Interannual variation in fish migration patterns and habitats of the Blackwood River and its tributaries: annual progress report

July 2008

Prepared for

Department of Water
Government of Western Australia

Prepared by

Centre for Fish and Fisheries Research
Murdoch University
Perth, Western Australia

Interannual variation in fish migration patterns and habitats of the Blackwood River and its tributaries: annual progress report

Prepared for

Department of Water
July 2008

Prepared by

SJ Beatty, FJ McAleer & DL Morgan
Centre for Fish & Fisheries Research
Murdoch University
South St Murdoch
Western Australia
Email: fish@murdoch.edu.au

Acknowledgements

The authors would like to thank the Department of Water for funding this study. We would particularly like to thank Adrian Goodreid, Rob Donohue and Natasha Del Borrello for their significant contributions throughout the project. Many thanks to Ash Ramsay, Richard Pickett, Andrew Bland and Rob and Peter Muirden from the Department of Water, Bunbury for providing cross-sections, discharge and water quality data. The continued tireless field support of Andrew Rowland, Travis Fazeldean, Simon Visser, Mark Allen, David John and Trine Hansen is hugely appreciated. Most photographs by the authors except Western Hardyhead and Freshwater Cobbler by Mark Allen.

Frontispiece: Balston's Pygmy Perch, Pouched Lamprey, Nightfish and Western Mud Minnow (Photographs D. Morgan).

Summary and Recommendations

The temporal and spatial patterns of migration patterns and population demographics of fish and crayfish communities and their relationships to environmental variables of the Blackwood River and key tributaries was undertaken between 2005-2006 by Beatty *et al.* (2006). The current annual progress report provides a comprehensive update of findings from the monitoring program in the period 2005-2008; noting that the study is scheduled to be completed in mid-2010.

The overall aim of the ongoing study was to relate patterns of fish and crayfish migrations to prevailing environmental variables in the Blackwood River and describe interannual variations in these patterns. Subsequently, the study aims to use those relationships between hydrology and aquatic fauna to indicate flow requirements of key species and allow future quantification of ecological changes under variable flow regimes.

The specific aims of the study are to:

- Compare the seasonal and interannual patterns of population demographics and migrations of the fish and freshwater crayfish fauna within the Blackwood River between sections receiving different amounts of groundwater inputs.
- Compare the seasonal and interannual patterns in population demographics and migrations of the fish and freshwater crayfish within perennial and seasonal tributaries.
- Determine interannual and seasonal patterns of key environmental variables within the Blackwood River main channel sites and tributaries.
- Identify and quantify relationships between migration patterns, population demographics and the key environmental variables.
- Determine flow and habitat requirements of key indicator species from the main channel and tributaries and develop ongoing monitoring protocols to enable future quantification of potential aquatic ecosystem changes in the Blackwood River resulting from changes in hydrological regimes.

Environmental variable summary

- The greater discharge during base flow conditions in the main channel sites in early 2006 (i.e. March) compared to those experienced in 2007 and 2008 were probably the result of the above average rainfall between October 2005 and January 2006.
- The water temperature traces from the data loggers between 2005 and 2008 clearly indicate that most are highly associated with ambient air temperatures. However, Milyeannup Brook continued to maintain a less variable and lower temperature than the other tributaries.
- This was attributed to the input of the Yarragadee Aquifer groundwater that results in the buffering of the water temperature against air temperature fluctuations.

- Conductivities in the tributary sites show that Milyeannup Brook and Poison Gully generally remained fresher than the other tributaries in baseflow conditions (see also section on Milyeannup Brook Baseflow Monitoring).
- The trends in conductivity of the main channel sites clearly show the effects of the increase groundwater input due to the Yarragadee Aquifer with the Denny Road baseflow conductivity in March 2007 and 2008 ~60% fresher than those upstream of the zone. This difference was even greater than that recorded during the (relatively high discharge) baseflow conditions in 2006 when a ~40% difference was recorded.
- Continued monitoring of the physicochemical conditions in these systems scheduled for 2008-2010 will provide an extended seasonal baseline data set to allow future changes to be quantified.

Main channel summary and recommendations

Freshwater Cobbler was identified as a key indicator species of river connectivity in the main channel of the Blackwood River due to its movement over riffle zones during the baseflow period in 2006 that was apparently related to baseflow discharge (Beatty *et al.* 2006).

- The general lack of Freshwater Cobbler in the tributaries of the Blackwood River is probably due to its inability to negotiate the shallow riffle zones generally present throughout these smaller aquatic systems.
- Freshwater Cobbler upstream movement during March baseflow in the Blackwood River appears to be positively related to discharge and preliminary linear models may be used to set minimum baseflow discharges required for riffle connectivity.
- Low baseflow discharge appears to restrict the ability of larger, mature Freshwater Cobbler to negotiate the riffle zones with smaller immature individuals (<100mm TL) dominating captures in the relatively low baseflows experienced in March 2007 and 2008.
- Preliminary modelling (of Freshwater Cobbler movement and baseflow discharge in the current report) suggests that minimum March baseflow discharge required for any upstream movement of Freshwater Cobbler at Denny Road and Milyeannup Pool riffles is 391 L/sec (19 cm depth) and ~92 L/sec (5cm depth), respectively.
- From the preliminary modelling (of Freshwater Cobbler movement and baseflow discharge in the current report), reductions of ~8% and ~33% reductions from the relatively low March 2007 discharges recorded at Denny Road and Milyeannup Pool riffles, respectively, may prevent any upstream Freshwater Cobbler moving over these riffle zones.
- Ongoing sampling during subsequent baseflow conditions in 2009 and 2010 is required to both validate and strengthen these models and will allow preliminary models to also be created for the riffle zones at Gingilup and Orchid Place.
- More precise validation of these preliminary minimum flow and depth requirements of Freshwater Cobbler movements should also be tested under controlled laboratory conditions via swimming ability trials.
- A tracking program (using acoustic and radio-tracking techniques) of Freshwater Cobbler at key riffle sites would provide additional information on their habitat

use and requirements, and on their impetus to migrate between pools during baseflow conditions.
- Potential impacts on Freshwater Cobbler populations (e.g. on feeding ecology and access to spawning habitats) of periodic isolation within pools habitats also needs to be examined.

Tributaries summary and recommendations

This summary will focus on the widespread Western Minnow and the Milyeannup Brook fish fauna; a system identified by Beatty *et al.* (2006) as being of particular conservation importance. Breeding of Western Minnow, Western Pygmy Perch, Balston's Pygmy Perch and the Mud Minnow takes place in tributaries and considerable spatial, seasonal and interannual variability in the migrations of these species has been revealed.

Western Minnow

- The monthly patterns in upstream (and downstream) spawning migrations of the Western Minnow into tributaries exhibited considerable interannual variation.
- Migration into the perennial Milyeannup Brook from the main channel occurred at least one month earlier in both 2006 and 2007 than in Rosa Brook.
- Similarly, in Poison Gully, in May and June 2007, there was considerable movement into this system by the species.
- Upstream and downstream migration of Western Minnow in the tributaries during the main migration and flow period (August to December) was again positively related to the mean discharge from the tributaries; however this was less significant than the previous analysis in Beatty *et al.* (2006).
- The strength of upstream and downstream movement of the Western Minnow during this major migration period in tributaries was positively and significantly related indicating that upstream movement of Western Minnows into tributaries can be used to predict the subsequent downstream movement of the species from the systems.
- Validation of these migration and flow relationships will be possible via re-analysis with the addition of data obtained from the sampling scheduled for winter/spring 2008 and 2009.
- Currently micro-chemical examination of otoliths and water microchemistry of all tributaries and a number of main channel sites is being conducted to further quantify relative importance of the various tributaries in terms of spawning habitat.

Milyeannup Brook

- Inter-annual variation in baseflow distance in Milyeannup Brook is considerable as evidenced by a length of flow decrease from a distance of ~2500m from the Blackwood River in March 2006 down to between 1600-1800m in 2007 and 2008.
- The upstream extent of the baseflow distribution of Balston's Pygmy Perch in Milyeannup Brook is upstream distribution was consistently between Mil 4 and Mil 5 (i.e. <~1600m from the Blackwood River).

- Balston's Pygmy Perch was not recorded in riffle zones on any occasion and were only found in habitats with an average depth of >~19cm suggesting that it has a preference for pool habitats.
- Western Minnow, Western Pygmy Perch and Nightfish were generally more prevalent and concentrated in pool habitats; however, each species was recorded in riffle zones suggesting they may have the ability to occupy a wider range of aquatic habitats in Milyeannup Brook during baseflow conditions than Balston's Pygmy Perch.
- Freshwater crayfishes were shown to occupy both pool and riffle habitats with no clear preference being evident.
- It is recommended that these relationships be validated by undertaking the scheduled replicate sampling during baseflow conditions in March 2009 and 2010 and then subsequently recommend specific aquatic habitat requirements of these native fishes in Milyeannup Brook.

Contents

BACKGROUND

Fish and freshwater crayfishes of the Blackwood River

Initial descriptions of the fish fauna of the Blackwood River catchment were undertaken by Morgan *et al*. (1998, 2003)). More recently, finer scale baseline studies of fishes within and adjacent to the Yarragadee Aquifer Discharge Zone (hereafter named YADZ) were completed by Morgan *et al*. (2004) Morgan & Beatty (2005) and by CENRM (2005). A more comprehensive study that described the temporal changes in migration patterns and population demographics and related these patterns to environmental variables of the Blackwood River and key tributaries during the period 2005-2006 was undertaken by Beatty *et al* (2006). This research has largely been driven by a requirement to determine the relationships between hydrology and the aquatic fauna to indicate flow requirements and allow future quantification of ecological changes under variable flow regimes. The current annual progress report provides a comprehensive update of findings from the monitoring program in the period 2005-2008; noting that the study is scheduled to be completed in mid-2010.

To put into context the importance of the Blackwood catchment to ichthyological fauna, it is notable that it is one of only of two catchments that host all eight species of freshwater teleost that are endemic to south-western Australia (Morgan *et al*. 1998, 2003; Morgan & Beatty unpublished data). Salinisation throughout both most of the upper catchment and the main channel has led to a decline in the range of many of the salt-intolerant fishes and much of the upper catchment and main channel is dominated by salt-tolerant species (Morgan *et al*. 2003). Thus, salinisation of the catchment has seen many of the species that are not tolerant to higher salinity levels become restricted to the forested sections of the river that receive discharge from sources such as the Leederville Aquifer and Yarragadee Aquifer (Morgan *et al*. 2003, Morgan & Beatty 2005, Beatty *et al.* 2006).

Within the Yarragadee Aquifer discharge zone Beatty *et al.* (2006) demonstrated that groundwater is integral to the maintenance of populations of a number of species including Mud Minnow (*Galaxiella munda*), Balston's Pygmy Perch *(Nannatherina balstoni*) and the Pouched Lamprey (*Geotria australis*).

Aims:

The overall aim of the ongoing study was to relate patterns of fish and crayfish migrations to prevailing environmental variables in the Blackwood

River and describe interannual variations in these patterns. Subsequently, the study aims to use those relationships between hydrology and aquatic fauna to indicate flow requirements of key species and allow future quantification of ecological changes under variable flow regimes

Specific aims were to:

- Compare the seasonal and interannual patterns of population demographics and migrations of the fish and freshwater crayfish fauna within the Blackwood River between sections receiving different amounts of groundwater inputs.
- Compare the seasonal and interannual patterns in population demographics and migrations of the fish and freshwater crayfish within perennial and seasonal tributaries.
- Determine interannual and seasonal patterns of key environmental variables within the Blackwood River main channel sites and tributaries.
- Identify and quantify relationships between migration patterns, population demographics and the key environmental variables.
- Determine flow and habitat requirements of key indicator species from the main channel and tributaries and develop ongoing monitoring protocols to enable future quantification of potential aquatic ecosystem changes in the Blackwood River resulting from changes in hydrological regimes.

METHODOLOGY

Study sites

Blackwood River main channel

Site selection for determining the temporal changes in population demographics and migrations of the fish and crayfish fauna in the Blackwood River main channel was based on their differing proximities to the major zone of groundwater discharge and to the discharge measurement sites as designated by the Department of Water. For example, in 2005/2006 the fish fauna found within two sites in the Blackwood River main channel that is subjected to the major discharge of ground water (from the Yarragadee or Leederville Aquifers) was compared to two sites upstream of this discharge. In 2007/2008 this was modified to three sites subjected to discharge of groundwater, from either the Yarragadee or Leederville Aquifers, and one site directly upstream of the discharge.

The two sites within the main channel in 2005/2006 that receive groundwater input were immediately downstream of the mouth of Milyeannup Brook (referred to as Milyeannup Pool) (34.0909°S, 115.5661°E) and just upstream of the mouth Rosa Brook (referred to as Denny Road) (34.1081°S, 115.4505°E). Additionally, Gingilup (34.10445°S, 115.51947°E), which is gauged by the Department of Water, was included. The two upstream sites were Jalbarragup Road crossing (34.0421°S, 115.6025°E) and Quigup (33.9736°S, 115.7008°E) in 2005/2006. In 2007/2008 monitoring ceased at Quigup in favour of a compilation of three sites in close proximity; namely Darradup during March 2007, Jalbarragup Road Crossing (as above) from March to November 2007 and Orchid Place in March and April 2008 (see Figure 1).

Sampling was conducted in October, November and December 2005; February, March, June, August and September 2006; March, May, June, August, September, October, November and December 2007 and March and April 2008. Sampling is scheduled to continue until mid 2010.

Blackwood River tributaries

A number of tributaries were similarly monitored for comparison of the aquatic fauna with both each other and the main channel. These include Milyeannup Brook, Poison Gully, Layman Brook, Rosa Brook, McAtee Brook and St Johns Brook. Milyeannup Brook and Poison Gully are directly maintained in dry months (summer/early autumn) by groundwater discharge from the Yarragadee Aquifer. Layman Brook receives groundwater discharge from the Yarragadee Aquifer during winter and spring but not summer; when it ceases to flow and usually dries. The temporal changes in the population demographics and migrations of the fish and crayfish fauna within these tributaries were compared with two adjacent tributaries that flow seasonally, i.e. Rosa Brook and McAtee Brook which are within the Leederville Aquifer discharge zone . In addition, St Johns Brook, which is situated within the Leederville Aquifer discharge zone, was seasonally sampled in June and November 2007 and June 2008.

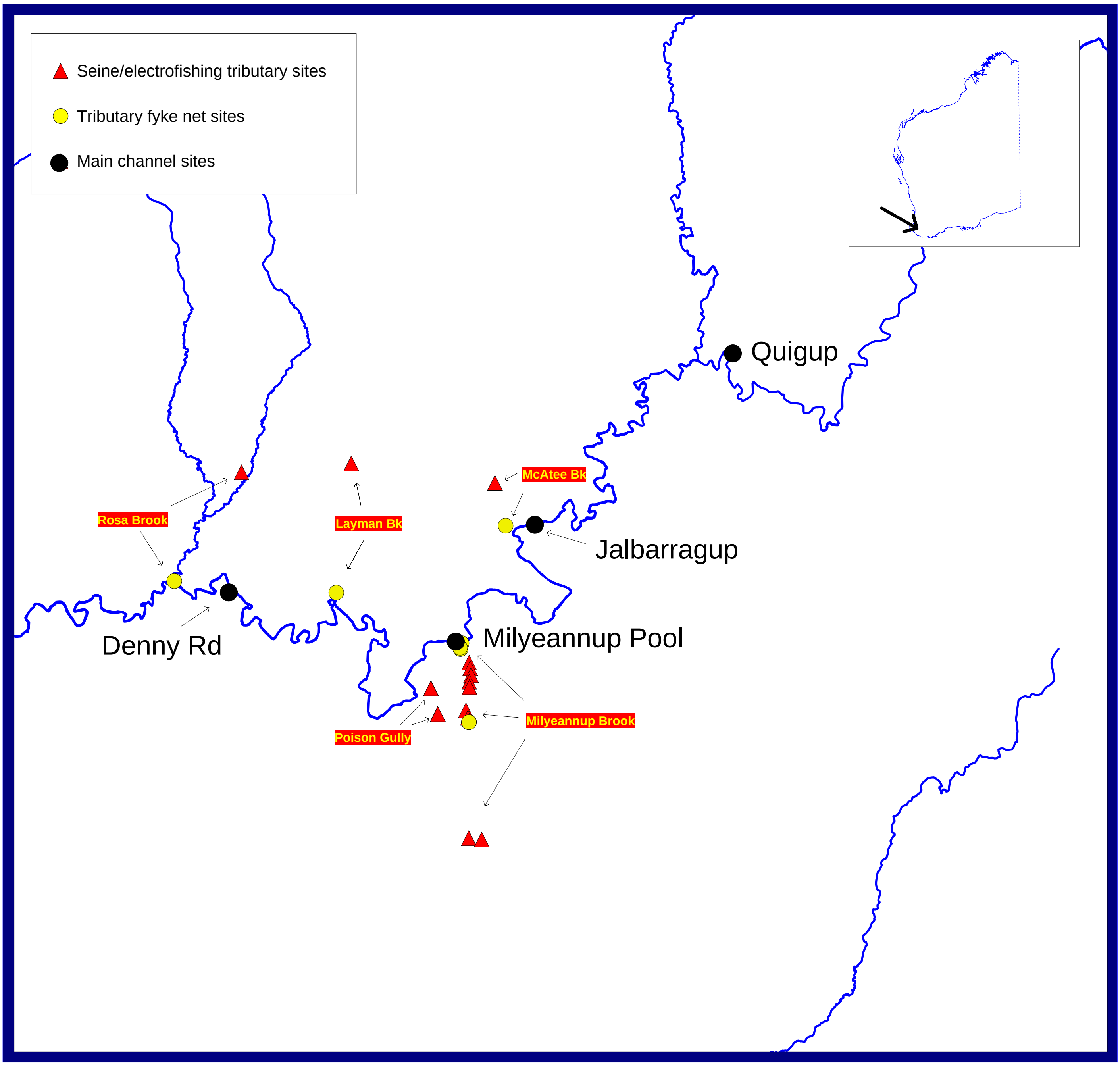


Figure 1 Sampling sites in the main channel and tributaries of the Blackwood River.

