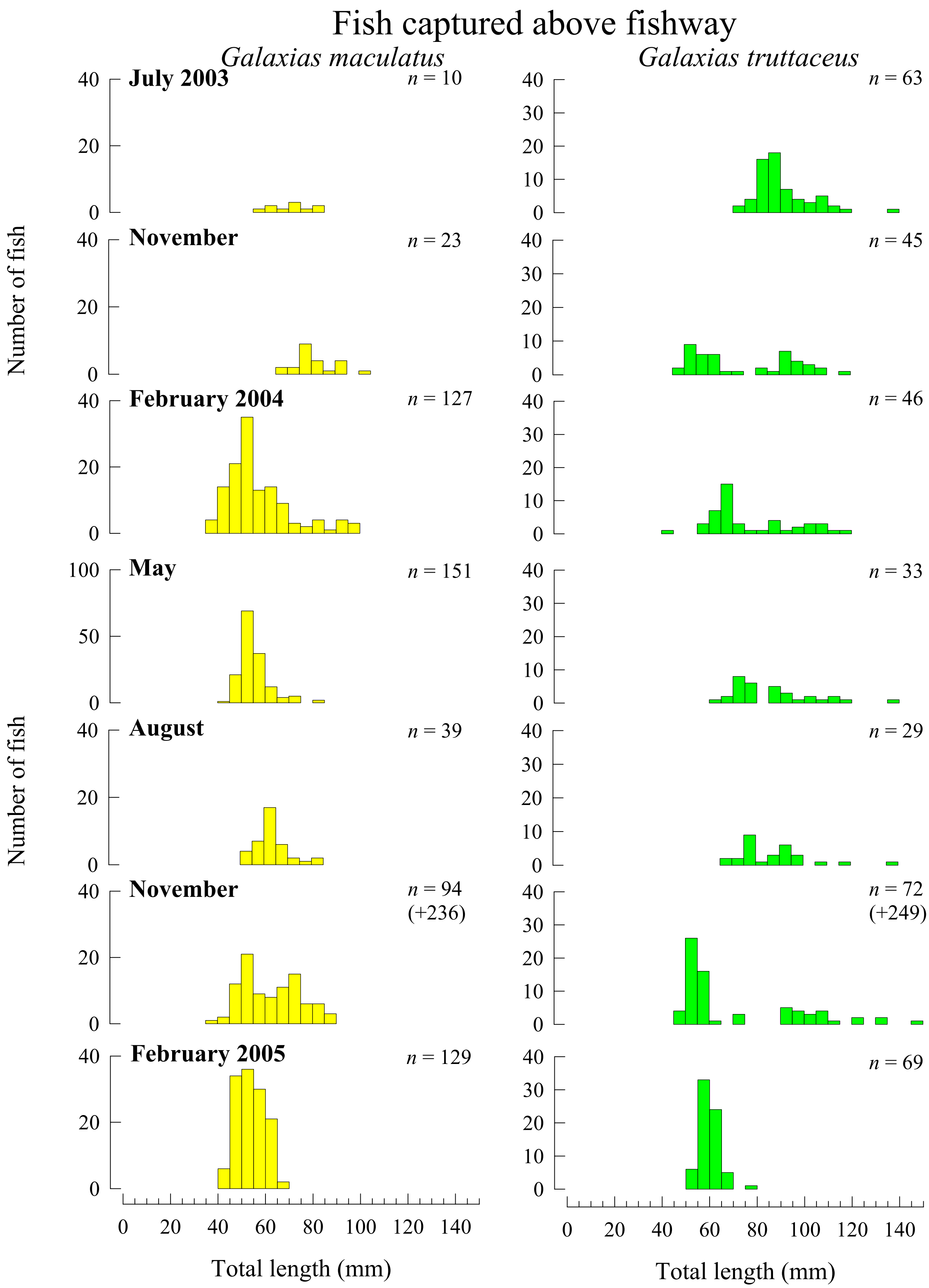

Figure 11 Length-frequency histograms of the trout minnow (*Galaxias truttaceus*) and spotted minnow (*Galaxias maculatus*) captured upstream of the Goodga River Fishway: after the fishway had opened in July and November 2003; in February, May, August and November 2004; and in February 2005. N.B. No fish were captured above the fishway prior to the fishway being opened.

Fish species captured moving downstream over the gauging station

During May, August and November 2004 a trap was set to determine the abundance and size distribution of fish that moved downstream over the Goodga River Gauging Station (see below).

Plankton net set below the Goodga River Gauging Station to determine the extent to which fish moved downstream over the wall.

During the spawning period (May) only three *G. truttaceus* moved over the weir during the day, but 28 were caught in the trap during the night (Figure 12). Those were all large, mature fish that, in the case of females, had presumably recently spawned, i.e. they had no eggs visible through their abdomen, in comparison to mature (gravid) females which have eggs that are visible. While there were no fish found in the trap in August, 554 and 175 *G. truttaceus* were found in the trap in November during the day and night, respectively. Catches during the day consisted of 99.5% of 0+ fish with only three large adults captured, however, during the night 12% of the fish caught were large adults (Figure 12). This suggested that large adults probably avoided the weir during the day but at night failed to detect it. It also suggested that they were more active at night, whereas juveniles were more active during the day.

In the case of *G. maculatus*, larger fish were also generally only found falling over the weir during the night and juvenile downstream movements were greater during the day (Figure 13). For example, during November a total of 194 0+ (<65 mm TL) *G. maculatus* were found in the trap during the day compared to only two adults (>65 mm TL), i.e. ~99% juveniles (0+). In contrast, during the night while only 24 0+ *G. maculatus* fell over the fishway compared to 28 adults, i.e. ~46% 0+.

From the above results a number of questions arise: Why are the larger fish (>0+) of both species falling over the weir mainly at night and why do so many more smaller fish (0+) fall over the weir during the day? As mentioned, it is possible that adult fish are more active at night and this is supported by migrations up the fishway by *G. truttaceus* but not supported for *G. maculatus*, whereby the larger fish were found to use the fishway during the day. Fish falling over weirs is potentially an important issue, particularly large weirs and the Goodga River Weir is no exception. Of the 760 *G. truttaceus* and 277 *G. maculatus* that 'fell' over the weir, 111 (or 14.6%) of the *G. truttaceus* and 28 (or 10.1%) of the *G. maculatus* were found dead when the trap was retrieved. It is unknown whether death of these fish was caused from them being buffeted in the trap by the water falling over the weir or whether the initial fall onto concrete footing of the weir caused an initial injury that resulted in death or whether both factors attributed to their inability to survive the fall. The results of this part of the study strongly suggest that, irrespective of whether a fishway has been constructed, weir designs need to take into account the downstream movement of fish. Simple plastic pool slide-like structures could be fitted to weirs to reduce mortality from falls. Considering that both species are generally surface feeders, and may thus spend considerable time on the surface, a floating device could be employed to guide fish upstream of the weir to the fishway exit. However, this may also lead to an increase in the amount of debri that accumulates on the fishway and thereby may reduce the ability of the fishway to function.