Environmental variables

Water quality monitoring

As with the previous report for the 2005-2006 sampling period (i.e. Beatty *et al*. 2006), the climatic regime for the entire sampling period (2005-2008) were obtained for the Australian Bureau of Meteorology for Bridgetown (where long-term data is available). These patterns in rainfall and temperature were compared to long term data to provide indications of variability or consistency of the climate during the sampling period with that typically observed for this region. The prevailing rainfall has particular implications for influencing surface flow regimes of the study sites.

Temperature data loggers (*Tinytag*™) that were in place previously at all tributary and main channel sites (see Beatty *et al*. 2006) were periodically downloaded and replaced as necessary when battery life was exhausted or they were lost (possibly due to vandalism). Data from the loggers were downloaded and temperature regimes of the various aquatic systems were graphically compared.

On each sampling occasion at each site, *in situ* measurements of temperature (in addition to the temperature data loggers), conductivity, pH, and dissolved oxygen were obtained from the middle of the water column at three locations at each sites and a mean (± 1 SE) determined.

Discharge, baseflow riffle profiles and stage-height relationships

Monthly instantaneous discharge measurements were undertaken in all tributary sites sampled between October 2005 and April 2008. These estimates were taken by Department of Water (Bunbury branch) staff at the approximate times that sampling took place for fish migrations.

Mean monthly main channel discharges were obtained from the Department of Water gauging stations at Nannup, Darradup, Gingilup and Hutt Pool. The monthly discharges for Milyeannup Pool and Denny Road (i.e., those without adjacent gauging stations), were estimated using both the instantaneous measurements taken during baseflow months in 2007 and 2008 (as part of the cross-section profiles, see below), and by interpolation of monthly discharges from the readings at the other gauging stations (monthly conversion formulas were applied in consultation with Ash Ramsay Department of Water, Bunbury).

Riffle zones, at the downstream end of the Darradup, Gingilup, Milyeannup Pool and Orchid Place, were identified as potential barriers for upstream migration of Freshwater Cobbler during periods of low flow. In order to estimate minimal flow requirements of the Freshwater Cobbler in the main channel of the Blackwood River, base-flow cross-sectional profiles (two or three, depending on the longitudinal riffle profile) were taken across the riffle zones at Denny Road, Gingilup, Milyeannup Pool and Darradup riffle zones in March and May in 2007, and March and April in 2008; coinciding with sampling of base-flow fish movements at those riffles. These cross-sectional profiles, and the Water Stage Levels on each of the four sampling occasions, were plotted to allow the determination of minimum riffle depths that Freshwater Cobbler were able to negotiate by determining if they were moving over the riffles at those times. The relationships between the baseflow discharge and stage height at each riffle zone were determined by fitting curves to the scatter-plots.

Using the relationships between discharge and upstream movement of Freshwater Cobbler over three subsequent baseflow periods (i.e. March 2006, 2007, 2008) at Denny Road and Milyeannup Pool, the discharge and stage heights at each riffle, and the depths across the profiles at different stage heights, estimates of the minimum discharge and riffle zone depths for upstream Freshwater Cobbler movement were determined (see methodology section on Relationship between Freshwater Cobbler and baseflow discharge).

Fish and crayfish monitoring

A number of techniques were employed to examine the fish and crayfish fauna of the main channel and tributary sites in the Blackwood River. Each method is outlined below, i.e. the use of fyke nets (11.2 m in width, including two 5 m wings and a 1.2 m wide mouth fishing to a depth of 0.8 m, 5 m long pocket with two funnels all comprised of 2 mm woven mesh); seine nets (5, 10 and 15 m nets comprised of 2 mm woven mesh and a 26 m seine net consisting of two 9 m wings of 6 mm woven mesh and an 8 m bunt of 3 mm mesh); 240 and 12 v electrofishers; and crayfish traps during 2005/2006. During the 2007/2008 sampling concentrated on emerging trends in migration patterns and utilised fyke nets. Additional fyke nets designed specifically for Poison Gully and St John's Brook were also employed.

Blackwood River main channel

Species migrations

At the main channel sites (see Figure 1), fyke nets were used to determine temporal trends in species migrations. Fyke nets were set facing upstream, to determine downstream movements of fish, and facing downstream, to determine upstream movements of fish. Each fyke net was set for a period of 72 hours and sampled every 24 hours.

Each fish and freshwater crayfish captured was identified, a sub-sample measured (total length (TL) for fish and orbital carapace length (OCL) for crayfish) to the nearest 1 mm and where possible sexed and released. A subsample of most species was retained for analyses of biological indices such as gonadal development and aging, some of which are provided in this report, but most of which are to be investigated further.

The mean number of each species captured on each occasion was adjusted to account for total number of each species migrating through a section of the river. The total numbers referred to here on in are the actual numbers captured, while the migration figures reflect the adjusted data to show the approximate numbers of fish actually migrating and to thus allow for comparisons between the various riverine reaches.

Blackwood River tributaries

On each sampling occasion (during stream flow), fyke nets were set over 72h in Milyeannup Brook (two sites). Additionally, Layman Brook, Rosa Brook, McAtee Brook and Poison Gully (Figure 1). St Johns Brook was sampled seasonally i.e. June and November 2007 and March and June 2008. At each site, one net was set facing upstream, to capture fish that were moving downstream, while another was set facing downstream (to capture fish moving upstream) and each was checked every 24 hours. As with the main channel site captures, the percent coverage of each set was determined and the catches later adjusted to 100% of the stream width.

The shallow, diffuse nature of Poison Gully required smaller fyke nets. These were used elsewhere, but still consisted of 2mm woven mesh. The same methodology i.e. three, 24h sets was utilised with these modified fykes. Fish species were identified, with a large sub-sample measured for total length (mm TL) for fish and orbital carapace length (mm OCL) for freshwater crayfish before being released. Those not measured were identified and counted to determine total numbers and immediately released. A small sub-sample of native species was retained for biological investigation into the gonadal development (up to ~30 per month) and for genetic analysis (see Phillips *et al*. (2007) for *Nannatherina balstoni* and *Galaxiella munda*).

Freshwater crayfish were identified, measured to the nearest 1mm OCL, sexed and released. A small number were retained for determination of size at sexual maturity.

Relationships between fish movement and environmental variables

The analysis undertaken followed closely that described in Beatty *et al*. (2006). Regression analysis was undertaken for a number key species in the tributaries, and for the Freshwater Cobbler in the main channel (the species identified as an appropriate indicator of river connectivity due to the apparent relationship to baseflow discharge by Beatty *et al.* (2006)). The current analysis included additional migration periods for the tributaries (August to December 2007) and main channel (see below for details) reflecting the extended sampling period from the previous analysis (i.e. from 2005-2006 *cf.* 2005-2008). Freshwater Cobbler movement pattern analysis was also refined via specific sampling of key riffle zones during baseflow and also undertaking complementary hydrological data including cross-sectional profiles and discharges at those monitoring sites (courtesy of the Department of Water, Bunbury). This was aimed at estimating the flow requirements to maintain migratory ability through key riffle zones during base-flows.

The robustness and predictive ability of the relationships and models presented will be enhanced via the additional sampling scheduled for 2008-2010.

Tributaries

Overall analysis

As with the 2005-2006 analysis in Beatty *et al*. (2006), the fishes included in analyses were those where adequate migration data were recorded (i.e. utilised the most number of tributaries). These species included the Western Minnow, Western Pygmy Perch and Nightfish. The relationships between the upstream and downstream movement of the above species during the major flow and breeding periods (i.e. the period that all four tributaries were flowing, August to December 2005-2007) and the prevailing environmental variables in Milyeannup Brook, Rosa Brook, McAtee Brook, and Layman's Brook were determined (see Beatty *et al*. (2006) for details of the specific statistical analyses).

Milyeannup Brook baseflow monitoring

Finer scale monitoring of fish and crayfish populations and environmental variables along Milyeannup Brook was undertaken at those sites previously examined during baseflow conditions in 2006 (see Beatty *et al*. 2006 for the location of the sites in Milyeannup Brook). Sampling took place in March 2007 and 2008 and involved examination of fish and crayfish distributions within habitat types at key sites, and also the measurement of hydrological characteristics within those broad habitat types present (i.e. pool and/or riffles) at each of those sites. This aimed to determine preliminary habitat preferences of each species during baseflow conditions in Milyeannup Brook.

On each sampling occasion at Mil 3 (just upstream of Brockman Hwy), Mil 4, Mil 5, and Mil 6 (limit of surface water in both 2007 and 2008), fish and freshwater crayfish densities were determined in up to three habitat types (pool and riffles where present) at each site using double pass electrofishing with each habitat sectioned off using stop nets. All fish were identified and measured to the nearest 1mm TL (fish) or OCL (crayfish) and a density determined by measuring the area of the habitat between the stop nets. Densities of each species within each habitat in baseflow conditions in 2007 and 2008 were graphically compared.

Depth profiles were taken across three cross-sections and along one longitudinal-section on each occasion. Mean and maximum depths of both section type in each habitat and also each habitat overall was determined and displayed graphically. The instantaneous discharge at each site (where flow was evident) was determined on both occasions via measuring channel width, depths and flows rates (using a hand-held flow meter). Mean water temperature, conductivity, pH, dissolved oxygen, and turbidity were also determined for each site.

In order to determine whether relationships existed between the depth of baseflow habitats in Milyeannup Brook and the density of species occupying those habitats, preliminary linear regression analysis was conducted between these variables and scatter-plots generated.

Main Channel

Freshwater Cobbler movements and environmental variables: 2005-2008

The association between the strength of upstream and downstream Freshwater Cobbler movements and the above key environmental variables were examined over all sampling occasions to determine whether those relationships determined by Beatty *et al*. (2006) were maintained using a greater dataset. For overall sampling time analysis, all sampling occasions at all sites were included in stepwise regression analysis to determine which of the environmental variables best explained the variation in upstream or downstream Freshwater Cobbler movements in the Blackwood River main channel.

Subsequently, mean movements of Freshwater Cobbler in the main channel sites, pooled for the major migration periods (i.e. in this case between December-April 2005-2006, and December-April 2007-2008), were similarly related to mean environmental variables during those periods. These relationships therefore allowed direct comparison to those previously determined using the single 2005-2006 summer/autumn period by Beatty *et al*. (2006).

Freshwater Cobbler and baseflow discharges
Determining minimum discharges and riffle depths for upstream movement of Freshwater Cobbler (which was identified as an indicator species of river connectivity) was achieved using both migration and hydrological data (see previous section on discharge and base-flow riffle profiles) gathered at two riffle sites in the main channel of the Blackwood River. The month with the consistently lowest discharge (i.e. March, see results section) was chosen for this analysis in order to provide minimum flow and depth requirements. It should be noted that the reliability of these calculations will be enhanced by subsequent scheduled sampling in March 2009 and 2010 as this will increase the number of years sampled from three to five for the Denny Road and Milyeannup Pool riffles, and also allow the inclusion of additional riffle zones at Gingilup and Orchid Place (for which only two and one March sample, respectively, have thus far been taken).

The relationship between mean upstream movements of Freshwater Cobbler and discharge at the four riffle zones in March 2006 (Denny Road and Milyeannup Pool riffles only), 2007 and 2008 were determined using regression analysis (it should be noted that these regressions have limited power due to sample sizes of only three per riffle). The relationships determined for Denny Road and Milyeannup Pool riffles were then used to determine the discharge at which the model would predict movement to be zero (i.e. rearranging the model when movement equalled zero to determine discharge).

The zero-movement discharge estimates were then used to determine the minimum depth across each riffle that the Freshwater Cobbler movement would hypothetically cease. This was achieved by first using the non-linear relationships of stage height and discharge at each riffle (see previous section on discharge and base-flow riffle profiles) to determine the stage heights at those zero-movement discharges. These zero-movement stage heights were then plotted on the cross-sections of the riffle zone to determine the maximum depths (deepest passage) that would be present at those minimum discharges. The shallowest maximum cross-sectional depth was inferred to represent the depth at which Freshwater Cobbler would cease to be able to move upstream over these riffle sections in the Blackwood River.

Freshwater Cobbler population analysis
In order to further examine patterns in migrations of Freshwater Cobbler, a total of 437 were tagged using individually numbered t-bar tags at each main channel site over the study period (see Table 2). The total length of each fish tagged and recaptured was measured to aid in the future validation of growth and movements of this species. Furthermore, in each month of the

main migration period (late spring – early autumn, see Figure 20), the gonadosomatic index (GSI) was calculated for both sexes. This index compares the proportion of the gonad to the overall body weight to determine spawning periods as a precipitous decline in the GSI is generally used to indicate the period of peak spawning. First the gonads of each fish are removed and weighed to the nearest 1 mg. The GSI is then calculated for each fish from the equation $W_1/W_2 \times 100$, where W_1 is the wet weight of the gonad and W_2 is the wet weight of the fish.

The length at maturity of the population of Freshwater Cobbler in the Blackwood River main channel was determined by comparing the length and gonad stage of females during the spawning period. Gonads are identified and assigned as either ovary or testis on the basis of their morphological appearance, to one of the seven maturity stages i.e. I - virgin, II - maturing virgin or recovering spent, III - developing, IV - developed, V - mature or gravid, VI - spawning and VII - spent (Laevastu (1965)). The logistical regression equation: $P_L = 1/(1+e^{-\ln 19(L-L_{50})/L_{95}-L_{50}})$, is then applied to the percentage of individual mature females and (ovarian and testes stages III-VII) grouped into 10 mm TL increments. The data is then randomly re-sampled and reanalysed to create bootstrap estimates. The medians of these estimates are used as the point estimates for parameters and the probability of maturity at each length category. The bootstrap estimates also determine the 95% confidence limits (CL) of the parameters. From this data it is then possible to determine both L_{50} and L_{95}, or the size at which 50% and 95% of the population is mature.

RESULTS and DISCUSSION

Water quality and discharge regimes in the main channel and tributaries

Examination of the climatic conditions in the Blackwood River study area (Figure 1), it is evident that the 2005-2006 sampling period was typified by above average spring 2005 to summer 2006 rainfall with a delayed onset of major winter rainfall in 2006. During the same period in 2006-2007, the reverse occurred with a well below average spring and early summer rainfall followed by variable rainfall in later summer and autumn 2007 (Figure 2). The very low late spring and summer rainfall in the 2007-2008 period was also notable.