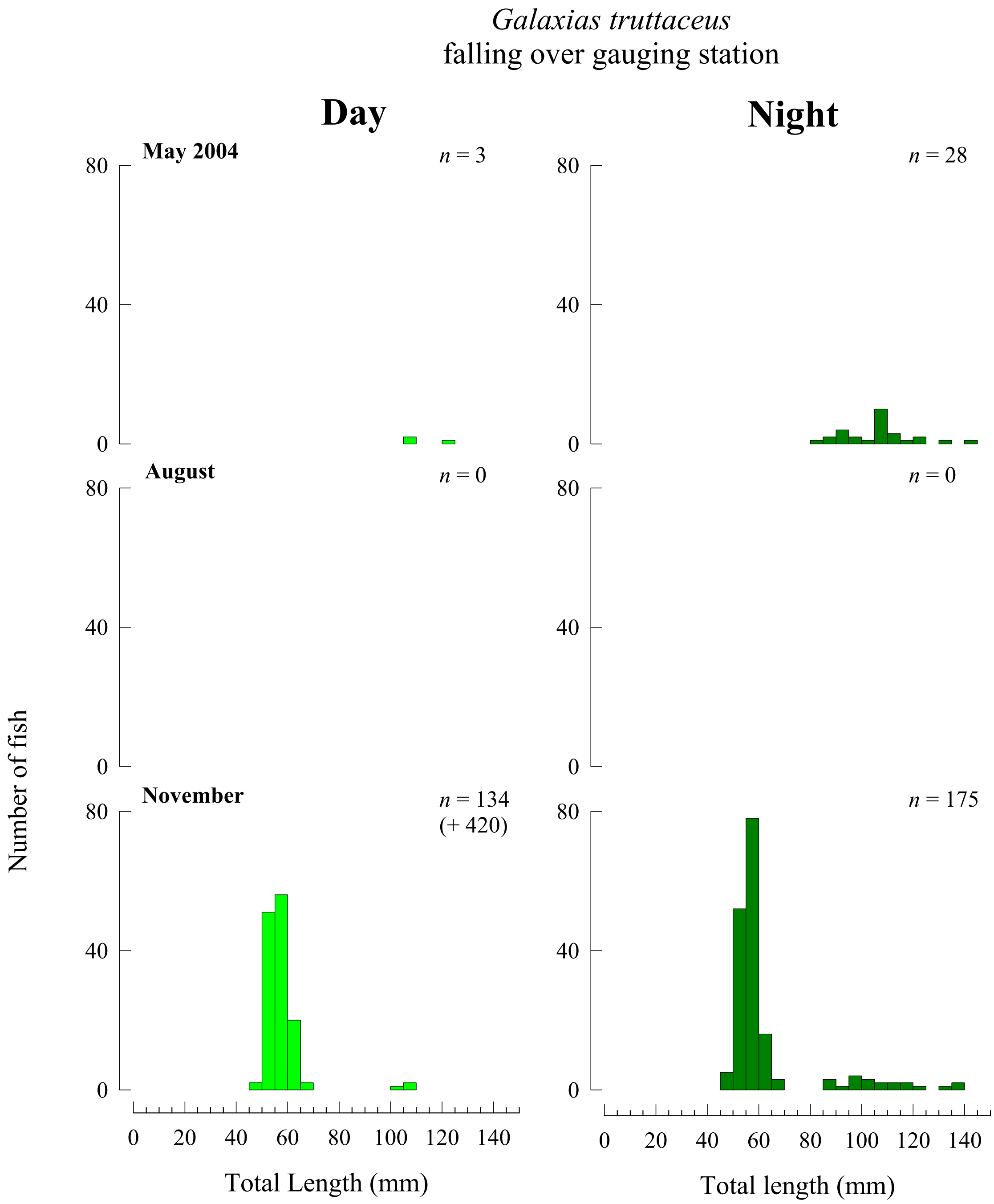

Figure 12 Length-frequency histograms of the trout minnow (*Galaxias truttaceus*) captured in the trap set under the Goodga River Gauging Station (i.e. the fish captured had 'swum' over the gauging station) in May, August and November 2004. N.B. The +420 in November represents an additional 420 0+ fish that were counted but not measured.

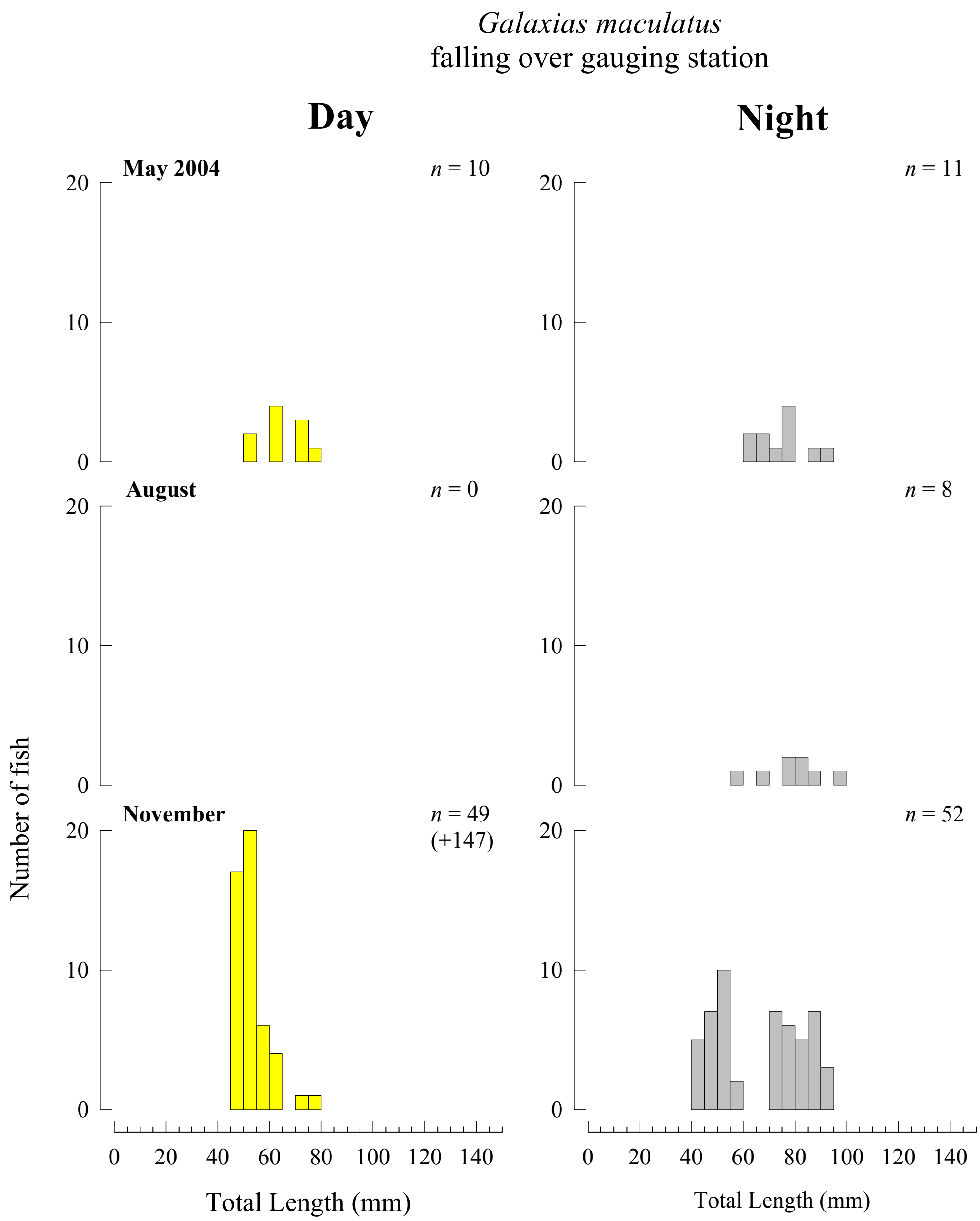

Figure 13 Length-frequency histograms of spotted minnow (*Galaxias maculatus*) captured in the trap set under the Goodga Weir (i.e. the fish captured had 'swum' over the weir) in May, August and November 2004. N.B. The +147 in November represents an additional 147 0+ fish that were counted but not measured.

Barriers to fish migration in the Angove River

During February, May, August and November 2004 the fish species in the section of the Angove River, below the Angove River Gauging Station were monitored (Figure 1). While there are three dams on the Angove River, the most downstream one (i.e. the gauging station) was sampled as *G. truttaceus* had not been recorded upstream of the bottom weir, a situation that paralleled the Goodga River prior to the construction of the fishway (Morgan 2003).

Electrofishing the gauging station on the Angove River

Galaxias truttaceus was found below the gauging station on the Angove River during February (10 fish), August (1 fish) and November (32) 2004, but not during the spawning period (i.e. May) (Figure 14). Those captured ranged in total length from 87-168 mm in February, the sole May fish was 120 mm TL and those in November ranged from 58-74 mm TL. Although only 42 *G. truttaceus* were captured, the largest of these fish (168 mm TL) was almost 20 mm longer than the maximum size previously recorded in Western Australia (this study in the Goodga River).

Similar to the migration of fishes evident in the Goodga River, there was a large number of juvenile new recruits of *G. truttaceus* below the gauging station in November 2004. However, the modal length class of the 0+ fish captured in the Angove River was 60-65 mm TL, which was 10 mm longer than those captured on the Goodga River Fishway (50-55 mm TL) during the same period (see Figures 4 and 14) and no fish smaller than 58 mm TL were recorded in the Angove River. This suggests that either growth is faster in the Angove River or that the spawning period is earlier. The latter argument would help to explain the absence of adult *G. truttaceus* below the Angove River Gauging Station during the May sample.

There was also a pronounced increase in the number of *G. maculatus* captured below the Angove River Gauging Station during the November sample (Figure 14). The lengths of these fish ranged from 57-113 mm TL and were far larger that those found during the same period in the Goodga River (modal length 45-50 mm TL) (Figures 5 and 14). Similarly, two of the 86 *G. maculatus* captured in the Angove River were >120 mm in total length, i.e. 129 and 121 mm TL, while of the 1649 *G. maculatus* captured in the Goodga River, none was >110 mm TL and only 10 were >100 mm TL. The distinct differences in population demographics of both *G. truttaceus* and *G. maculatus* in the Angove River compared to the Goodga River have important implications not only for future fishway designs in the Angove River but also in terms of species conservation, particularly in respect to *G. truttaceus* which in Western Australia is restricted to these two systems. The differences in ecological traits of the species in each system may have been fostered through biological and thus genetic isolation or from exposure to different environmental conditions and represent discrete populations.

Similar to the Goodga River, western pygmy perch (*Edelia vittata*) in the Angove River were most abundant during spring (i.e. November) when they undertake an upstream spawning migration. Their presence below the Angove River Gauging Station in August may be the result of an early upstream migration for what is usually a fairly protracting breeding season (Pen and Potter 1991). The Angove River is the most eastern extent of the western pygmy perch.

The Angove River is also important in that it contains another rare fish species, i.e. Balston's pygmy perch (*Nannatherina balstoni*), which until this study was only known from streams and lakes west of the Goodga River (Morgan *et al*. 1995, 1998). Thus, its capture in the Angove River (Figure 14) represents a notable range extension for the species.