The greater discharge during base flow conditions in the main channel sites in early 2006 (i.e. March, see Figures 3, 4, 5 & 6) compared to those experienced in 2007 and 2008 were probably the result of the above average rainfall between October 2005 and January 2006. This also corresponded with much stronger movement of Freshwater Cobbler during the baseflow conditions in 2006 compared with the subsequent two years (see Figure 17 and section on Relationship between Freshwater Cobbler and baseflow discharge).

The water temperature traces from the data loggers between 2005 and 2008 clearly indicate that most are highly associated with ambient air temperatures (Figure 8). However, along with the instantaneous water temperatures at the times of sampling in the tributaries (Figure 7), demonstrated that Milyeannup Brook maintained a less variable and lower temperature than the other tributaries (Figures 7 and 8). This is attributed to the input of the Yarragadee Aquifer groundwater that results in the buffering of the water temperature against air temperature fluctuations. That is, this system maintains cooler water temperatures during the baseflow period and is warmer during the winter period (see also section on Milyeannup Brook Baseflow Monitoring). Poison Gully, although also maintaining permanency due to aquifer discharge, does not display this buffering effect; probably due to the streams morphology in that it is a wider, shallower and more diffuse stream line which would increase the influence of air temperature.

Main channel water temperatures upstream and downstream of the major aquifer discharge zone (i.e. Denny Road and Milyeannup Pool, Figures 7 & 8) did not differ during baseflow period as may have been expected. This was probably due to the effect of external heating of the cooler aquifer water as it flows downstream offsetting the lower temperature of the aquifer water.

Conductivities in the tributary sites show that Milyeannup Brook and Poison Gully generally remained fresher than the other tributaries in baseflow conditions (see also section on Milyeannup Brook Baseflow Monitoring) (Figure 9). Those tributaries that cease to flow and pool during baseflow (i.e. St John’s Brook, Rosa Brook and McAtee Brook) showed elevated salinities during baseflow due to evapoconcentration of salt without fresh groundwater input; however, all remain fresh throughout the year. Although Rosa Brook dries and exhibits elevated salinities at the Denny Road sampling site, further upstream at the confluence of Rosa Brook and Mowen Road permanent flowing water is located. It is recommended that the Mowen Road site is sampled and compared to the Denny Road site as the permanent flow, and

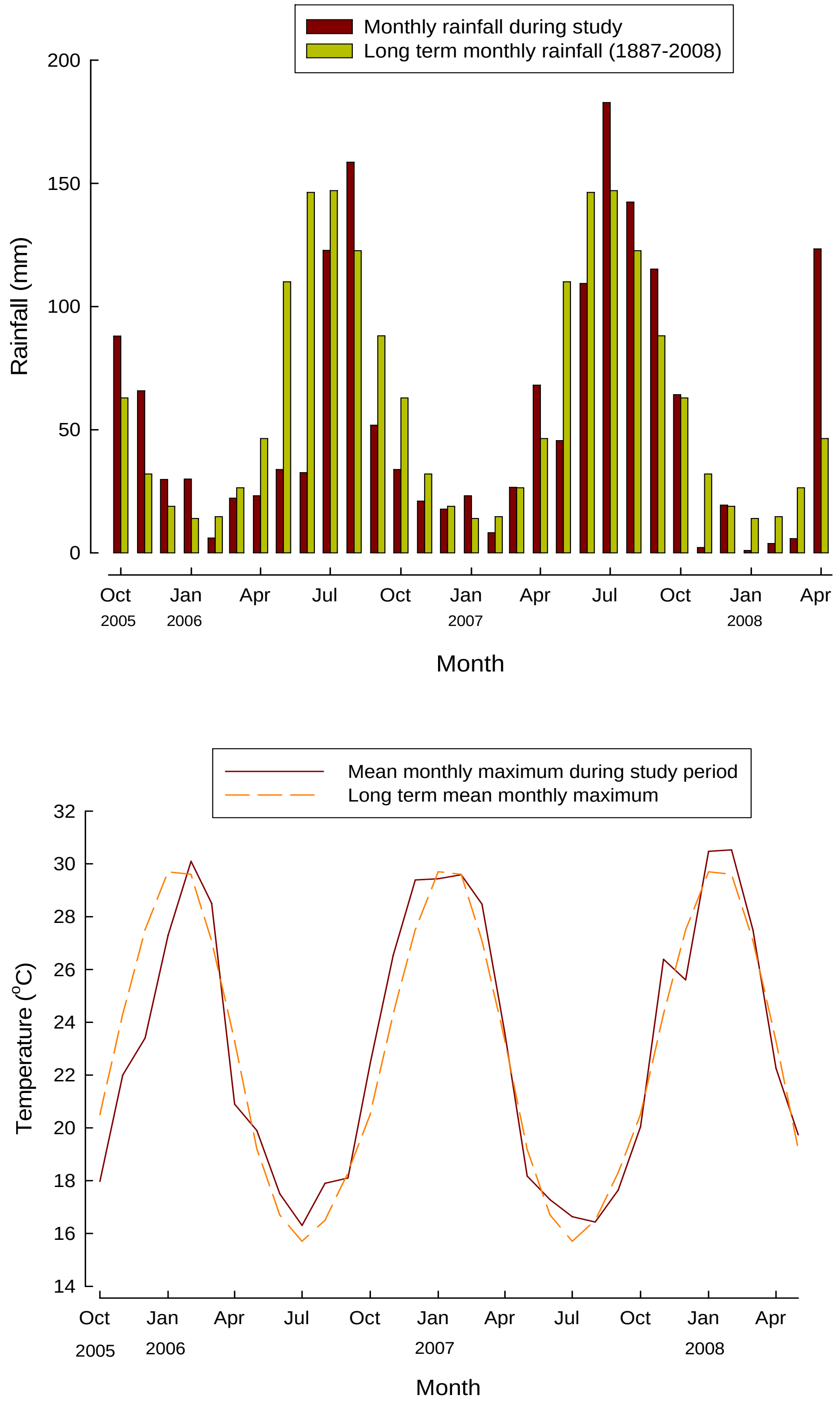


Figure 2 Mean monthly rainfall (top) and maximum air temperatures (bottom) during the study period and long term averages (from Bridgetown). Data from Australian Bureau of Meteorology.

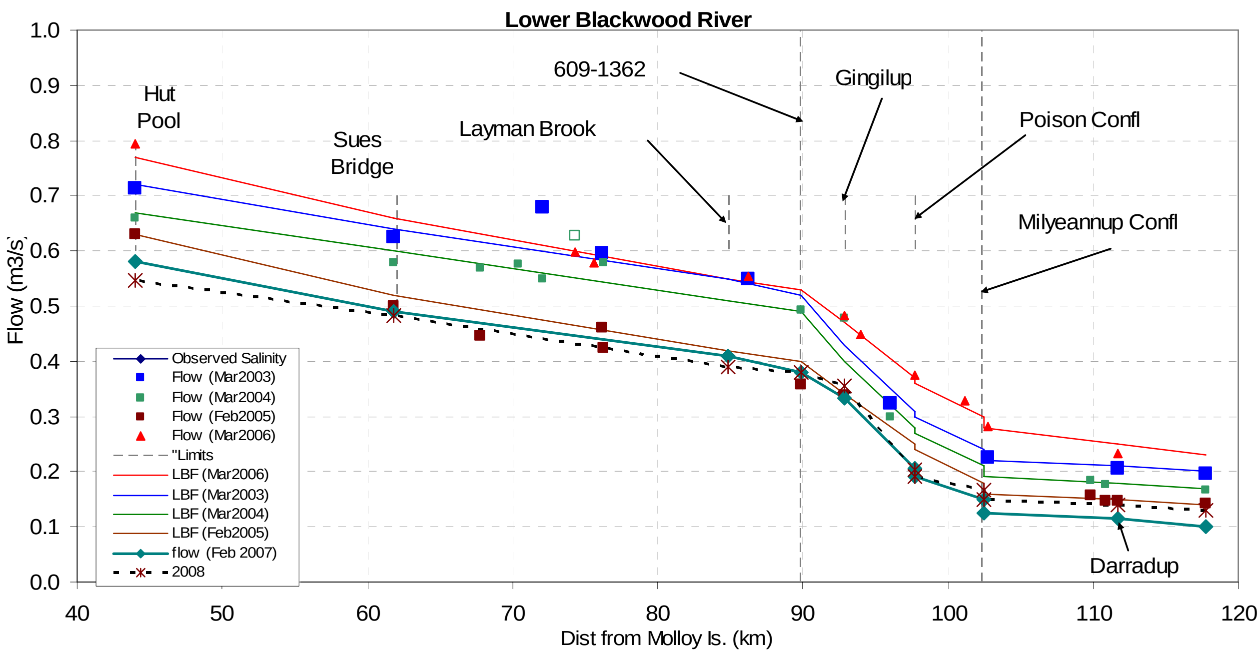


Figure 3 Consecutive annual baseflow longitudinal discharge traces in the main channel of the Blackwood River in March (2003-2008). N.B. the relatively high baseflow discharge in March 2006 compared to 2007 and 2008. (Figure from Department of Water, Bunbury).

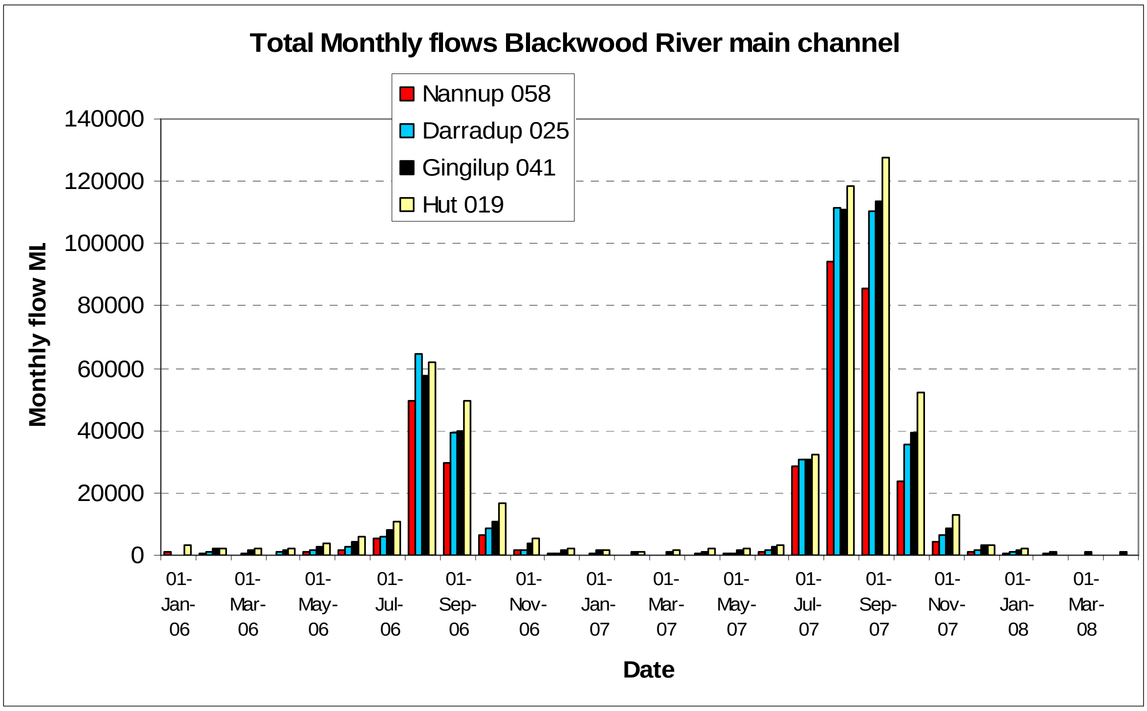


Figure 4 Total monthly flows at sites in the main channel of the Blackwood River from January 2006 to March 2008. (Figure from Department of Water, Bunbury).

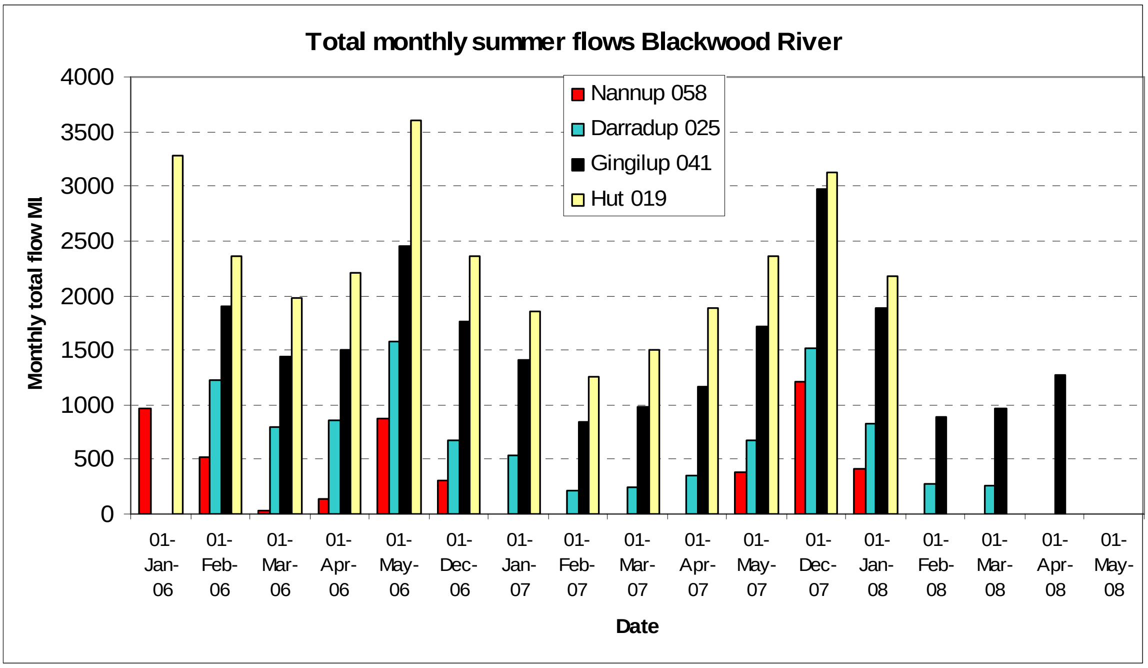


Figure 5 Total monthly summer flows at sites in the main channel of the Blackwood River from January 2006 to May 2008. N.B. Greater base flows in March 2006 compared with 2007 and 2008. Hut Pool data not yet available for February to May 2008. (Figure from Department of Water, Bunbury).

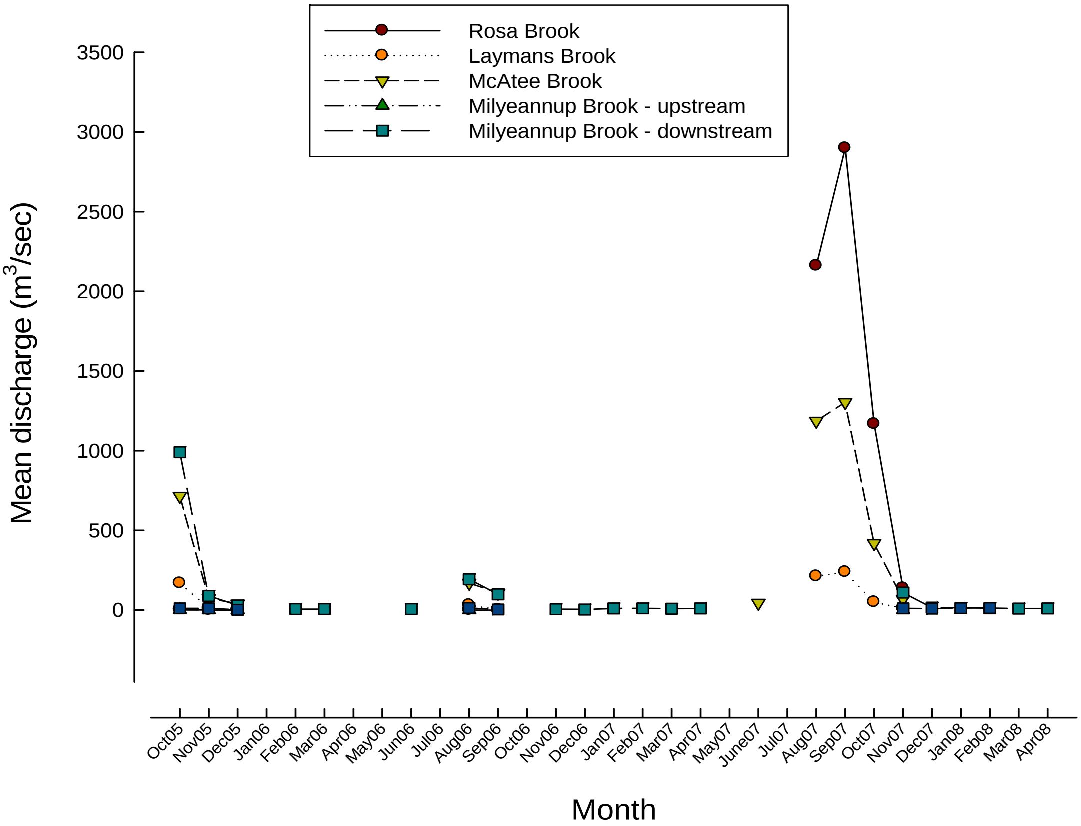


Figure 6 Mean discharge at tributary sites in the main channel of the Blackwood River from October 2005 to April 2008.

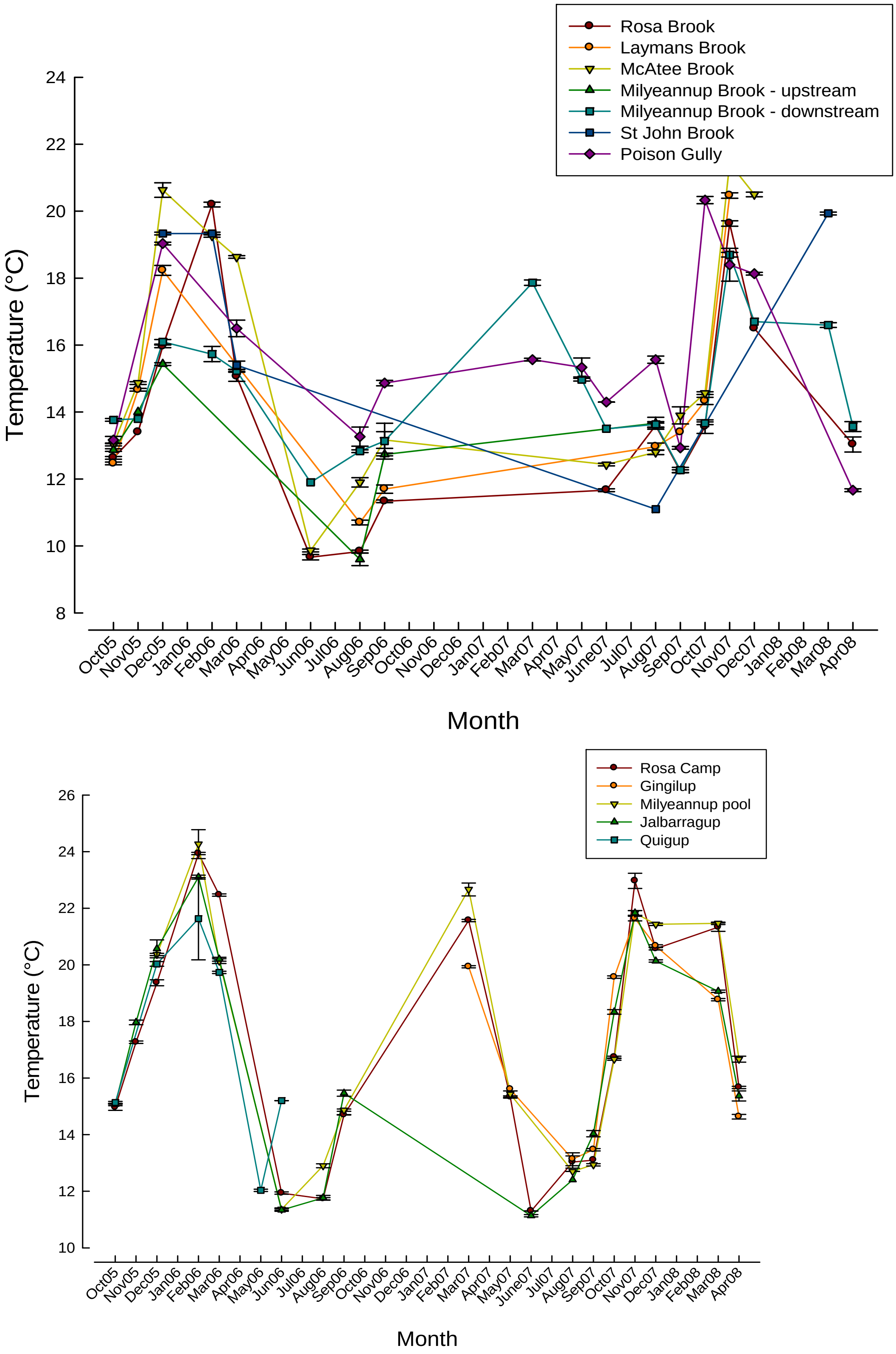


Figure 7 Mean instantaneous water temperature at sites in the tributaries (top) and main channel (bottom) of the Blackwood River between October 2005 and April 2008.

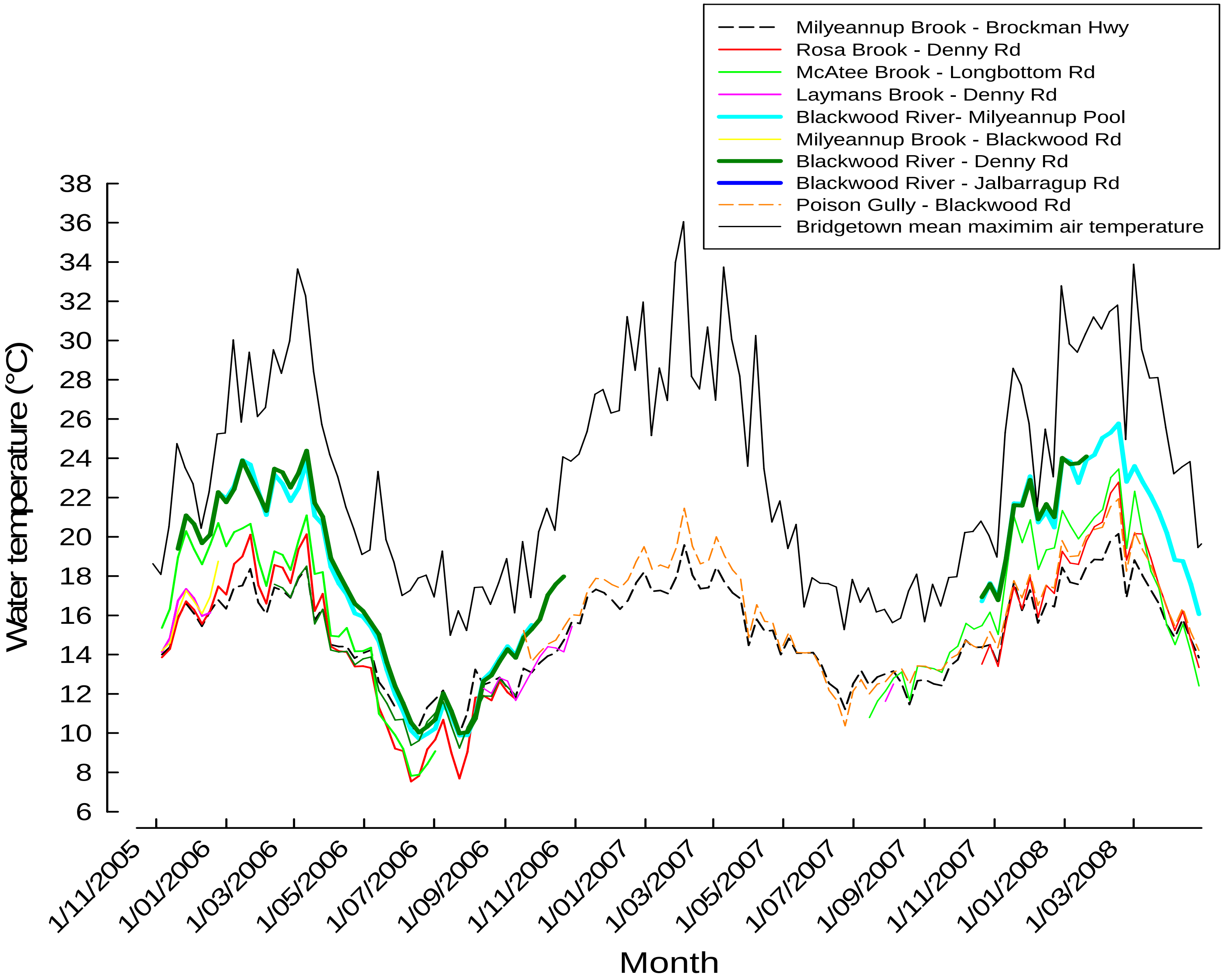


Figure 8 Water temperatures from the data loggers (logged every 3 hours) at sites in the Blackwood River and its tributaries. N.B. the close association of water temperatures in all sites and maximum air temperature (in Bridgetown) and cooler water temperature during summer in Milyeannup Brook.

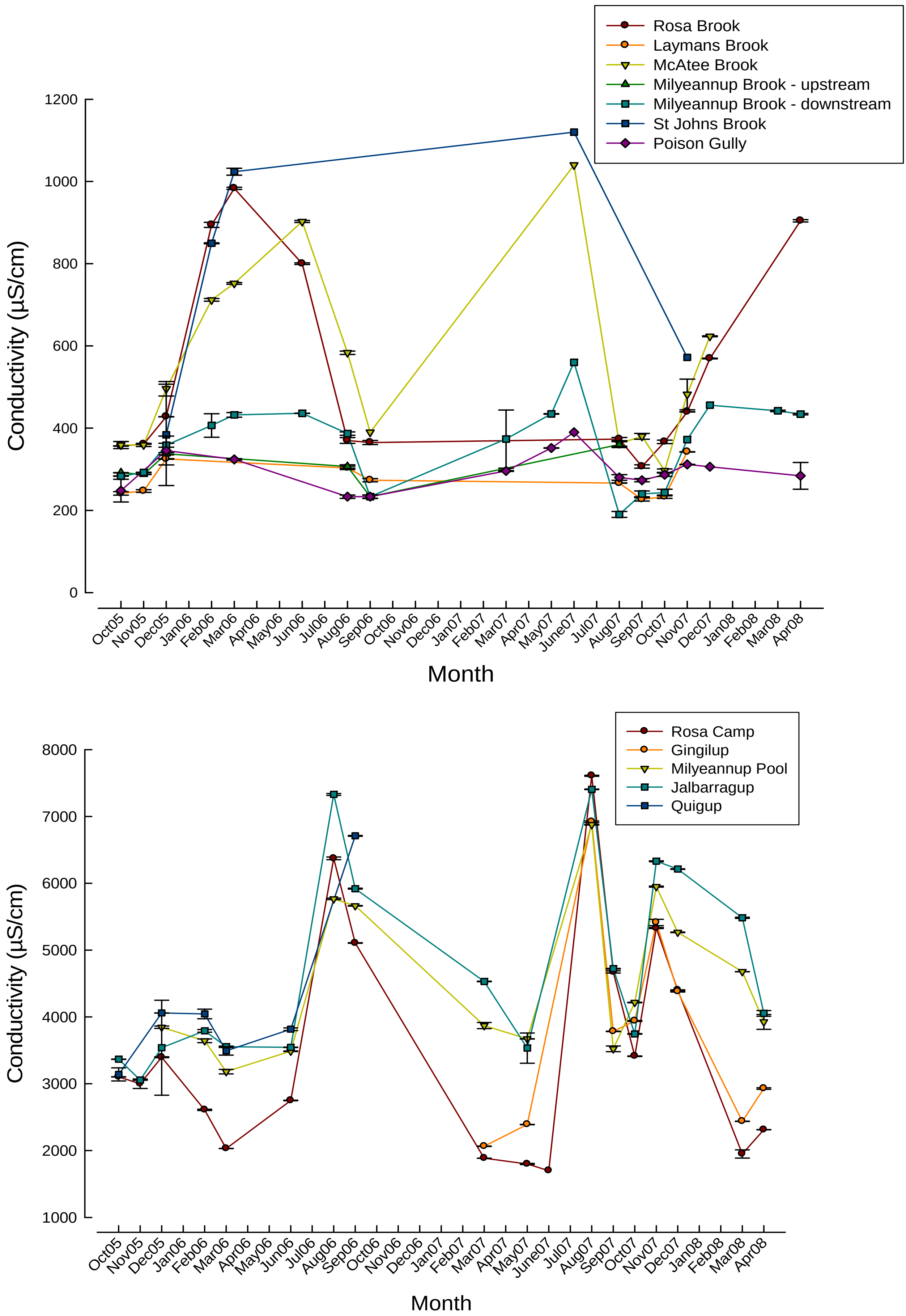


Figure 9 Mean instantaneous conductivities at sites in the tributaries (top) and main channel (bottom) of the Blackwood River between October 2005 and April 2008. N.B. fresher conditions at the more downstream sites (i.e. Denny Road and Gingilup) during baseflow periods.

presumably lower salinity, provides an important habitat for the Mud Minnow (Morgan *et al.* 2003, 2004).

The trends in conductivity of the main channel sites clearly show the effects of the increase groundwater input due to the Yarragadee Aquifer (see Figures 8 and 9) with the Denny Road baseflow conductivity in March 2007 and 2008 ~60% fresher than those upstream of the zone. This difference is even greater than that recorded during the (relatively high discharge) baseflow conditions in 2006 when a ~40% difference was recorded. The relationship between the main channel baseflow discharge and conductivity is significantly negatively related (Figure 10). This clearly demonstrates the importance of groundwater input in reducing the salinity in the main channel of the river during baseflow period when many of the tributaries cease to flow. This has implications for the seasonal habitat usage patterns of salt-intolerant freshwater species in the Blackwood River. For example, the fact that the Mud Minnow is not found in the main channel of the Blackwood River (Beatty et al. 2006, see also Mud Minnow section in the current report) may be due to its inability to tolerate the prevailing conditions in that habitat (particularly salinity). Phillips et al. (2007) demonstrated that the Mud Minnow populations in the various tributaries of the Blackwood River have considerable genetic variability; further supporting this theory of isolation.

The trends in PH are generally to decrease during baseflow conditions compared with high-flow periods (Figure 11). This is probably due to the increased influence of acidic tannins from riparian vegetation and salt water during reduced water levels. Figure 12 shows that dissolved oxygen levels were highly variable between sites and seasons. Generally, dissolved oxygen levels were lower during summer period.

Cross-sectional profiles and stage-height-discharges

Figures 13 to 16 demonstrate that discharge and depths at key riffle zones in the main channel are lower during March compared to April or May. Furthermore, it can be seen that the baseflow discharge over these riffles in March 2008 was greater than in March 2007 and that a clear relationship between the stage height and discharge was evident at the Denny Road and Milyeannup Pool riffle zones (Figures 13 and 15). These relationships were subsequently used to predict the minimum depths and discharge for Freshwater Cobbler upstream movement over these two riffle zones (see subsequent section on Relationship between Freshwater Cobbler and baseflow discharge). Subsequent hydrological and fish migration analysis during baseflow conditions scheduled to occur in 2009 and 2010 will further validate the preliminary relationships presented in the current report.