Balston's pygmy perch (*Nannatherina balstoni*)

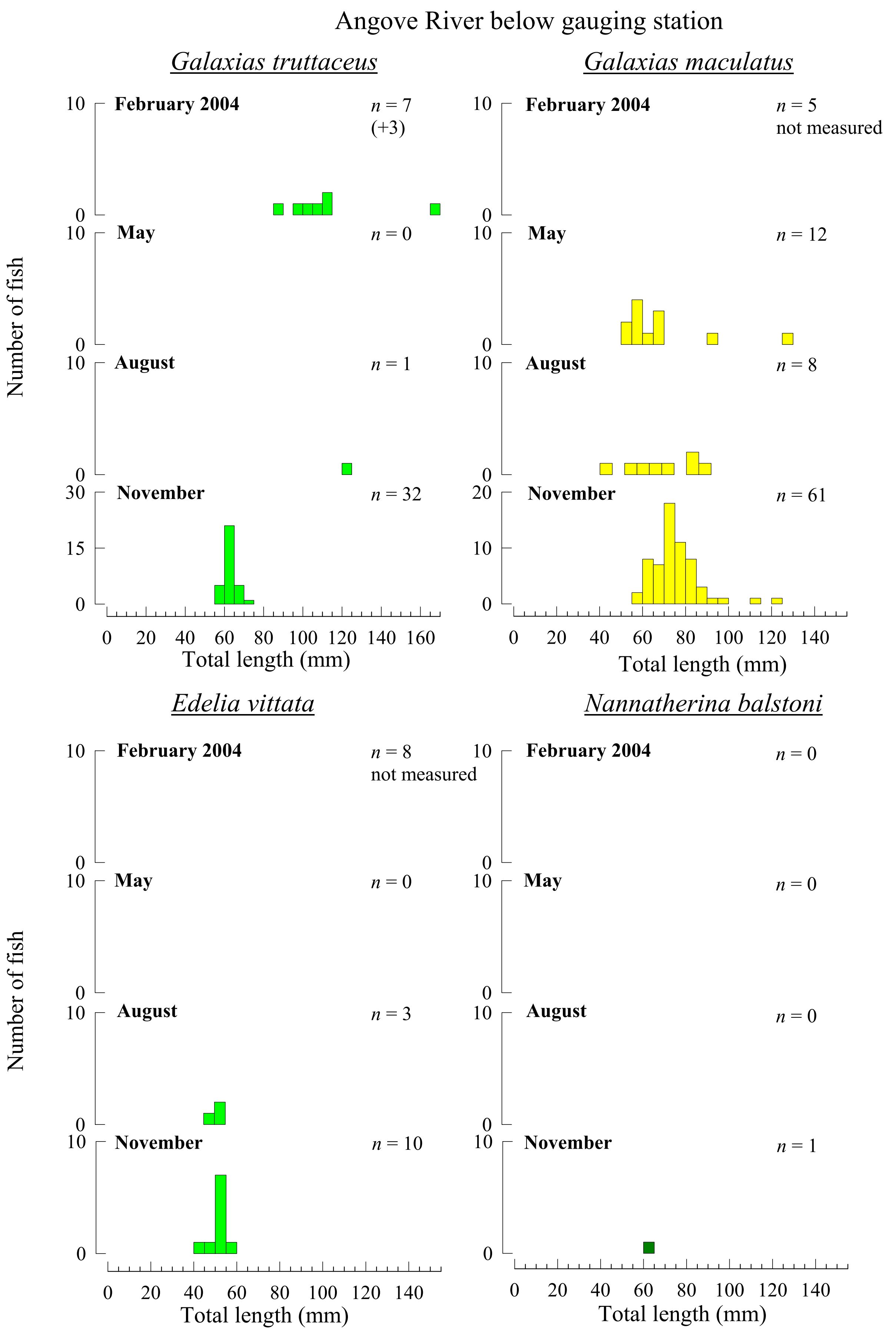

Figure 14 Length-frequency histograms of trout minnow (*Galaxias truttaceus*), spotted minnow (*Galaxias maculatus*), western pygmy perch (*Edelia vittata*) and Balston's pygmy perch (*Nannatherina balstoni*) captured below the Angove River Gauging Station in February, May, August and November 2004. N.B. *Galaxias maculatus* and *E. vittata* were not measured in February 2004.

Conclusions and recommendations

The Goodga River Fishway has effectively doubled the length of riverine habitat available to *G. truttaceus* and *G. maculatus* in the Goodga River, and the fishway was found to function not only prior to the spawning periods of these species but during the recruitment of large numbers of juveniles, i.e. for juvenile *G. truttaceus* in November and for juvenile *G. maculatus* in spring, summer and autumn (see Figures 4 and 6). Those juveniles are presumably migrating upstream from Moates Lake (see Morgan 2003, Chapman 2004). The abundance of *G. truttaceus* and *G. maculatus* upstream of the fishway increased from 0 prior to the fishway opening to 0.14 and 0.02 fish/m^2, respectively in July. The density of both species increased substantially in November to 0.33 and 0.17 fish/m^2 for *G. truttaceus* and *G. maculatus*, respectively. During sampling in February the density of both species further increased to 0.61 fish/m^2 for *G. truttaceus* and 1.69 fish/m^2 for *G. maculatus*. Further sampling suggested that the upstream population was again influenced by the massive upstream migration of juvenile fish in November 2004 before densities stabilised again in February 2005 and may have reached a carrying capacity.

Both *G. truttaceus* and *G. maculatus* were found to utilise the fishway in day-light hours rather than at night, however large *G. truttaceus* were more commonly captured at night and the mean size of *G. maculatus* on the fishway during the day was larger than during the night. The relative sizes of fish caught in the top and bottom of the fishway suggests that all size classes of both species that are found in that part of the river were able to successfully negotiate the fishway.

Edelia vittata was captured on the fishway during the day in November 2003 and 2004, a period that coincides with their spawning period. It is thus suggested that they move upstream during day-light hours during their spawning period to offset the downstream movement of resultant larvae. They were not captured upstream of the fishway suggesting that they are yet to establish a population in this part of the river.

Pseudogobius olorum was not captured on or above the fishway. This is possibly a result of the species being benthic and that the fishway entrance is elevated above the substrate.

It is recommended that the fishway be regularly checked to ensure that oblong turtles and debri are not stuck in the slots and do not impact on the ability of the fishway to function. The fishway entrance should be modified to enhance the upstream migration of *P. olorum*.

During this study large numbers of fish were found to fall over the weir wall. A substantial proportion of these were deceased but it is known whether the trap or the fall onto the concrete footing lead to their death. A simple plastic pool slide-like structure could be fitted to weir to minimise the impact of such a fall. This is extremely important in terms of larval migrations (and survival), whereby the larvae of *G. truttaceus* are known to be swept downstream and into Moates Lake.

Part of the upper Goodga River flows through agricultural land, and the catchment in this area has numerous small stock dams. There is thus the potential for exotic freshwater fish and crayfish to enter to Goodga River via these dams. It is recommended that land owners in the catchment are made aware of the rarity of the species of the Goodga River and are advised not to stock their dams with exotic fish and crayfish. These dams could be stocked with *G. truttaceus* to gauge the efficacy of their ability to breed in a 'closed' environment.

The distinct differences in population demographics of both *G. truttaceus* and *G. maculatus* in the Angove River compared to the Goodga River have important implications not only for future fishway designs in the Angove River but also in the conservation of the river's fishes, particularly in respect to *G. truttaceus* which in Western Australia is restricted to these two systems. Similar to the Goodga River, western pygmy perch (*E. vittata*) were most abundant during spring (i.e. November) when they undertake an upstream spawning migration. The Angove River is the most eastern extent of the western pygmy perch. The Angove River is also important in that it contains another rare fish species, i.e. Balston's pygmy perch (*N. balstoni*), which until this study was only known from streams and lakes west of the Goodga River (Morgan *et al*. 1995, 1998). Thus, its capture in the Angove River (Figure 14) represents a notable range extension for the species.

The population of *G. truttaceus* in the Angove River is apparently restricted to the approximate 2 km of river below the weirs and Angove Lake, a scenario similar to that in the Goodga River prior to the construction of a fishway. This, together with the importance of the Angove River to the conservation of the south-west's endemic pygmy perches, demonstrates the need to assess the suitability of the construction of fishways for the Angove River. Biological information regarding species migrations and spawning periods should be assessed to assist in ensuring that the fishway functions during important life history stages of the target species.

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APPENDIX

Morgan, D.L. (2003). Distribution and biology of *Galaxias truttaceus* (Galaxiidae) in south-western Australia, including first evidence of parasitism of fishes in Western Australia by *Ligula intestinalis* (Cestoda). *Environmental Biology of Fishes* 66*: 155-167.*

Environmental Biology of Fishes **66:** 155–167, 2003.