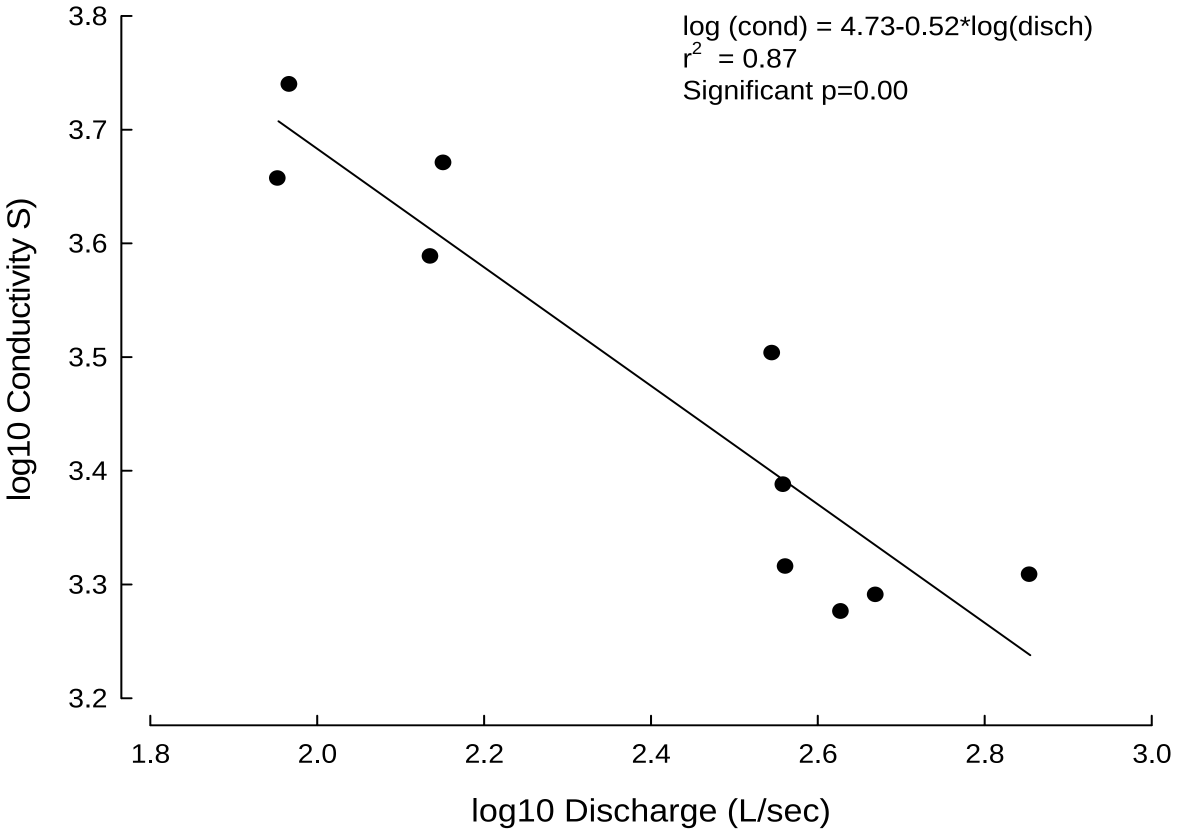


Figure 10 Relationship between the baseflow (i.e. March 2006-2008) discharges at all sites in the main channel and the mean water conductivities.

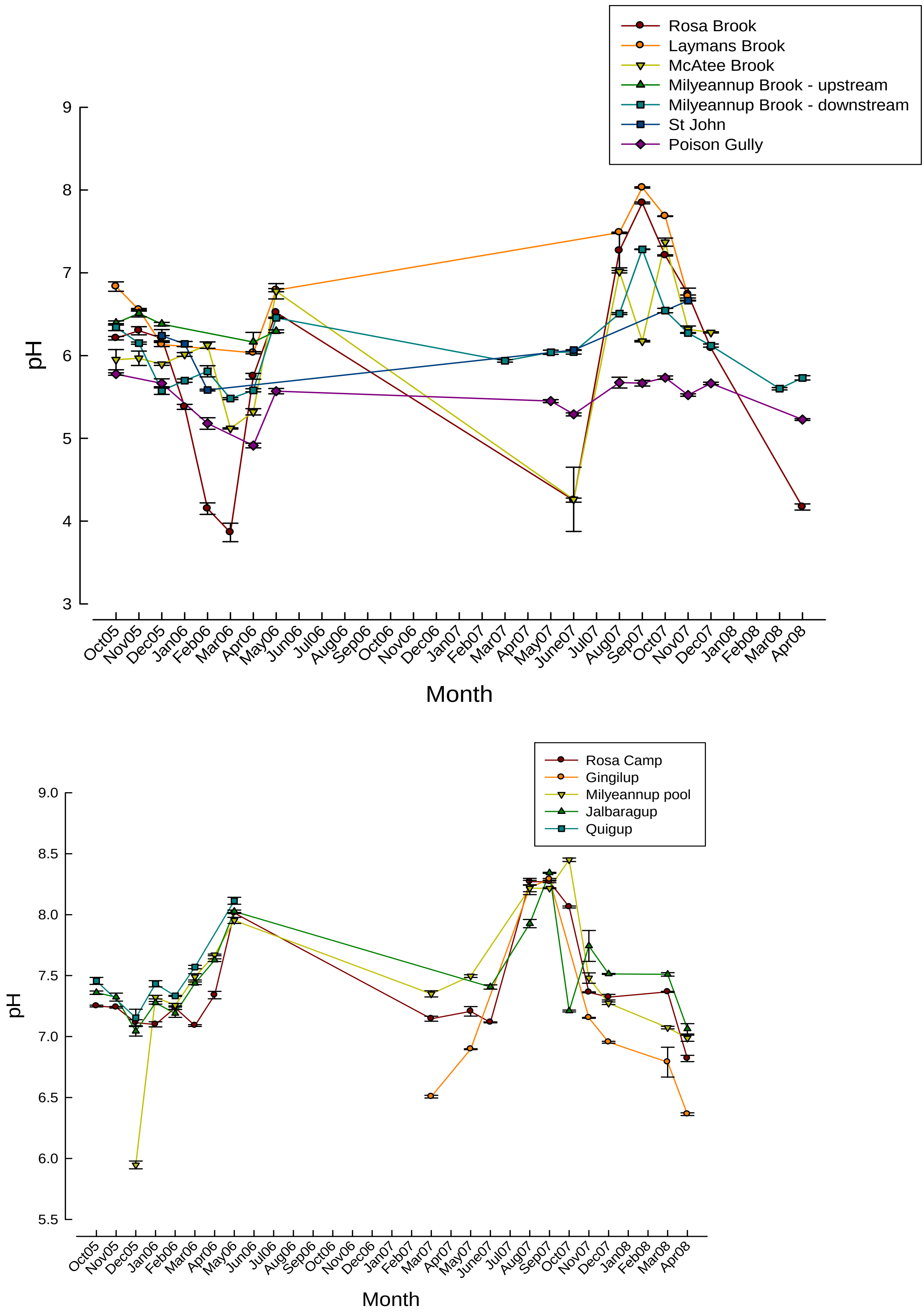
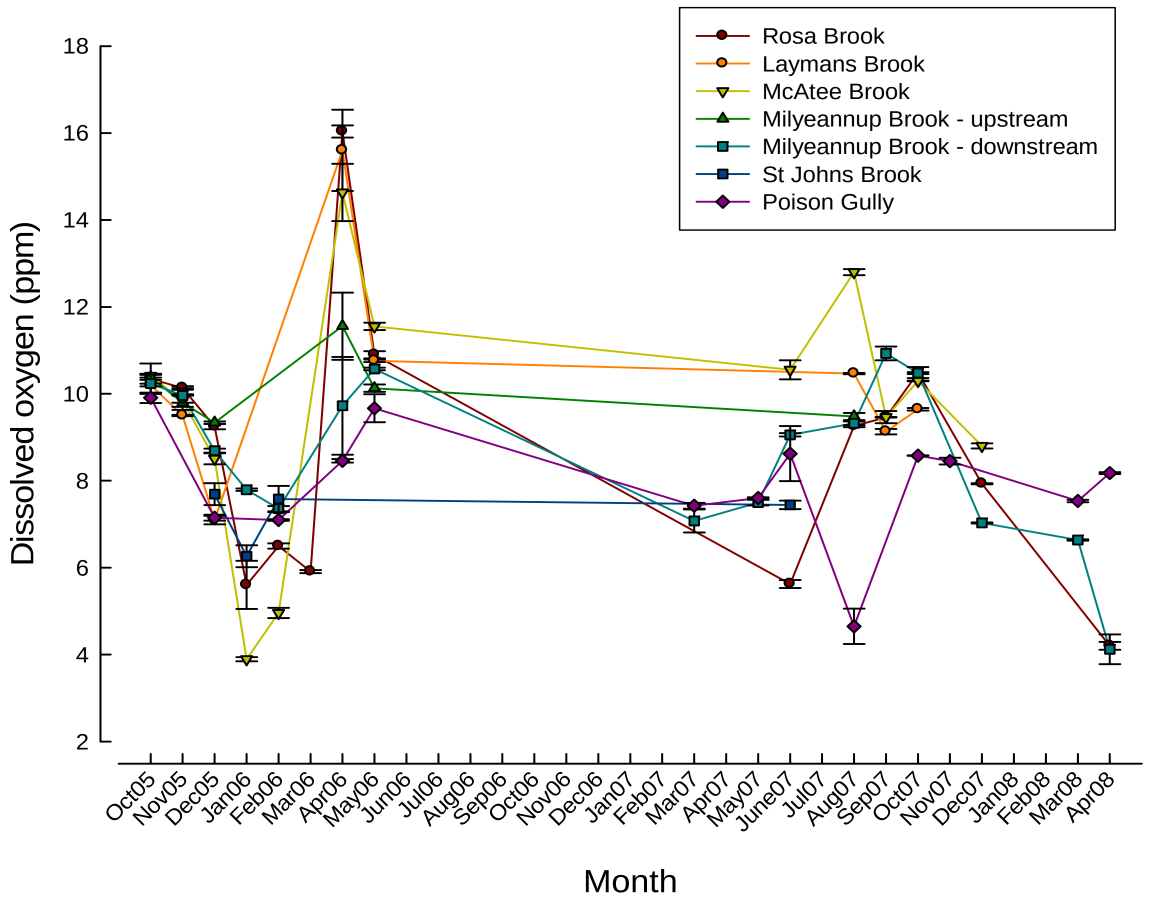


Figure 11 Mean instantaneous pH at sites in the tributaries (top) and main channel (bottom) of the Blackwood River between October 2005 and April 2008.



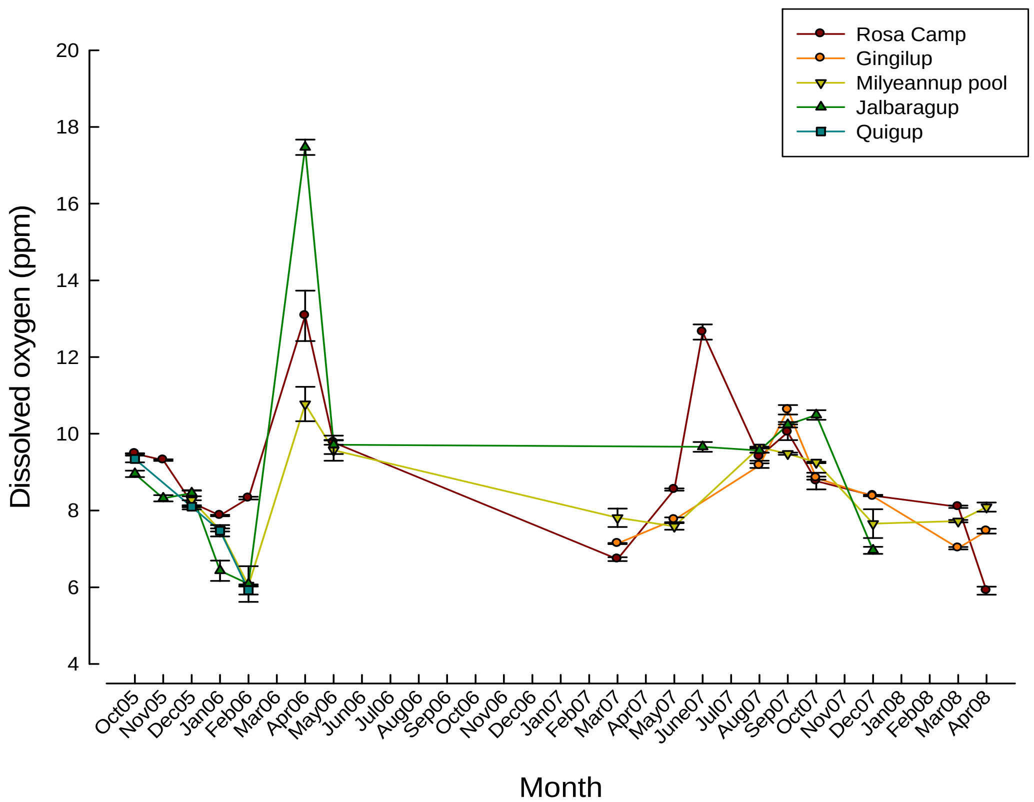


Figure 12 Mean instantaneous dissolved oxygen at sites in the tributaries (top) and main channel (bottom) of the Blackwood River between October 2005 and April 2008.

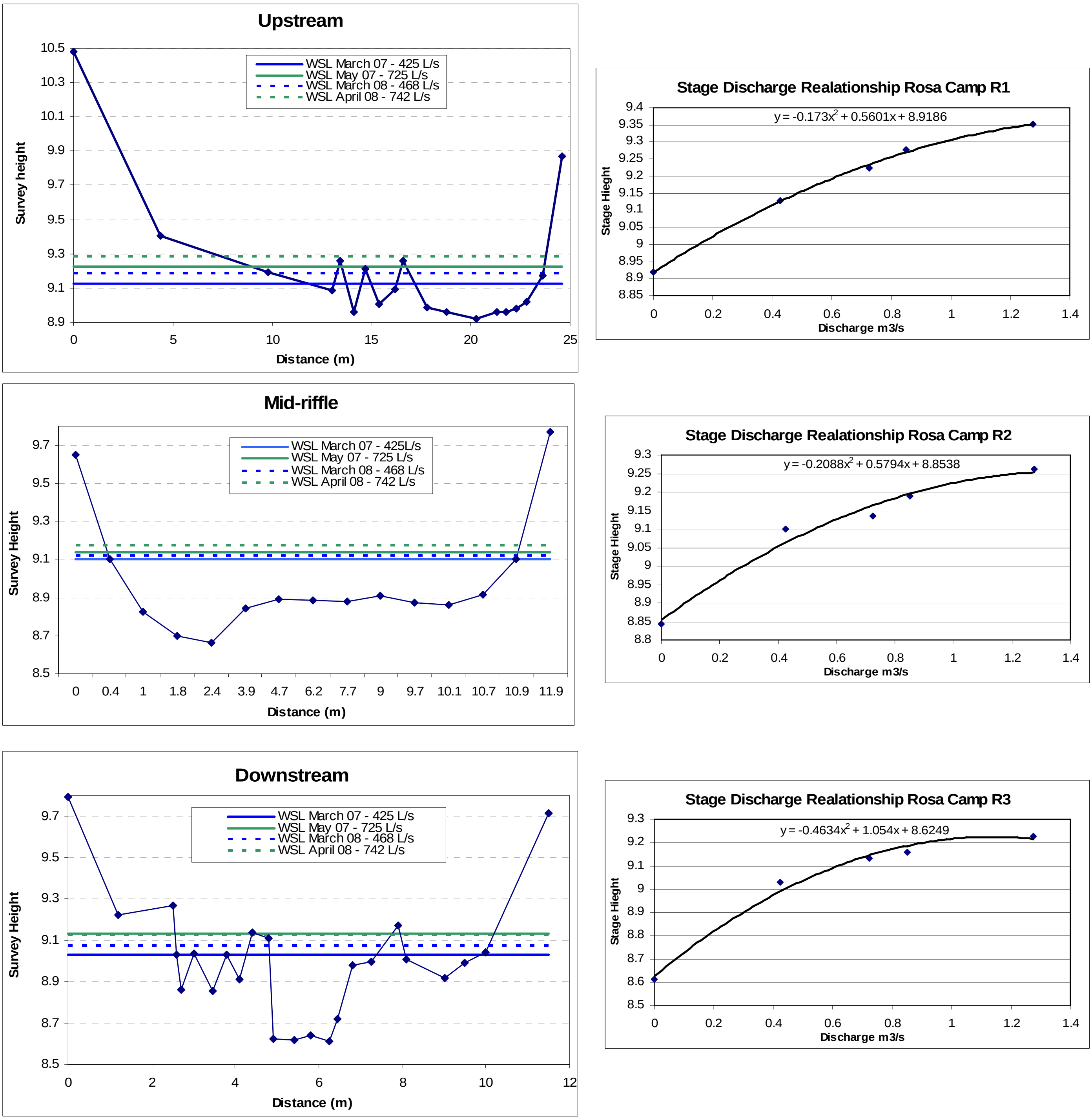
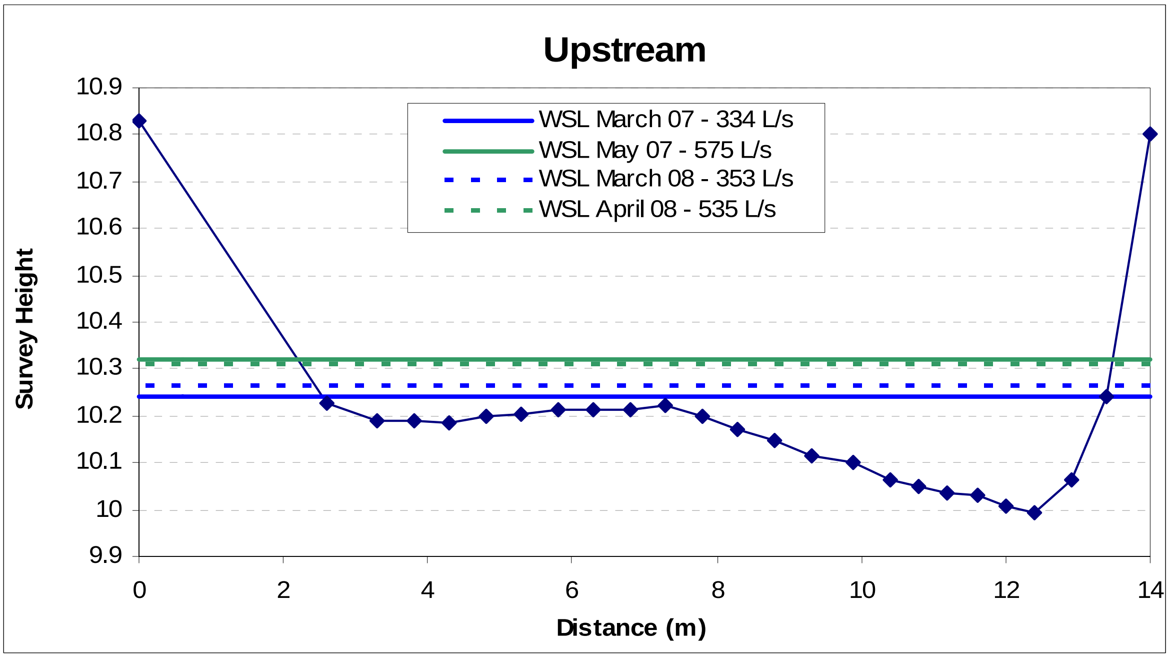


Figure 13 Cross-sectional riffle profiles during base-flow months in 2007 and 2008 at Denny Road in the Blackwood River. (Figure from Department of Water, Bunbury).



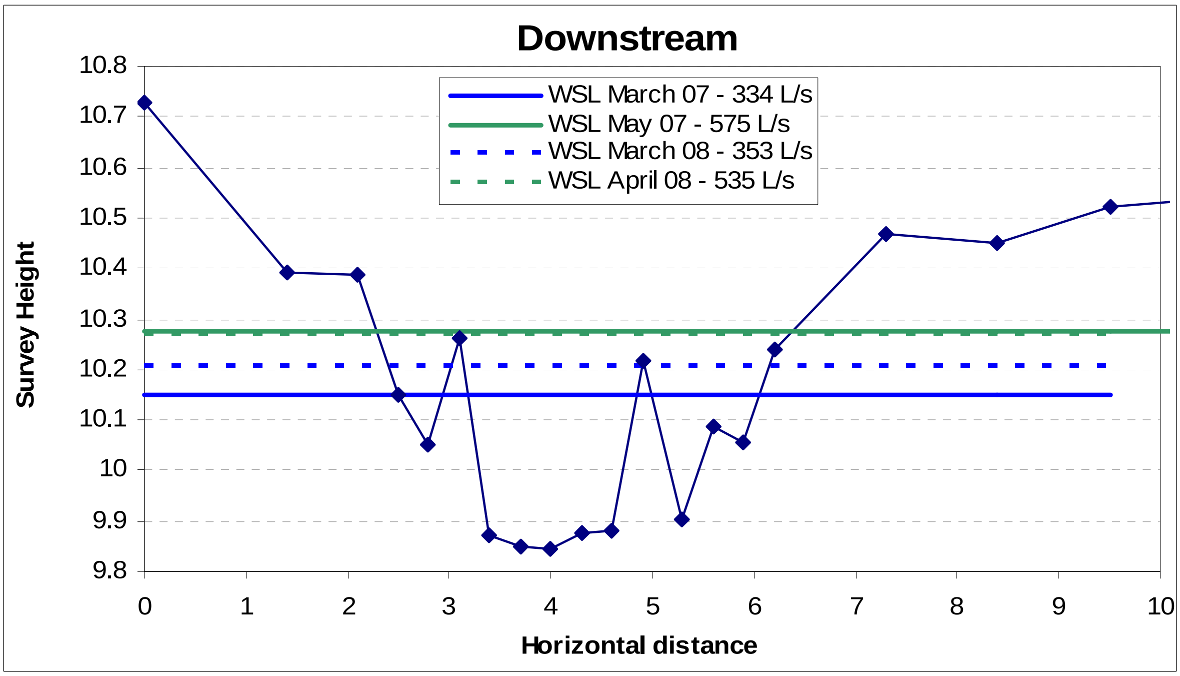


Figure 14 Cross-sectional riffle profiles during base-flow months in 2007 and 2008 at Gingilup in the Blackwood River. (Figure from Department of Water, Bunbury).

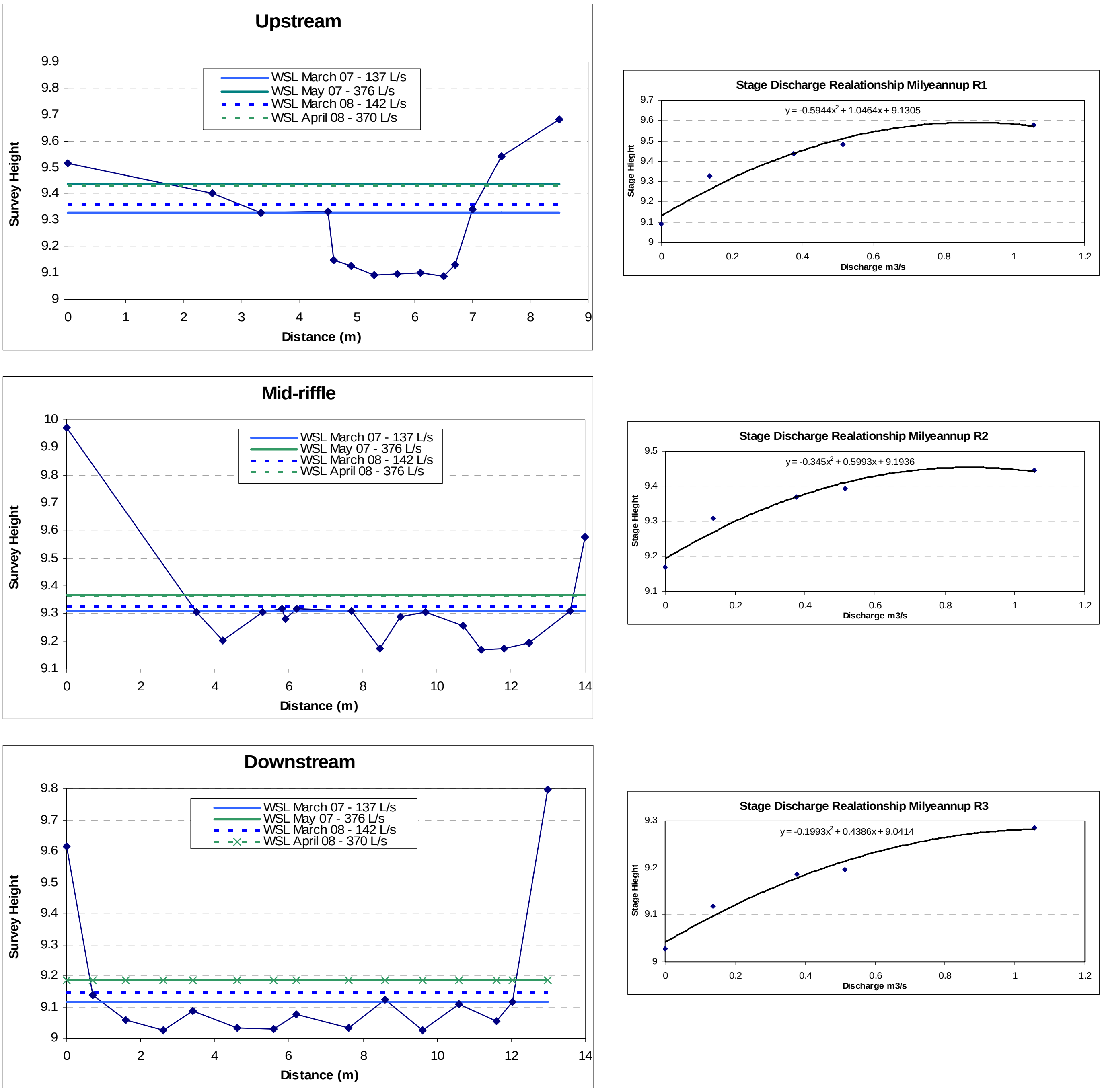


Figure 15 Cross-sectional riffle profiles during base-flow months in 2007 and 2008 at riffle downstream of Milyeannup Pool in the Blackwood River. (Figure from Department of Water, Bunbury).

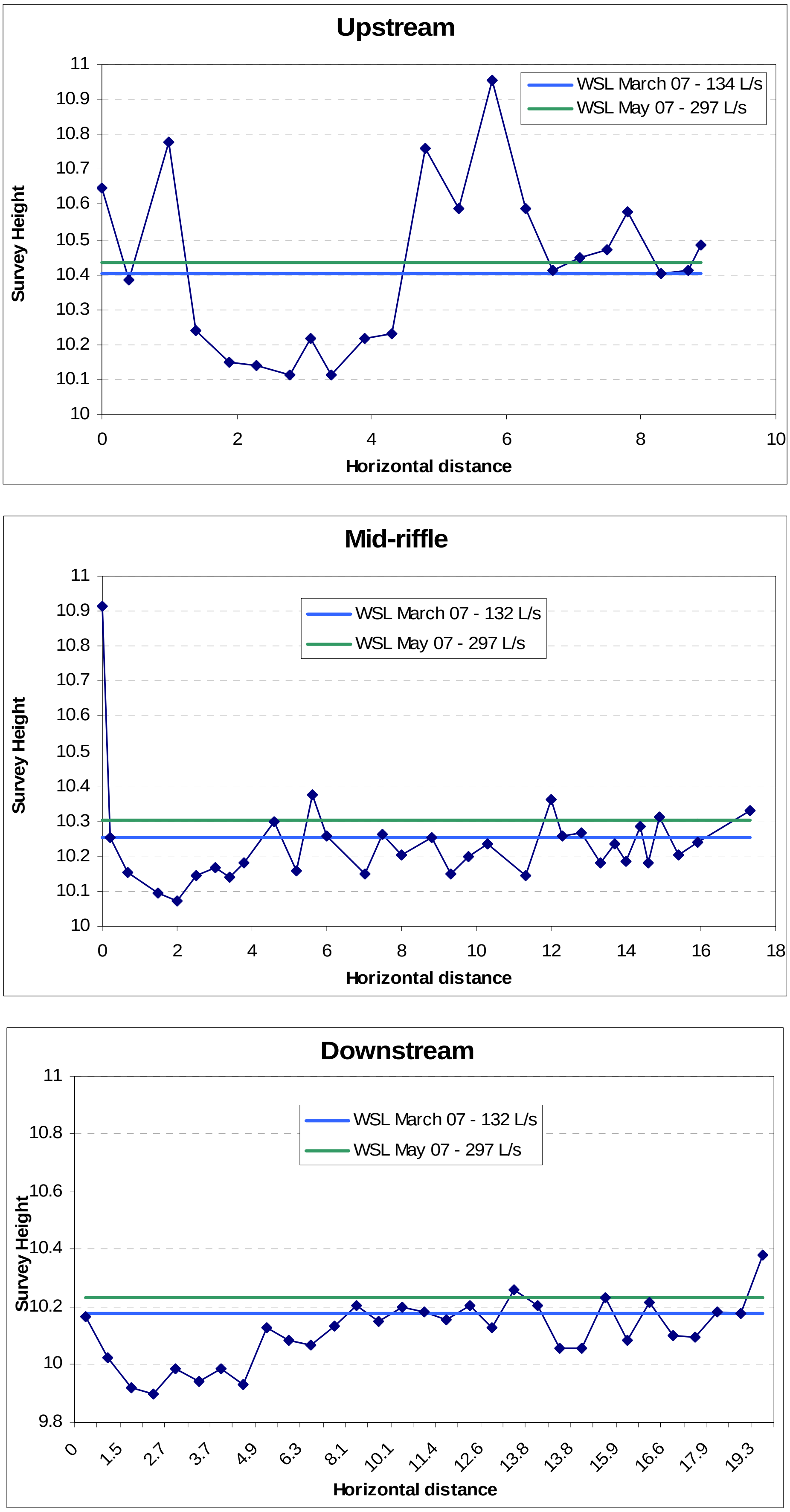


Figure 16 Cross-sectional riffle profiles during base-flow months in 2007 at a zone at Darradup in the Blackwood River. (Figure from Department of Water, Bunbury).

Species capture summary

During this study to date, six endemic freshwater teleost (fish) species, four estuarine fish species and four introduced fish species were captured. The anadromous (i.e. migrates into rivers from the ocean to breed) Pouched Lamprey, a Southern Hemisphere agnathan (i.e. jawless fish) was also captured, but was found in only three tributaries. The six fish species captured that are endemic to south-western Australia were the Freshwater Cobbler, Western Minnow, Mud Minnow, Balston's Pygmy Perch, Western Pygmy Perch, and the Nightfish. The estuarine species captured were the Western Hardyhead, South-western Goby, the Swan River Goby and Sea Mullet. The three introduced fishes captured were the Eastern Mosquitofish, Goldfish, Rainbow Trout and Redfin Perch (not captured in Beatty *et al*. 2006). Four species of endemic freshwater crayfish were captured, including the Marron, Gilgie, Restricted Gilgie and Koonac (Table 1). Below is an account of the distribution, population demographics and migration patterns of each species in the Blackwood River main channel.

Table 1 The total (and adjusted) number of each species of fish and freshwater crayfish captured in fyke nets in the Blackwood River main channel sites between September 2005 and March 2008.

SPECIES	**Total number (adjusted for stream width) of individuals of fish and crayfish caught in the Blackwood main channel using Fyke nets.**		
	MOVEMENT		
	Downstream	**Upstream**	**Total # captured**
Endemic freshwater fishes			
Freshwater Cobbler	1146 (5603)	4826 (37713)	5972 (43316)
Western Minnow	642 (2493)	1998 (9091)	2640 (11584)
Mud Minnow	0	0	0
Balston's Pygmy Perch	29 (140)	19 (68)	48 (207)
Western Pygmy Perch	222 (2009)	18 (379)	240 (2388)
Nightfish	61 (1886)	31 (788)	92 (2674)
Estuarine fishes			
South-western Goby	611 (4319)	202 (693)	813 (8012)
Swan River Goby	42 (510)	26 (62)	68 (572)
Western Hardyhead	1838 (8068)	2911 (6965)	4749 (15034)
Sea Mullet	0	4 (8)	4 (8)
Cont over page			
Introduced			

fishes			
Eastern Mosquitofish	1018 (1766)	316 (471)	1334 (2237)
Goldfish	1 (50)	0	1 (50)
Rainbow Trout	0	0	0
Endemic crayfishes			
Smooth Marron	83 (530)	90 (473)	173 (1003)
Gilgie	27 (193)	38 (41)	65 (235)
Restricted Gilgie	0	3 (5)	3 (5)
Koonac	2 (4)	1 (2)	3 (5)
Total number	5722 (27570)	10483 (56717)	16205 (84286)

Adult Pouched Lamprey in Milyeannup Brook

Freshwater Cobbler

Habitat associations

A greater number of Freshwater Cobbler were captured in the tributary sites during 2007/2008 compared with 2005/2006. Those captured in tributaries on all occasions were generally small (<220 mm TL with fifty-four, two and 250 captured in Rosa Brook, McAtee Brook and Milyeannup Brook, respectively (Figure 18). For example, the large movement of the species into Milyeannup Brook in June 2007 coincided with the flooding of the lower reaches thereby drowning out shallow downstream riffle zones. The general lack of this species in the tributaries therefore appears to be a result of inadequate ability to negotiate the numerous shallow riffle zones usually present in these tributaries.