Distribution and biology of *Galaxias truttaceus* (Galaxiidae) in south-western Australia, including first evidence of parasitism of fishes in Western Australia by *Ligula intestinalis* (Cestoda)

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Synopsis

The freshwater trout minnow, *Galaxias truttaceus*, is restricted to the small catchments of the Goodga and Kalgan Rivers in Western Australia. Its large geographic separation from populations in south-eastern Australia, and subsequent reproductive isolation and variation in the prevailing environmental conditions, has created marked differences in biology (and morphology) between the eastern and western populations of *G. truttaceus*. The biology (spawning period, longevity, growth rates, diet and parasitism) of *G. truttaceus* in the Goodga River is described and then compared with information on the biology of diadromous and landlocked populations in south-eastern Australia (i.e. Tasmania) (see Humphries 1989). In the Goodga River, ca. 34 and 8% of males and females, respectively, attain maturity at the end of their first year, while only four mature males and one mature female 0+ fish were found in the Tasmanian populations. Adults migrate upstream prior to spawning which peaks during April and May. Larvae, which hatch at ca. 6.5 mm (cf. 7.5–9.0 mm in Tasmania), move downstream into Moates Lake for a few months before re-entering the river. Of the 810 *G. truttaceus* collected, ca. 53, 34, 10, 2, 1, 0.2 and 0.1% belonged to the 0+, 1+, 2+, 3+, 4+, 5+ and 7+ age classes, respectively. In contrast, the Tasmanian populations have a much higher proportion of older fish. At the end of their first, second and third years, the males on average attain 60, 84 and 95 mm total length (TL), respectively, whereas females attain 63, 89 and 103 mm TL, respectively at those ages. Only one fish >140 mm TL was captured, which contrasts with the Tasmanian fish, where a substantial proportion are >140 mm TL. The diet of fish >40 mm TL consisted of between 65 and 96% terrestrial fauna (mainly coleopterans and hymenopterans) in the different seasons. Larval fish diets were largely comprised of copepods.

The occurrence of the introduced cestode *Ligula intestinalis* in ca. 7% of *G. truttaceus* represents the first record of this parasite in Western Australia. It was found to cause gonadal retardation and gross morphological deformities, the latter of which possibly increases the risk of avian predation.

Introduction

South-western Australia contains only 10 species of native freshwater fish, eight of which are endemic to the region (Allen 1982). Although the biology of the eight endemic species has been studied in recent years, information on the remaining two freshwater species in this region, namely *Galaxias truttaceus* and *G. maculatus*, is minimal. Both species are widely distributed throughout southern Australia, possibly reflecting the presence of a marine larval stage in the life-cycles of the diadromous forms of these species (McDowall & Frankenberg 1981, Allen 1989). Within Western Australia, *G. maculatus* occurs in many of the coastal streams along the south coast and is often very abundant (McDowall & Frankenberg 1981, Allen 1982, Morgan unpublished data). In contrast, the trout minnow, *G. truttaceus*, is the rarest galaxiid in this region, having been collected only from a small area between Albany and Two People's Bay

(McDowall & Frankenberg 1981, Allen 1982, Morgan et al. 1998, Morgan unpublished data). Previous records of *G. truttaceus* from the Pallinup and Fitzgerald Rivers (Lenanton 1974, Hodgkin & Clarke 1988, 1989, see specimens in the Western Australian Museum) are erroneous, with examination of these specimens proving them to be *G. maculatus*. Recent surveys by the author east of Two People's Bay to Esperance (~400 km, >200 sites) also failed to capture any *G. truttaceus*, but did record extremely large numbers of *G. maculatus*.

While *G. truttaceus* is generally considered to have a diadromous life style (i.e. migrates downstream to estuaries to spawn, with larvae spending some time in the ocean), there are several landlocked lacustrine populations in central Tasmania (McDowall & Frankenberg 1981, Allen 1989, Humphries 1989, 1990). Humphries (1989) suggested that the marked contrast between the population structure, fecundities, egg size and spawning period of the landlocked and diadromous populations of this species in Tasmania was a consequence of the flexibility in such traits.

This study aimed to determine whether the Goodga River/Moates Lake population of *G. truttaceus* is landlocked or diadromous and whether biological characteristics of this population resembled those of similar populations in south-eastern Australia. Thus, the population age and size structures, growth, longevity, spawning period, gonadal development, fecundity and diet of this species is described and then, where possible, compared to those populations in south-eastern Australia.

During this study it was noted that a number of fish contained several large cestodes in their body cavity. This finding represents the first report of such an infection in the region (e.g. Pen & Potter 1990, 1991a,b, Pen et al. 1991, 1993, Hewitt 1992, Morgan et al. 1995, 2000). Furthermore, as the parasite was identified as *Ligula intestinalis* (see Results), a Northern Hemisphere cestode that can cause severe disfigurement and reproductive retardation to its host, its prevalence was determined and the possible implications of such an infection are discussed.

Materials and methods

Sampling area

The Moates Lake drainage division in the Two People's Bay Nature Reserve, situated ca. 30 km east of Albany on the southern coast of Western Australia (Figure 1), is fed exclusively by two small streams, the Goodga River and Black Cat Creek (both generally <15 m wide). The catchments of these systems are only ca. 16 and 4 km^2, respectively. Periodic connection to the Southern Ocean occurs between June and August via a series of swamplands that connect it to Gardner Lake and then drain into a narrow (<10 m wide) entrance channel (Figure 1). A sand bar blocks the entrance channel for most of the year, but is excavated by the Department of Conservation and Land Management (CALM) in early–late winter each year.

Environmental variables

The water temperature, pH and conductivity were recorded for the study sites in each month. Rainfall data for Albany was supplied by the Western Australian Bureau of Meteorology.

Sampling equipment

Fish were captured using seine nets, a larval tow net and sweep nets. The seine nets used were 1, 5, 10 and 26 m long and, with the exception of the 26 m net which consisted of a 10 m pocket of 3 mm mesh and two 8 m wings of 6 mm mesh, were each made of 3 mm woven mesh and fished to a depth of 1.5 m. The conical larval tow net had a diameter of 800 mm and consisted of 500 μm mesh.

Sampling constraints

As the population of *G. truttaceus* in the Moates Lake system clearly represents one of only a very few in Western Australia (McDowall & Frankenberg 1981, Allen 1989, Morgan et al. 1998), and as initial surveys revealed that they were present in small numbers, the governing body CALM permitted a maximum of 30 fish to be collected in each month, spread over several years. Sampling was undertaken at 6–8 weekly intervals between May 1996 and December 1997 and then monthly until September 1998. Further samples were collected in May, June and July 1999. Since a maximum of only 30 individuals were collected on each sampling occasion, the data for the different sites and the corresponding months of the different years have been pooled. Fish were anaesthetised in benzocaine and placed on ice. Larval fish, which were identified using a complete series of different-sized animals, were preserved in 100% ethanol.

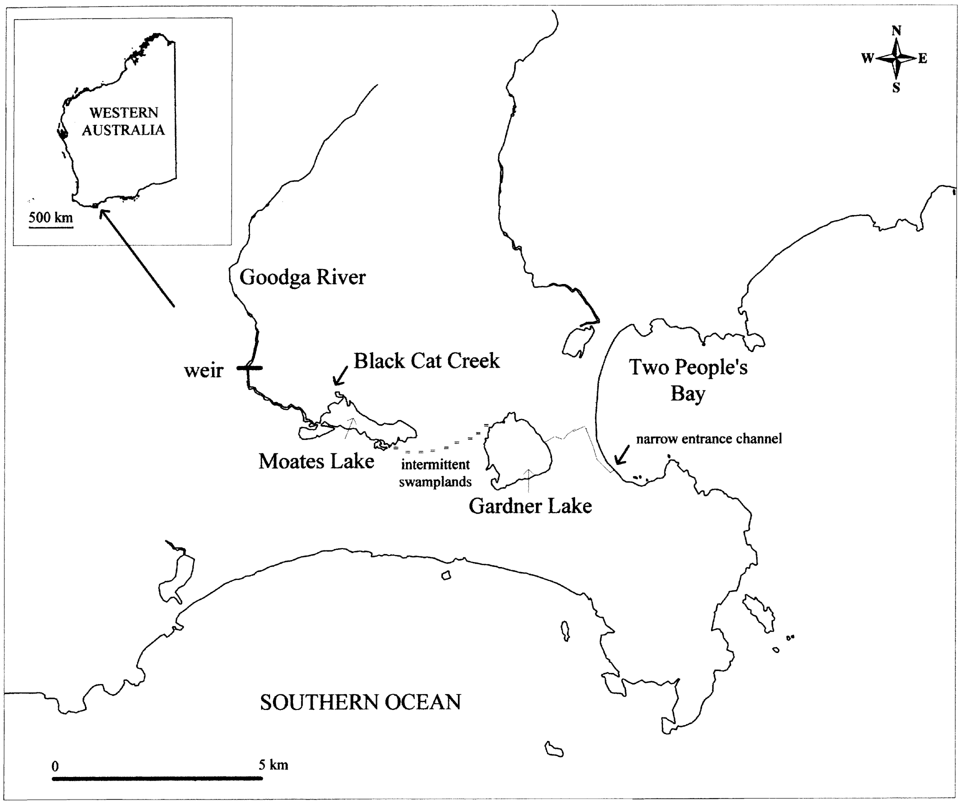

Figure 1. Sampling locations and distribution of *G. truttaceus* in Western Australia.

Biological measurements, age and growth

The total length (TL) and weight of each fish were measured to the nearest 1 mm and 1 mg, respectively. In order to allow viable comparisons between this population and those in Tasmania, where Humphries (1989) recorded standard length (SL), the SL was also measured for 40 fish of each sex and the relationship between SL and TL calculated.

The sagittal otoliths of each fish were removed and later placed in methyl salicylate and examined under a dissecting microscope at ×50 magnification. The marginal increment, i.e. the distance between the outer edge of the translucent zone and the periphery of each otolith, was measured. For otoliths with only one translucent zone, the marginal increment was expressed as a percentage of the distance between the nucleus and the outer edge of that zone, whereas for otoliths containing two or more translucent zones, it was expressed as a percentage of the distance between the outer edges of the two outer zones. Each of the above measurements was made along the same axis.