Migration patterns

On the majority of sampling occasions, the strength of the upstream migration of Freshwater Cobbler was greater than the downstream migration (Figure 17 and 18). A notable exception occurred during June 2007 in Milyeannup Brook which is likely to have been a response to flooding within the Brook. The migration strength generally peaked in late spring and summer (Figure 17), with greatest migration strength being recorded in the more downstream sites that received greater groundwater discharge (i.e. Denny Road and Milyeannup Pool) compared to the upstream sites (i.e. Jalbarragup and Quigup). Spatial differences in migratory patterns existed within the main channel with the peak upstream migrations in the downstream sites occurring during February, compared to March and November in Quigup and Jalbarragup, respectively (Figure 18). Movement of Freshwater Cobbler was at a minimum during winter 2006/2007 and autumn 2008.

Furthermore, the spawning period of female Freshwater Cobbler coincided with their major migration period between late spring and summer as indicated by a decline in their GSI during that time (indicating that eggs had been released from ovaries) and the high proportion of Stage VII fish captured (Figure 19). In addition, it was determined, via regression analysis, that the length at maturity for Freshwater Cobbler is L_{50} = 171.6 and L_{95} = 226.4 i.e. at approximately 171 mm TL and 226 mm TL, 50% and 95% of the population is sexually mature (Figure 20).

Of the 437 tagged Freshwater Cobbler during 2005/2006, a total of 86 (19.7%) were recaptured (Table 2). Of these, 68 were recaptured once, 14 twice, five three times and two were recaptured four times (Table 2). With the exception of one fish, all were caught at the initial tag-capture site. This suggests that there is a very high degree of site fidelity

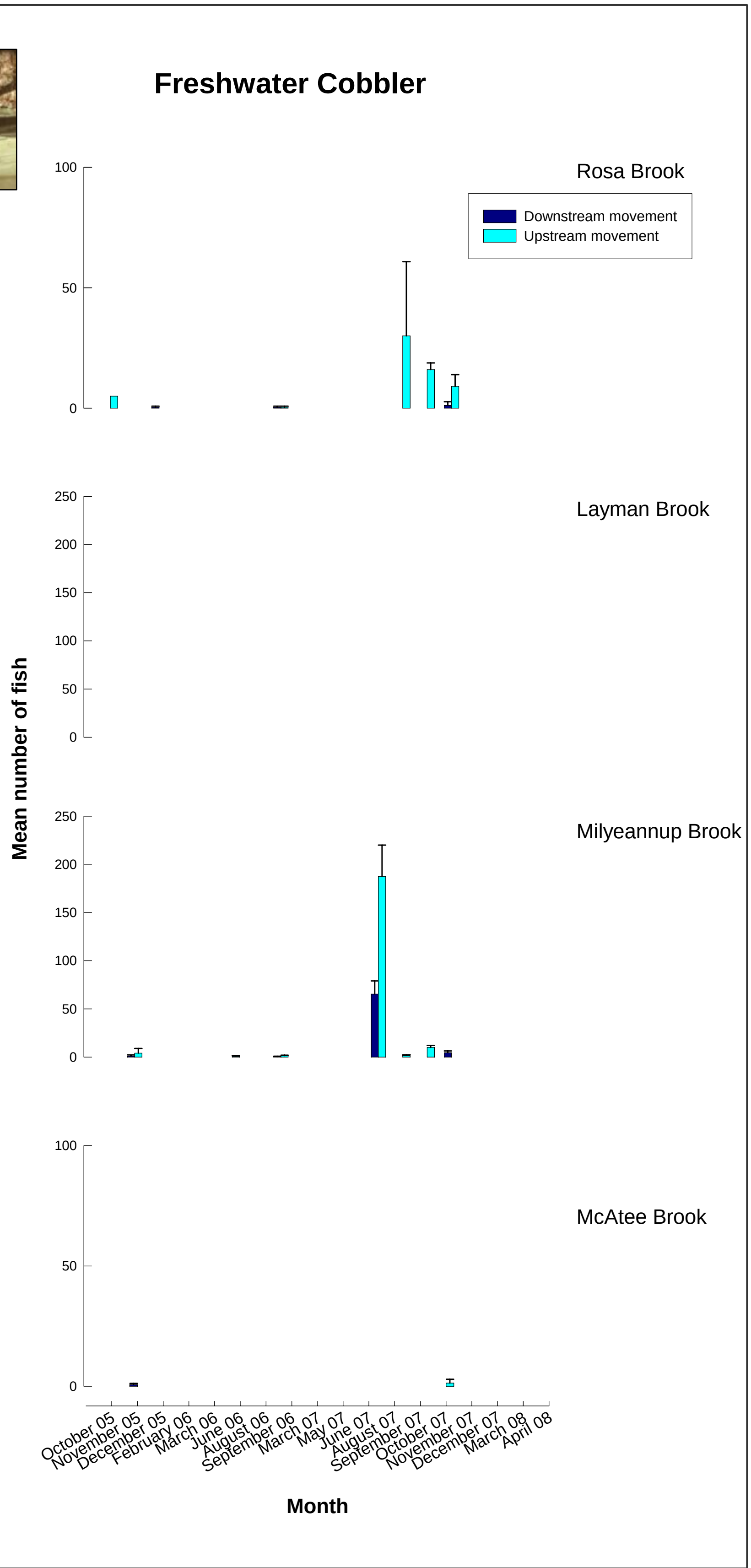


Figure 17 Upstream and downstream movement of Freshwater Cobbler in the tributaries.

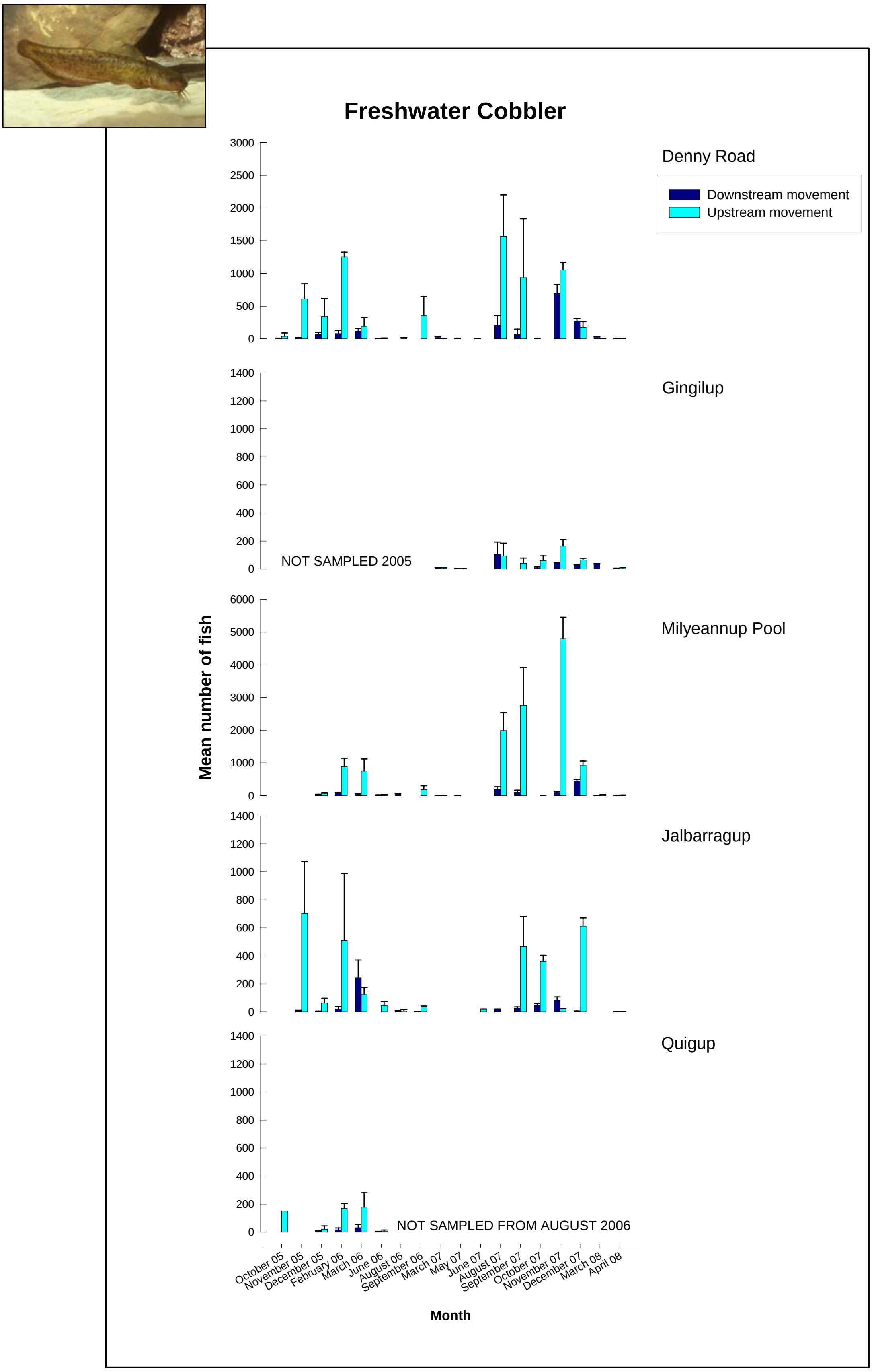


Figure 18 Upstream and downstream migration of Freshwater Cobbler in the Blackwood River main channel sites.

by this species in the Blackwood River. This assertion is further supported by anecdotal evidence from local fishermen. Years of fishing in the area has led some locals to believe that fishing effort cannot be concentrated in one area as a site becomes "fished out". They see cobbler as having distinct populations and target different populations or "cobbler holes" accordingly.

Although a high degree of site fidelity occurs in this system, there are nonetheless large localised upstream migrations by this species during times of low flow as a precursor to spawning and for feeding. Groundwater discharge during baseflow conditions is therefore important in providing adequate passage through riffle zones that would otherwise be barriers to its migration; and would be particular important in years of low input of surface flows (see next section).

Freshwater Cobbler migration relationships to environmental variables 2005-2008
The mean upstream movement of Freshwater Cobbler in all sampling months between October 2005 and April 2008 was positively correlated (r^2=0.32, p=0.000) with the mean downstream movements during those sampling times (Table 3, Figure 22). That is, periods of cobbler movement activity were typified by both increased upstream and downstream movements through the sampling sites.

Although Beatty *et al.* (2006) found that upstream movements of Freshwater Cobbler were positively related to water temperature (all sampling months 2005-2006); this relationship was not evident in the extended period to 2008. The lack of a significant relationship between upstream movement and temperature was influenced by the lower upstream movement of cobbler recorded in warmer (baseflow) period in early 2007 and 2008 compared with the substantial upstream movements recorded in summer 2006 when baseflow discharge was greatest (see migration Figures 17 and 18; and baseflow relationships in the next section). However, a very weak positive correlation (r^2=0.10, p=0.006) between downstream movement and water temperature existed between 2005 and 2008 (Figure 22).

Both the upstream and downstream movements of Freshwater Cobbler in the main channel during summer 2005-2006 and 2007-2008 were positively related to the mean discharge at those sties during those periods (Figures 22 & 23). The current study therefore revealed there was a significant relationship between downstream movement and discharge that was not revealed in the previous analysis of the single summer period in 2005-2006 (Beatty *et al*. 2006). However, the relationship between upstream movement were weaker in the current study (r^2 = 0.5, p = 0.03) compared to the 2005-2006 period alone (r^2 = 0.97, p = 0.01). From Figure 24, it can be seen that there was more variability in the additional four data points from the 2007-2008 summer period that resulted in the weakening of the predictability of the linear regression. However, additional scheduled sampling in 2008 and 2009 will result in further validation of these apparent relationships.

Relationship between Freshwater Cobbler movements and baseflow discharge
Direct comparisons between upstream movements of Freshwater Cobbler at the four riffle sites in March 2006, 2007, 2008 (i.e. the month with lowest discharge and greatest proportion of groundwater contribution to the total discharge) suggested that the strength of upstream movement through those riffles was positively related to discharge. The robustness of this relationship is currently limited due to sample size (i.e. three consecutive years); however, this reliability will be further strengthened by the scheduled sampling in March 2009 and 2010. Nonetheless, Figure 25 shows the relationship between upstream movement of Freshwater Cobbler and discharge during baseflow periods in 2005-2008. Although not yet significant, relatively strong positive relationships appeared to exist at both the Milyeannup Pool Riffle (r^2 =0.98, p = 0.06) were recorded at and Denny Road (r^2 = 0.76, p = 0.22) (Figure 25).

The relationships between baseflow discharges and depths over key riffles and upstream movement of Freshwater Cobbler through these riffles were used to infer minimum baseflow and depth requirements for upstream movement over two key riffles for which three subsequent March samples were obtained (i.e. Denny Road and Milyeannup Pool Riffle).

From using the linear models presented in Figure 25, it was estimated that Freshwater Cobbler movement would be totally precluded at discharges of 391 L/sec and 92 L/sec at Denny Road and Milyeannup Riffle, respectively (Table 3). Based on this zero-movement discharge, analysis of the riffle cross-sections and the discharge-stage height relationship, the depth across rifles when zero movement discharge would occur was estimated at 0.19 and 0.05 m for Denny Road and Milyeannup Riffle, respectively (Table 4).

These preliminary minimum estimates are for zero movements, however, it can be seen from the length-frequencies of the relative few Freshwater Cobbler captured moving over these two riffles in 2007 and 2008 that the sizes were relatively small (dominated by juveniles 40-100 mm TL) compared to the greater number that moved over them in the relatively high-flow event in March 2006 (no fish under 100 mm TL, dominated by mature adults 180-340 mm TL) (Figures 19 and 21). This suggests that larger, mature Freshwater Cobbler may be inhibited from upstream movement through these riffle zones at a discharge and associated minimum depths considerably greater than the estimates in Table 4.

SUMMARY AND RECOMMENDATIONS

- The general lack of Freshwater Cobbler in the tributaries of the Blackwood River is probably due to its inability to negotiate the shallow riffle zones generally present throughout these smaller aquatic systems, alternatively it may due to the absence of specific dietary components.
- Freshwater Cobbler upstream movement during March baseflow in the Blackwood River appears to be positively related to discharge and preliminary linear models may be used to set minimum baseflow discharges required for riffle connectivity.

- Low baseflow discharge appears to restrict the ability of larger, mature individuals to negotiate the riffle zones.
- Preliminary modelling suggests that minimum March baseflow discharge required for any upstream movement of Freshwater Cobbler at Denny Road and Milyeannup Pool riffles is 391 L/sec (19 cm depth) and ~92 L/sec (5cm depth), respectively.
- From the preliminary modelling of Freshwater Cobbler movement and baseflow discharge in the current report, reductions of ~8% and ~33% reductions from the relatively low March 2007 discharges recorded at Denny Road and Milyeannup Pool riffles, respectively, may prevent any upstream Freshwater Cobbler moving over these riffle zones.
- Ongoing sampling during subsequent baseflow conditions in 2009 and 2010 is required to both validate and strengthen these models and will allow preliminary models to also be created for the riffle zones at Gingilup and Orchid Place.
- Validation of these preliminary minimum flow and depth requirements of Freshwater Cobbler movements should also be tested under controlled laboratory conditions via swimming ability trials.
- A tracking program (using acoustic and radio-tracking techniques) of Freshwater Cobbler at key riffle sites would provide additional information on their habitat use and requirements, and on their impetus to migrate between pools during baseflow conditions.
- Impacts on Freshwater Cobbler populations (e.g. on feeding ecology and access to spawning habitats) of periodic isolation within pools habitats also needs to be examined.