The age of fish at the time of capture was calculated using a birth date of 1st May (see Results for rationale). For each sex, von Bertalanffy growth curves were fitted to the age at length data using a non-linear technique (Gallucci & Quinn 1979) and a non-linear sub-routine of the SPSS package (SPSS Inc. 1988). The von Bertalanffy growth equation is $L_t = L_\infty[1 - e^{-K(t-t_0)}]$, where L_t is the length at age t (years), L_∞ is the asymptotic length, K is the growth coefficient and t_0 is the hypothetical age at which the population would have length zero. The lengths of the larvae and 0+ fish that could not be sexed were incorporated, on an alternating basis, into the length at age data sets used to calculate the growth curves for the different sexes.

Reproductive biology

The gonads of fish were removed, weighed to the nearest 1 mg and staged macroscopically using the morphological criteria of Laevastu (1965). The ovaries of most females were fixed in Bouin's fixative for 24 h, dehydrated in a series of alcohols, embedded in paraffin wax, sectioned at 6 μm and stained using Mallory's trichrome. These sections were used to verify both the macroscopic stages and to examine the trends in oocyte development during the year. The diameter of individual oocytes in the sections was calculated by measuring their maximum and minimum diameters through the nucleus to the nearest 10 μm and then averaged. Up to 30 randomly-selected oocytes in each section were measured (N.B. This method precludes measurement of hydrating oocytes or those in which the nucleus is migrating). The gonadosomatic index (GSI) for each fish was calculated from the equation $W_1/W_2 \times 100$, where W_1 = the wet weight of the gonad and W_2 = the wet weight of the fish.

The fecundities of six female *G. truttaceus*, immediately prior to spawning, were calculated by extrapolating from the number of mature eggs in one weighed ovary of each fish and the weight of the other ovary (N.B. The latter lobe was used for histology).

In order to determine the length at first maturity of the different sexes, a logistic equation was fitted, using a non-linear sub-routine in SPSS, to the percentages of both male and female *G. truttaceus* with gonads at stages IV–VII, in sequential 2 mm increments, during the breeding season. The logistic equation is $P_L = 1/[1 + e(-\ln 19((L - L_{50})/(L_{95} - L_{50})))]$, where P_L is the proportion of fish with gonads at stages IV–VII at length interval L and L_{50} and L_{95} are the approximate respective lengths at which 50% and 95% of the population mature.

Dietary analysis

To determine the main prey of *G. truttaceus*, the stomachs of at least 30 fish in each season were removed, the contents identified and the relative contribution of each prey type to the overall volume estimated for each season (Hynes 1950). The gut contents of a small number of larval fish from Moates Lake were also determined.

Cestodes

Cestodes within the body cavity of *G. truttaceus* were identified using the description provided by Chubb et al. (1987). The prevalence of infection and the percentage contribution by mass (% cestode weight = cestode weight/(somatic weight − cestode mass) × 100) were recorded.

Results

Environmental variables

The water levels of Moates Lake are highest in winter and early spring and lowest in mid-autumn. Both the Goodga River and Black Cat Creek are spring fed and flow throughout the year. Mean monthly rainfall for the study area between 1877 and 1998, and during the study period, followed a highly seasonal pattern, i.e. highest in winter (120–150 mm month^{-1}) and lowest in summer (12–30 mm month^{-1}). Mean water temperatures of the Goodga River and Black Cat Creek also followed a seasonal pattern with a minimum of 11.7°C in mid-winter (i.e. July), rising to a maximum of between 20°C and 23°C during November and March. The waters in the study sites are acidic (mean pH ranged from 4.2 to 6.5) and non-saline (mean conductivity ranged from 311 to 1660 μS cm^{-1}).

Age compositions and growth rates

The relationships between TL and SL of *G. truttaceus* are TL = 1.149SL + 1.622 (r = 0.995) for males, and TL = 1.171SL + 0.49 (r = 0.996) for females.

Since the number of fish containing more than one translucent zone on their otoliths was low in several months, the values for the marginal increments on the otoliths of these fish have been pooled (Figure 2). The marginal increments for these fish and for those fish with only one translucent zone declined precipitously between April and May, and then rose progressively during winter, spring and summer (Figure 2). The fact that the marginal increment declined markedly only once during the year implies that a translucent zone only forms once a year and can thus be used to age *G. truttaceus*.

The 0+ cohort first appeared in May when a number of newly-hatched larvae (mean length 6.5 mm TL) with a modal length class of 5–10 mm were captured in the Goodga River, immediately downstream of the spawning aggregation of adults (Figure 3). All of the larval fish (<25 mm TL) that were obtained in subsequent months were caught on the surface in the middle of Moates Lake using a plankton tow. The 0+ fish (>25 mm TL) captured in July were found in the shallows of the lagoon at the entrance to the Goodga River. The modal length class of the 0+ cohort subsequently increased to 10–15 mm in June and by July many were in excess of 30 mm TL (modal length classes of 20–25

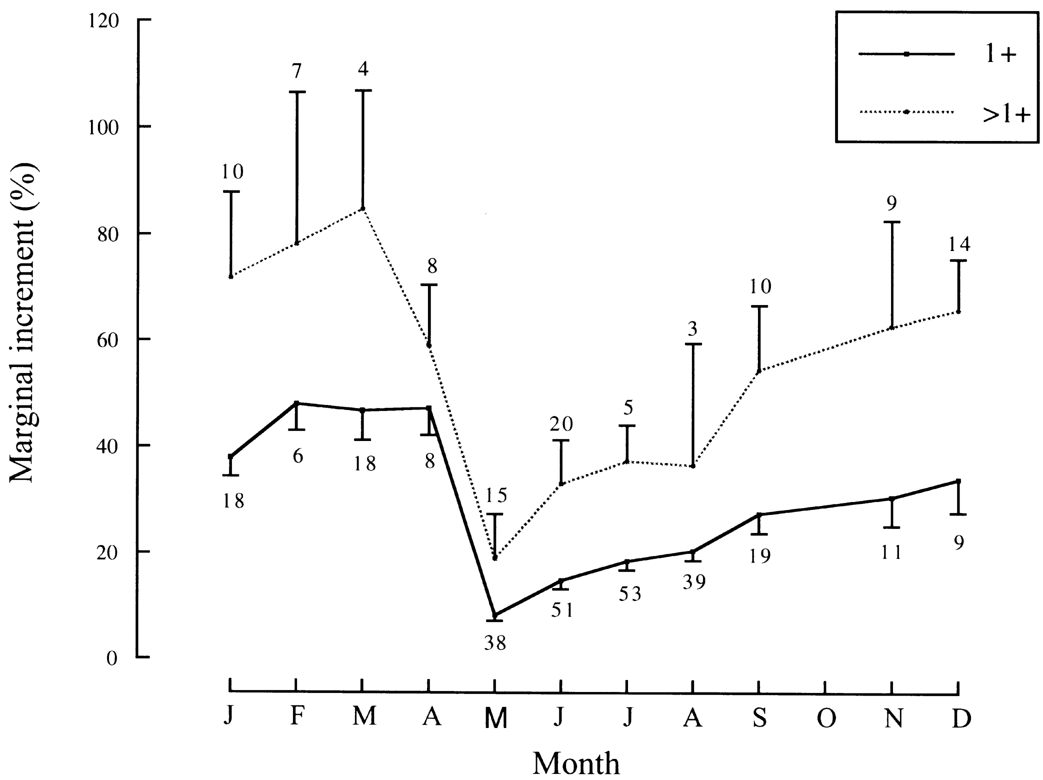

Figure 2. Mean monthly marginal increments on the otoliths of *G. truttaceus* containing 1 (−95% CI) and >1 (+95% CI) translucent zones. The sample sizes are also given.

and 35–40 mm for males, respectively and 35–40 mm for females) (Figure 3). These fish continued to grow rapidly during August and September when the modal length classes for both sexes increased to 40–45 and 50–55 mm TL, respectively. Between November and March the modal length class fluctuated between 50–55 and 55–60 mm TL. The modal length classes for the older age groups were much less defined, with overlap occurring between the 1+ cohort and most other age classes. While some of the males were found to live for over four years, two female fish over five years of age and one over seven were captured.

Of the 810 *G. truttaceus* collected during this study, 52.6, 34.4, 9.6, 2.2, 0.7, 0.2 and 0.1% belonged to the 0+, 1+, 2+, 3+, 4+, 5+ and 7+ age classes, respectively. While the overall ratio of females to males was 0.85 : 1, this ratio was 1.13 : 1 for the 0+ fish. The collective ratio of females to males for the older fish was 0.61 : 1.

The von Bertalanffy growth curve parameters for *G. truttaceus* in the study region are: $L_\infty = 118.4$ (± 3.51), $K = 0.66$ (± 0.044) and $t_0 = -0.17$ (± 0.022) for females, and $L_\infty = 106.4$ (± 2.53), $K = 0.72$ (± 0.042) and $t_0 = -0.15$ (± 0.024) for males. The marginally higher growth coefficient (K) for the males, i.e. 0.72 *versus* 0.66, reflects the fact that growth of this sex asymptotes earlier than that of the females, cf. 106.4 *versus* 118.4 mm (Figure 4). At the end of their first, second, third and fourth years of life, the males on average had reached 60, 84, 95 and 101 mm, respectively, compared with 63, 89, 103 and 111 mm, respectively for females. The largest female captured was a 7+ fish measuring 144 mm TL and weighing 17.05 g, while the largest male was a 3+ 123 mm fish that weighed 17.7 g.

Seasonal trends in gonadal development, gonadosomatic indices and fecundity

Female *G. truttaceus* with gonads at stage I or II, i.e. oocytes <100 μm and at the chromatin nucleolar and perinucleolar stage, were found in all months of the year, while fish with developing gonads (i.e. stage III, yolk vesicle oocytes 100–200 μm) first appeared

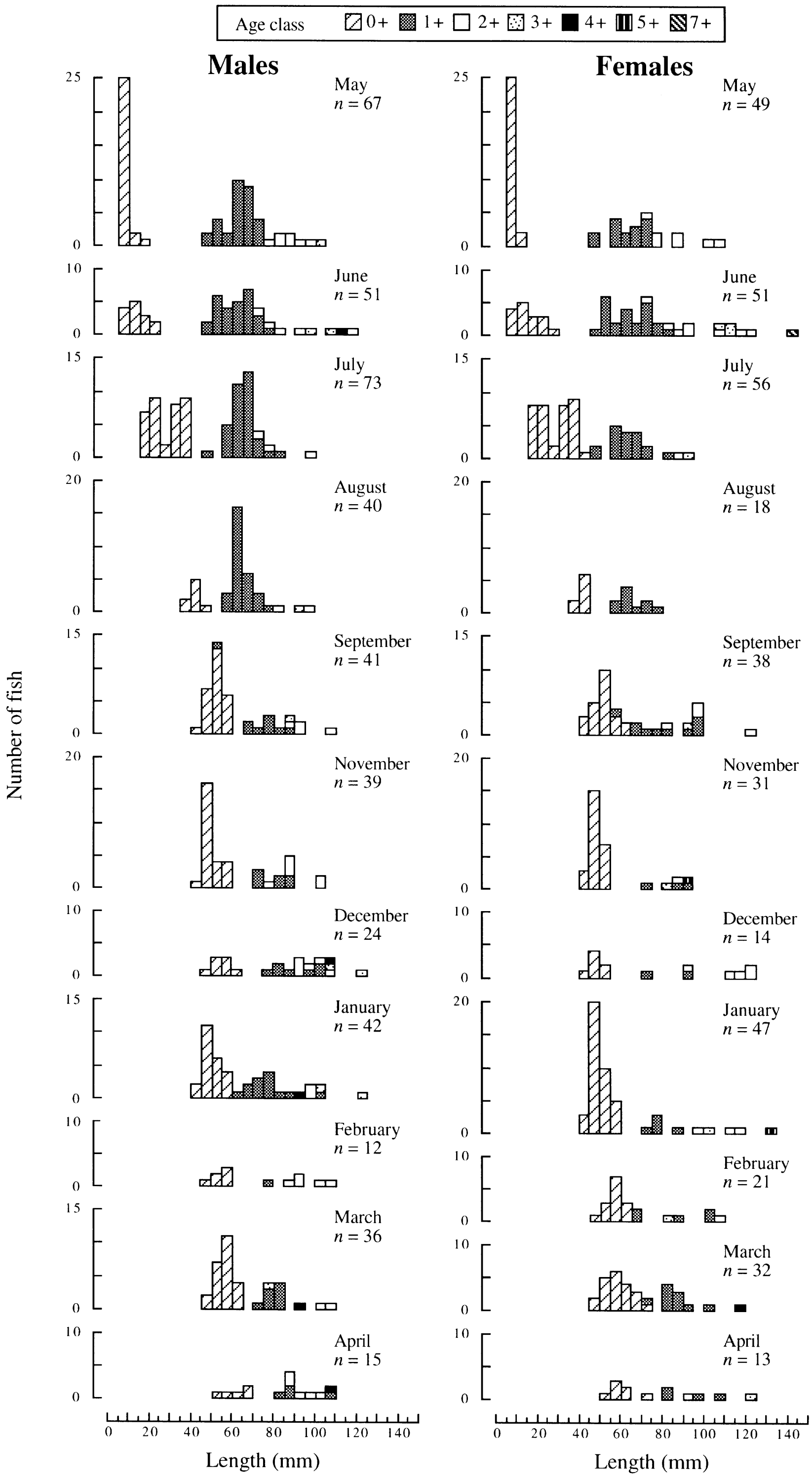

Figure 3. Length-frequency histograms of the different age classes of *G. truttaceus* captured in the different months in the Goodga River/Moates Lake system. n = number of fish.

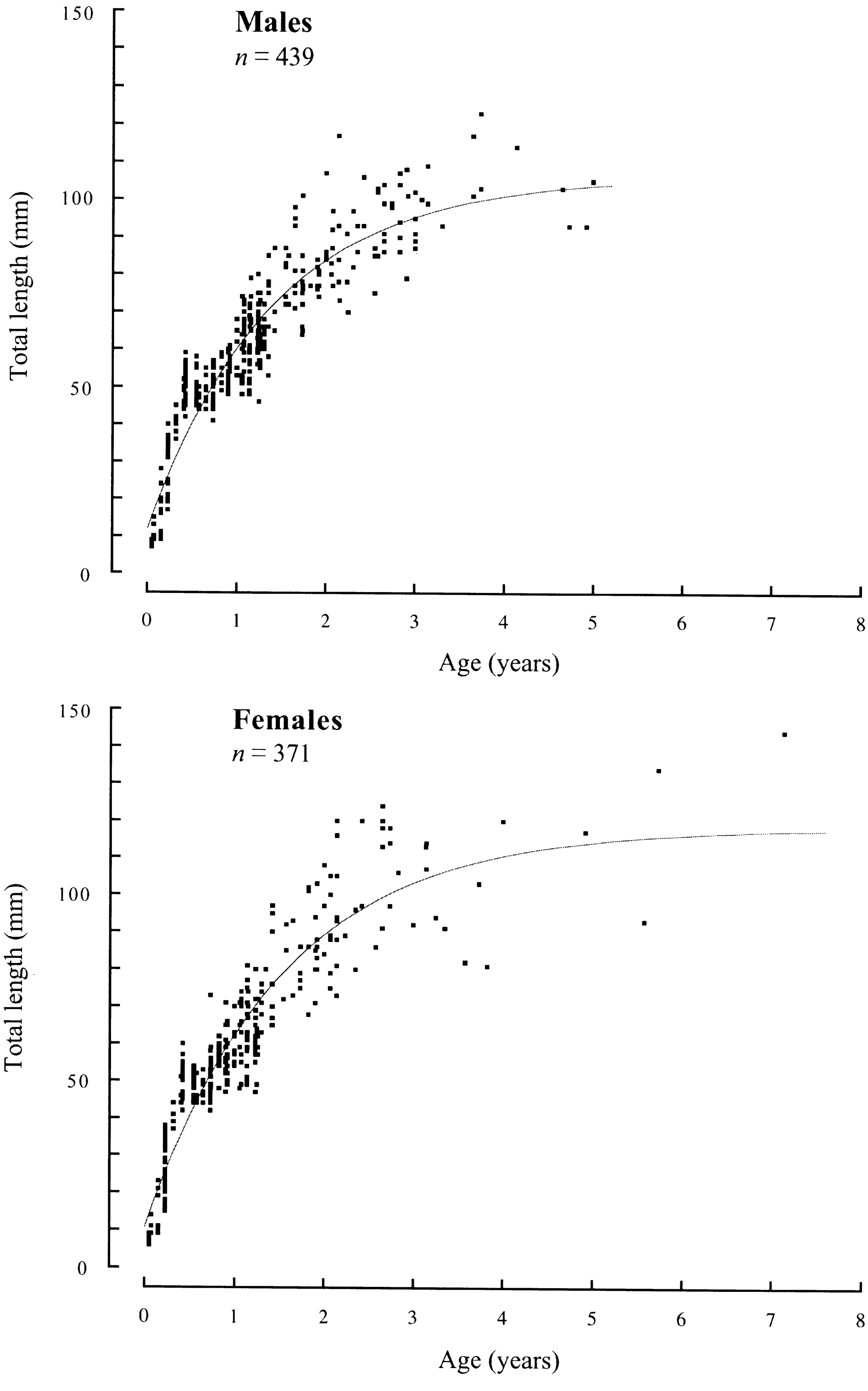

Figure 4. von Bertalanffy growth curves for male and female *G. truttaceus* captured monthly in the Goodga River/Moates Lake system. n = number of fish.

during December. Developed ovaries (stage IV) were first found in both sexes in February, while gravid (stage V) and spawning (stage VI, oocytes hydrated) fish were first found in April, when the maximum oocyte diameter had increased to 950 μm. Spent (stage VII) fish were first found in May and, except for one female in both June and July, all of the other females were either spent or at stages I/II after this month. Male gonads essentially followed the same trends exhibited by the females. The fact that only a few stage III ovaries and no stage III testes were found in March and April, suggests that once a gonad reaches stage III it will develop through to maturity.

The GSIs of both sexes have thus been calculated separately for fish with gonads at stages I/II and at stages III–VII (Figure 5). Thus, while the GSIs of many female and male *G. truttaceus* remained less than 0.5 in all months of the year, the GSIs of the maturing/mature (stages III–VII) males increased from ca. 0.2 in January to 3.5 in March and peaked at 12.3 in April before decreasing to 7.8 in May and then to 3.0 in June (Figure 5). The mean GSI of these males then rose marginally in July before again falling to below 1.0 in September and remaining at this low level for the rest of the year. The mean GSIs of the maturing/mature females followed a similar pattern, being low in January and February and then rising sharply to over 16.0 in April. The GSIs of the females then declined precipitously to <1.0 in May, before rising slightly for the next two months and then remaining low (Figure 5). The rise in GSIs in these latter months was the result of one large female in each month that had yet to release her eggs. The similar rise in male GSI in this month can be attributed to a number of mature males being found (Figure 5).

The fecundity of six fish, ranging in length from 69 to 120 mm TL (= 59–102 mm SL), ranged from 428 to 4460 with a mean of 2033. The relationship between fecundity (F) and TL was $F = 12.8174(10^{0.022TL})$ ($r = 0.976$), thus $F = 12.817(10^{0.026SL+0.011})$.

Estimate of spawning period and designation of a 'birth date'

The fact that the majority of spawning fish were first found between April and May, and all but two mature female fish captured in latter months were spent, together with the newly-released larvae being most abundant in May (Figure 3), suggests that spawning peaks between April and May. This population has thus been assigned a 'birth date' of 1st May.

Length and age at first maturity

The logistic curve, fitted to the proportion of fish with mature gonads in sequential 2 mm increments during the main spawning period, i.e. April to June, when gonads could easily be designated as immature (stages I/II) or mature (stages III–VII), yielded a L_{50} at first maturity of 73.4 mm for females and 59.4 mm for males. The lengths at which 95% of the different sexes had attained maturity were 82.3 mm for females and 99.4 mm for males.

While only ca. 8% of female *G. truttaceus* reach maturity at the end of their first year of life, over 90% attain maturity at age two. In contrast, ca. 34% of male *G. truttaceus* reach maturity at the end of their first year, while almost 80% were mature at the end of their second year.

Dietary analysis

The diets of fish over 40 mm TL in the Goodga River in each season were dominated by terrestrial fauna (Table 1). For example, during summer, autumn, winter and spring the diets consisted of ca. 96, 83, 65 and 76% of terrestrial fauna, respectively. Overall, the terrestrial fauna ingested included coleopterans (35%), hymenopterans (29%), unidentified insect parts (28%), dipterans (3%), arachnids (2%), orthopterans (2%) and aphids (1%). The other main prey types consumed include decapods (*Palaemonetes australis*), amphipods and fish (*Pseudogobius olorum*). Larval fish captured from Moates Lake fed exclusively on copepods.

Cestodes

The morphology of the plerocercoids examined resemble closely the pseudophyllidean cestode, *L. intestinalis*, described by Cooper (1918), Pollard (1974), Weeks & Penlington (1986) and Chubb et al. (1987) (Figure 6). This stage of the species is characterised by a scolex dome that is clearly bisected by a furrow extending down the length of both the dorsal and ventral sides (Figure 6, cf. SEM Chubb et al. 1987). The body bears deeply broken transverse annulations and is rounded and narrower posteriorly, while anteriorly it is often fatter and blunter.

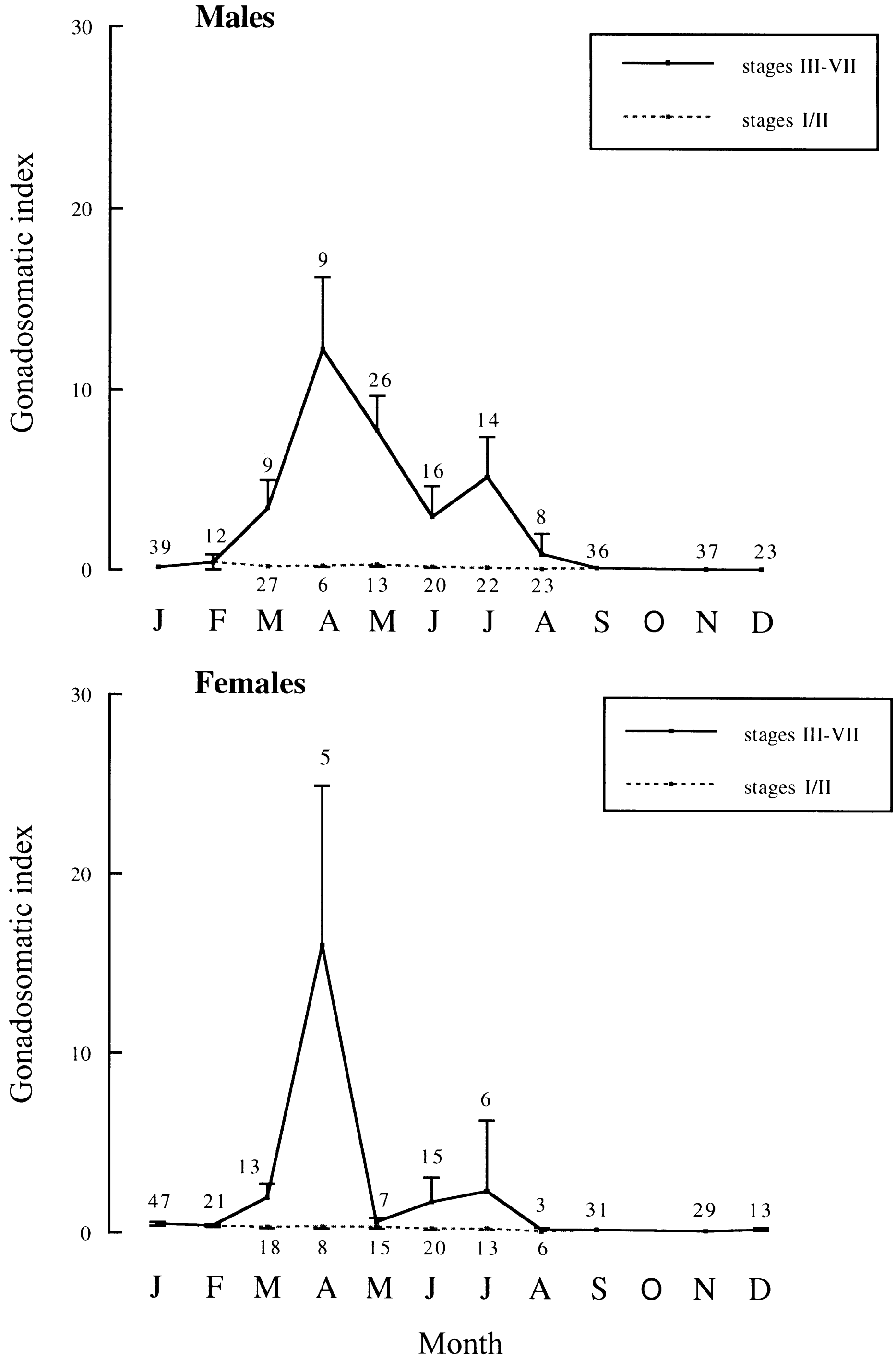

Figure 5. Mean monthly gonadosomatic indices of immature (stages I/II) (−95% CI) and maturing/mature (stages III–VII) (+95% CI) male and female *G. truttaceus* in the Goodga River/Moates Lake system. The sample sizes are also given.

Table 1. Percentage contribution (by volume) of the different prey taxa in summer, autumn, winter and spring to the diet of *G. truttaceus* in the Goodga River. n = number of fish examined.

Prey type	Summer ($n = 35$)	Autumn ($n = 52$)	Winter ($n = 30$)	Spring ($n = 30$)
Terrestrial insects	95.9	83.3	64.8	76.0
Copepoda	—	0.3	—	—
Collembola	—	0.1	2.2	2.5
Diptera larvae	—	0.5	3.9	1.3
Diptera pupae	—	1.1	0.6	6.7
Decapoda	0.2	4.2	4.0	3.8
Hemiptera	—	3.5	—	2.7
Aquatic Coleoptera	—	1.0	1.1	—
Trichoptera	—	3.0	1.1	0.8
Amphipoda	—	—	10.4	2.6
Fish	—	3.0	5.9	—
Other	0.5	—	5.6	3.5
Unidentified	3.4	—	0.4	—
Total	100	100	100	100

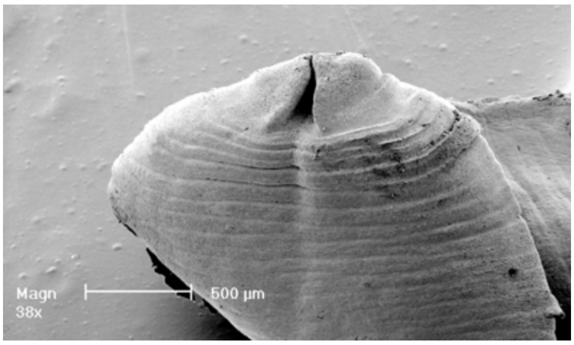

Figure 6. Scanning electron microscope (SEM) photograph of the anterior of the plerocercoid stage of *L. intestinalis*, showing scolex, annulations and furrow.

Ligula intestinalis was found within the body cavity of 44 individuals or ca. 7% of the 624 juveniles and adults dissected. The percentage contribution of such infections to the body weight of *G. truttaceus* ranged from 0.6 to 26.5%. While the maximum number of *L. intestinalis* in any one fish was 10, the mean infection rate was 1.5 cestodes in each infected fish.

No fish larger than 80 mm TL was found to be infected, with the infected fish ranging in length from 47 to 80 mm TL with a mean of 61 mm TL. Over 50% of the infected fish were <60 mm TL. On five occasions, the infections caused gonadal retardation of the host fish. Such infections often caused gross disorganisation and mutilation of visceral organs as well as massive external morphological disfiguration.

Discussion

Distribution

In this study *G. truttaceus* were found to be restricted to cool waters of the Goodga River/Moates Lake system in Western Australia, where they are landlocked. As they are confined to the cooler climatic regions of Australia, i.e. southern coast of Western Australia, Tasmania and southern Victoria, and have negligible growth during the warmer months (the period when the translucent zone on the otolith is formed), it can be concluded that *G. truttaceus* is primarily a coldwater species that is sensitive to the higher water temperatures normally encountered in most of the inland waters of south-western Western Australia. Furthermore, fish held in aquaria suffered massive mortalities when water temperatures exceeded 30°C.

The degree of separation, reproductive isolation and exposure to differing environmental conditions between the Goodga River population in Western Australia and those 3000 km away in eastern Australia has led to major differences in many of the biological parameters described below. Furthermore, in the Western Australian population, nine of the 25 morphometric characters measured by McDowall & Frankenberg (1981) represent the extremes of the ranges exhibited by all populations, whilst they also have a lower mean number of anal rays and vertebra (except for the landlocked Great Lake population in Tasmania) and a higher mean number of gill rakers than the eastern populations. Although these morphological differences may appear minor, the preliminary results of molecular studies by Gustavo Ybazeta (unpublished data) demonstrate substantial genetic divergence between the Goodga River population and those in eastern Australia, and that these genetic differences are greater than those between populations of other Australian galaxiids.

Habitat associations and diets

While juvenile and adults are largely confined to the narrow riverine environments of the Goodga River and Black Cat Creek, newly-hatched larvae were first found in the upper reaches of the Goodga River below the spawning population, which aggregates below an impassable weir (Figure 1). Larval fish are then transported to Moates Lake, where they spend the next 2–3 months feeding on the surface plankton (copepods), and at ca. 25 mm TL the juveniles move into the Goodga River where they remain. Thus, *G. truttaceus* utilises the lacustrine environment as a nursery area, feeding on the abundant copepod fauna, and then migrates back into the river system where it preys predominantly on terrestrial insects, such as coleopterans and hymenopterans, that fall onto the water surface. This high level of predation at the surface would minimise competition with the other dominant sympatric species, *G. maculatus* and *P. olorum*, which generally feed in the water column and/or on the benthos (Pollard 1973, Gill & Potter 1993, Morgan unpublished data). Resource partitioning of limited food resources in south-western Australian streams has also resulted in other species developing a high reliance on terrestrial insects, e.g. *Galaxias occidentalis*, *Galaxiella nigrostriata* and *Nannatherina balstoni* (Pen & Potter 1991a, Pen et al. 1993, Morgan et al. 1995, Pusey & Bradshaw 1996, Gill & Morgan 1998).

Comparisons of age and size compositions

The Goodga River population is dominated by 0+, 1+ and 2+ fish, with the older age classes contributing to <4% of the entire population. This contrasts markedly with the situation found in the Tasmanian populations where >50 and 30% of fish in the streams and lakes, respectively, are older than three years (Humphries 1989). Furthermore, while few Western Australian fish were >100 mm TL (∼85 mm SL), in some seasons over 50% of Humphries catches were comprised of fish larger than 100 mm TL. While Humphries (1989) captured many fish over 140 mm TL (∼120 mm SL), only one fish >140 mm TL was captured in the Western Australian population.

Gonadal development, spawning period and fecundities

While gonadal development of fish commenced in early summer, spawning occurred in mid-late autumn and was essentially completed by early winter. This situation is marginally earlier than the other freshwater species in south-western Australia (Pen & Potter 1991a,b, Pen et al. 1991, 1993, Morgan et al. 1995, 2000), but is consistent with the diadromous stream populations of this species in Tasmania (Humphries 1989). In contrast, the landlocked Tasmanian lake populations of *G. truttaceus* spawn in spring. While a decrease in photoperiod is the likely cue for the onset of gonadal development, the cue for spawning is most likely a decrease in temperature with a concomitant increase in water level. Such a conclusion agrees with Humphries (1989) for this species, and with *G. nigrostriata*, *N. balstoni* and *Lepidogalaxias salamandroides* in south-western Australia (cf. Pen et al. 1993; Morgan et al. 1995, 2000). In contrast to Humphries (1989) who found only four males and one female to mature in their first year of life in the Tasmanian populations, ca. 34% and 8% of males and females, respectively were found to mature in their first year in the Western Australian population. Thus, the lengths at first maturity (L_{50}), which is ca. 60 and 73 mm TL for males and females, respectively for the Western Australian population is smaller than the approximate L_{50} of fish in Tasmania (ca. 88 mm TL).

The fecundities given for *G. truttaceus* in Tasmania ($F = 3.362SL - 3.035$) are an order of magnitude lower than the Western Australian population ($F = 12.817(10^{0.026SL+0.011})$), however Humphries (1989) relationship appears incorrect. For example, he states 'fecundities in *G. truttaceus* ranged from 1000 eggs for a 72 mm stream fish to almost 16 000 for a 142 mm lake fish', but from his equation, a fecundity of 1000 would equate to a fish being ca. 300 mm SL. Comparisons are thus not made between the populations.

Newly-hatched larvae are considerably smaller in the Western Australian population (6.5 v 7.5–9.0 mm), as are the diameter of oocytes immediately prior to spawning (0.95 v 1.2–1.3 mm) (Humphries 1989).

Cestodes

The occurrence of *L. intestinalis* in the body cavity of *G. truttaceus* in the Goodga River provides the first record of this species parasitising fish in Western Australia. While it is known to infect numerous freshwater fish species in the Northern Hemisphere, it is only relatively recently that it has been reported from fish in the Southern Hemisphere, i.e. *G. maculatus* (48% infection) in Eastern Australia and *G. maculatus* and other species, including rainbow trout, *Oncorhynchus mykiss*, in New Zealand (Pollard 1974, Weeks & Penlington 1986). The complex life-cycle involves the adults parasitising fish eating birds, with the eggs being released from the birds, hatching and entering copepods, which are subsequently consumed by fish (Cooper 1918, Pollard 1974, Weeks & Penlington 1986). Large numbers of copepods are only ingested by *G. truttaceus* during the larval phase in Moates Lake, and since plankton trawls revealed significantly higher copepod densities in Moates Lake than in the Goodga River, it is most likely that infections occur during their first 3–4 months of life (i.e. May–August) in the lake. As no fish infected with *L. intestinalis* was >80 mm TL, it is very likely that the disfiguration caused by the parasite makes them vulnerable to avian predation, particularly when the population becomes aggregated below the small weir. This disfiguration caused to the host by the parasite, which in *G. truttaceus* was found to contribute up to 26% of the host's body weight, has been shown elsewhere to cause loss of condition and retardation of gonadal development (Owen & Arme 1965, Pollard 1974).

The low rate of infection (7%) of *G. truttaceus*, relative to the 48% of *G. maculatus* in Victoria, may indeed reflect the short lacustrine phase in the life-cycle of this species in the Moates Lake/Goodga River system. It is worth noting that preliminary data suggests that *G. maculatus*, which may remain within Moates Lake during their life, have much higher rates of infection than the sympatric *G. truttaceus*. For example, of 63 *G. maculatus* examined (for external morphological disfiguration only), 24 (or 38%) showed obvious signs of infection (i.e. gross disfigurement and heavily distorted and/or distended body cavity).

Pollard (1974) speculated that as the adult stage of *L. intestinalis* is of extremely short duration (<5 days), the most likely avenue of introduction into Australia was via an introduced fish host, where larval *L. intestinalis* may persist for over a year. Entry into the Moates Lake system may thus have occurred during brown and rainbow trout releases in the 1950s and 1960s (or from other releases into WA) or via an avian host migrating from south-eastern (or south-western) Australia.

Threats to this population

The adult *G. truttaceus* move upstream prior to spawning, with very few fish found in the lower sections of the river at this time, and form a spawning aggregation below the impassable Goodga River weir in mid-late autumn. At this time they are particularly vulnerable to predation from birds, and presumably especially so if infected with *L. intestinalis*. This upstream spawning migration is probably an attempt to offset any downstream movement of larvae, however, as the river is short, all larvae are initially transported into Moates Lake. In order to protect this rare population (species?) of native galaxiid, it is imperative that the non-native trout species, *O. mykiss* and *Salmo trutta*, or the European/redfin perch, *Perca fluviatilis*, or any other large predatory or competitive fish (e.g. mosquitofish, *Gambusia holbrooki*) are not inadvertently or deliberately liberated into the streams or lakes of the Two People's Bay Nature Reserve. Trout have previously been introduced into these waters and have elsewhere been shown to seriously impact native galaxiids, including *G. truttaceus*, through predation (e.g. Cadwallader & Eden 1982, Ault & White 1994). It is extremely fortunate previous introductions did result in self-maintaining populations.

It is important to preserve the limited habitat of this species in Western Australia, and it is recommended that the large proportion of the Goodga River that lies outside the Two People's Bay Nature Reserve should be incorporated into the Reserve. As a result of this study, the Natural Heritage Trust of Australia has provided funding to build a fish ladder at the weir which will not only open up an area of potential habitat that is presently devoid of fish, but will also reduce predation below the weir.

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