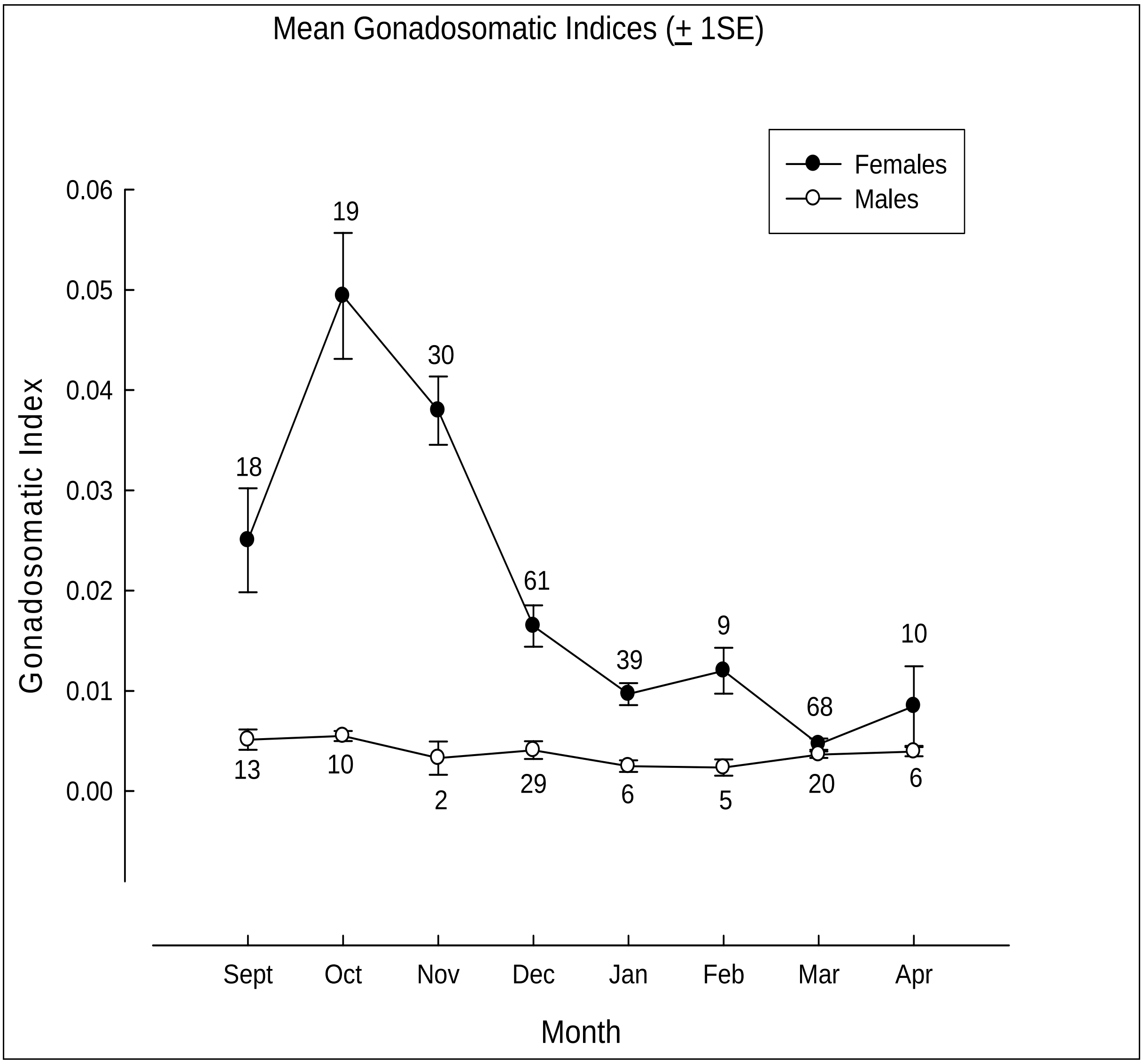


Figure 19 Mean gonadosomatic indices (GSI) (± 1 SE) for male and female Freshwater Cobbler in the main channel of the Blackwood River. Numbers are given.

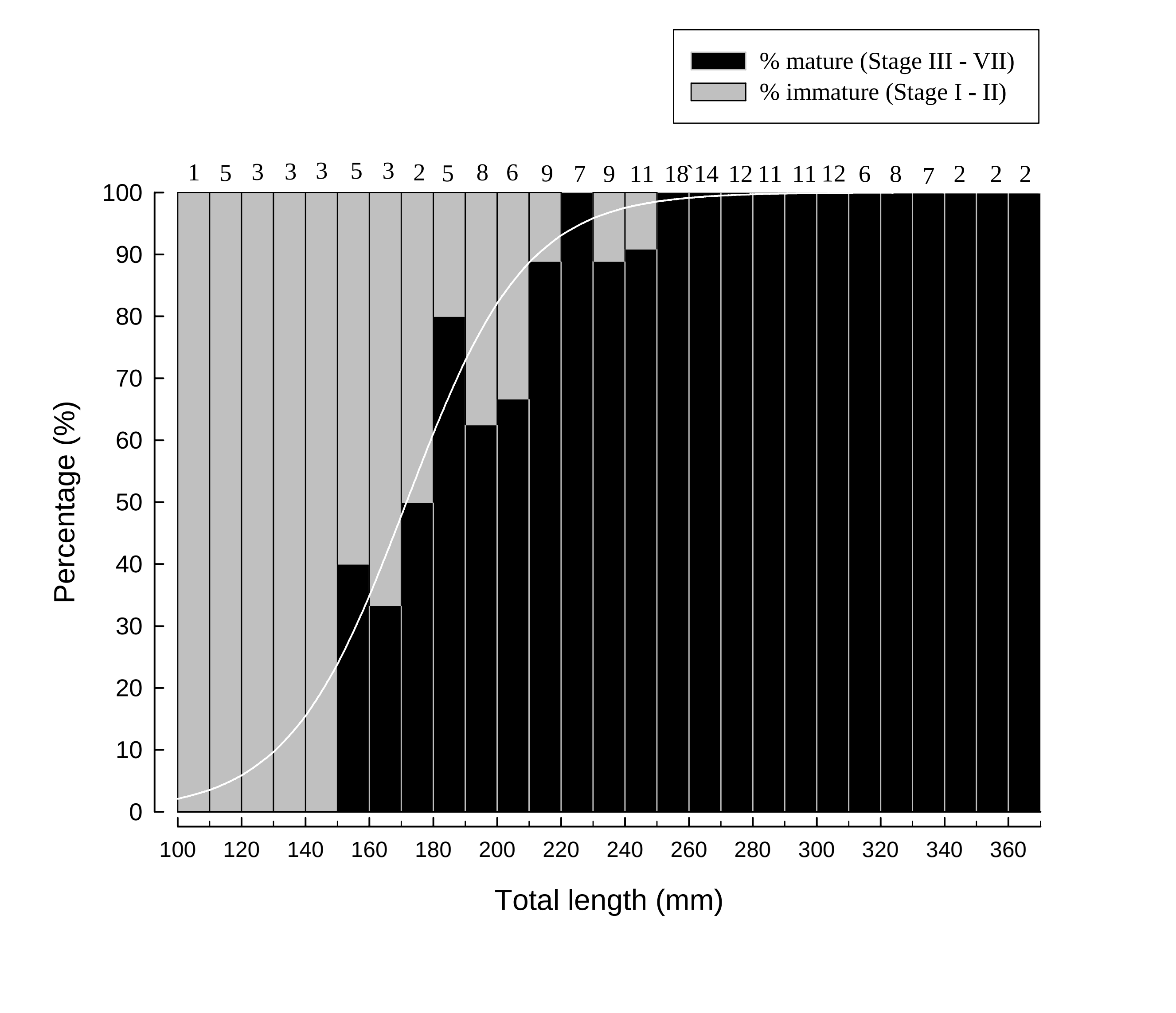


Figure 20 Length at maturity for male and female Freshwater Cobbler in the Blackwood River. L_{50} = 171.60; L_{95} = 226.40.

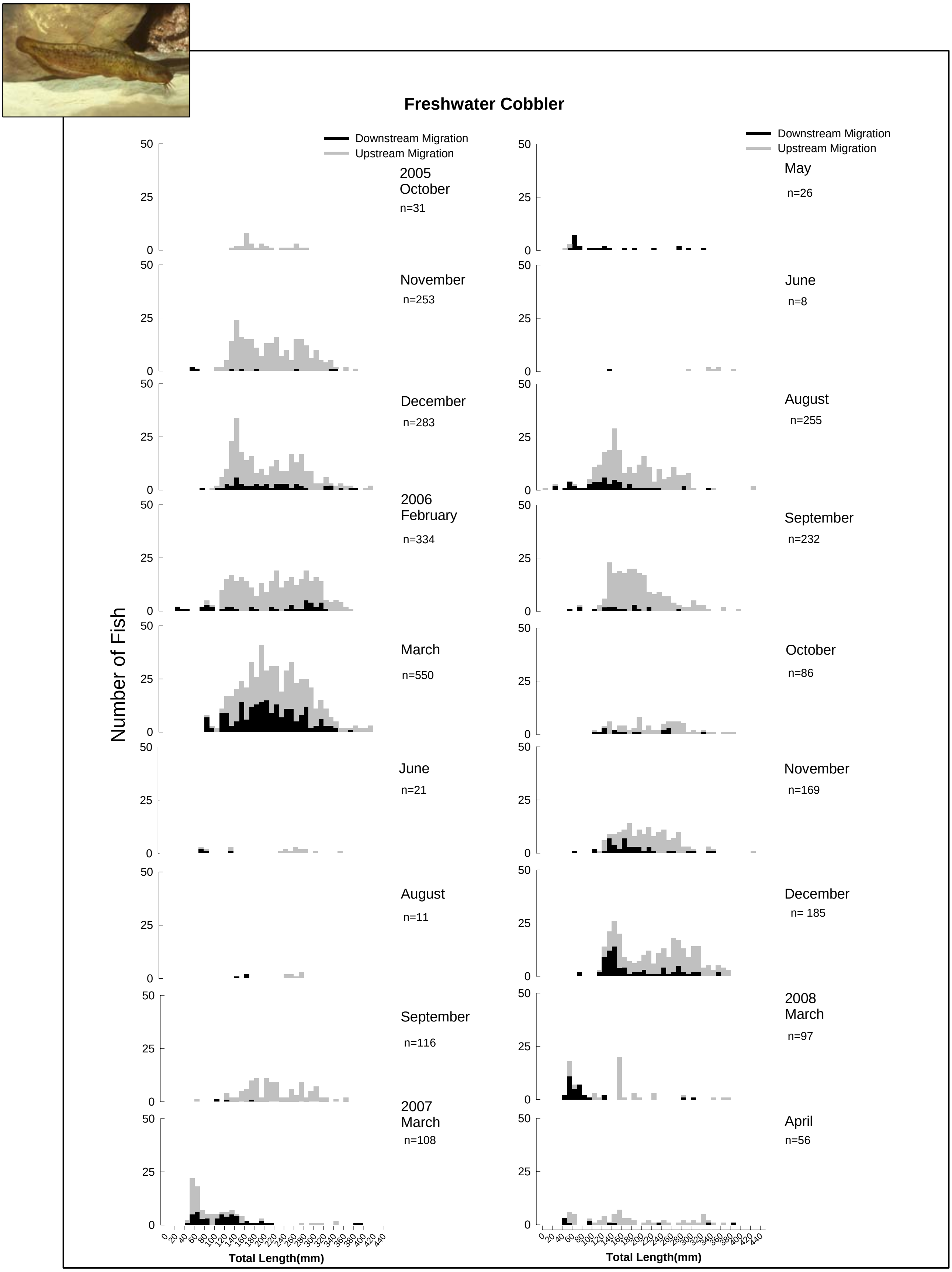


Figure 21: Length-frequency of Freshwater Cobbler, differentiated by upstream and downstream movement, in the Blackwood River main channel.

Table 2 Freshwater Cobbler tagged and recaptured in main channel sites of the Blackwood River. N.B. Includes % recaptured per site and % total of all recaptures when compared to total number tagged.

SITE	Number Tagged	# Recaptured (%)	# Recaptured Twice (%)	# Recaptured 3 times (%)	#Recaptured 4 Times (%)
Denny Road	215	42 (19.5)	8 (3.7)	1 (0.5)	
Milyeannup Pool	42	7 (16.7)	2 (4.76)		
Jalbarragup	110	17 (15.5)	4 (3.6)	4 (3.6)	2 (1.8)
Quigup	70	2 (2.9)			
TOTAL (%)	437	68 (15.6)	14 (3.0)	5 (1.1)	2 (0.5)

Table 3 Correlations between overall mean upstream and downstream movements of Freshwater Cobber in the main channel sites of the Blackwood River and prevailing environmental variables during the summer (baseflow) period (December to April). N.B. Data were log10 transformed, * denotes correlation is significant at the 0.05 level (2-tailed).

		Downstream	Upstream	Discharge	Temperature	Conductivity	pH	Dissolved O2
Downstream	Pearson Correlation	1						
	Sig. (2-tailed)							
Upstream	Pearson Correlation	.566	1					
	Sig. (2-tailed)	.143						
Discharge	Pearson Correlation	.767(*)	.756(*)	1				
	Sig. (2-tailed)	.026	.030					
Temperature	Pearson Correlation	.455	.851(**)	.673	1			
	Sig. (2-tailed)	.257	.007	.067				
Conductivity	Pearson Correlation	-.747(*)	-.502	-.905(**)	-.366	1		
	Sig. (2-tailed)	.033	.205	.002	.373			
pH	Pearson Correlation	-.193	-.396	-.288	.073	.365	1	
	Sig. (2-tailed)	.648	.332	.489	.863	.373		
Dissolved O2	Pearson Correlation	-.049	.332	.530	.173	-.515	-.318	1
	Sig. (2-tailed)	.909	.422	.177	.683	.191	.443	

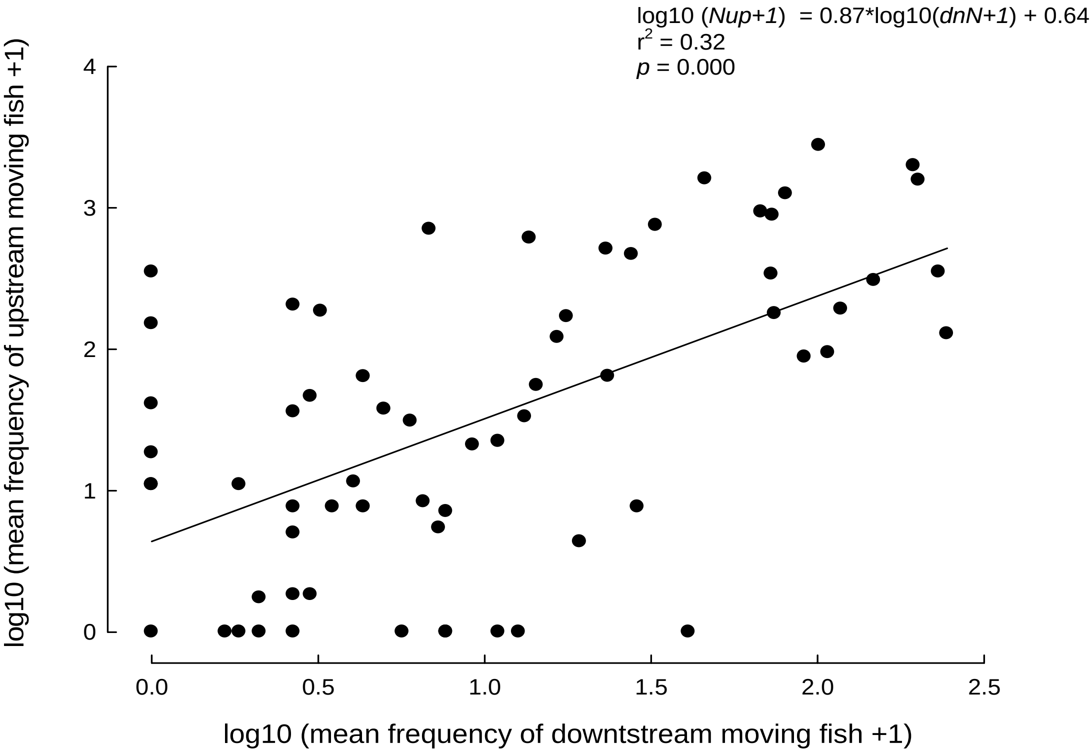


Figure 22 Relationship between the mean strength of upstream versus downstream movements of Freshwater Cobbler in the Blackwood River main channel in all sampling months between 2005 and 2008. N.B. Data were log10 transformed and migration number was standardised for effort; see text for details.

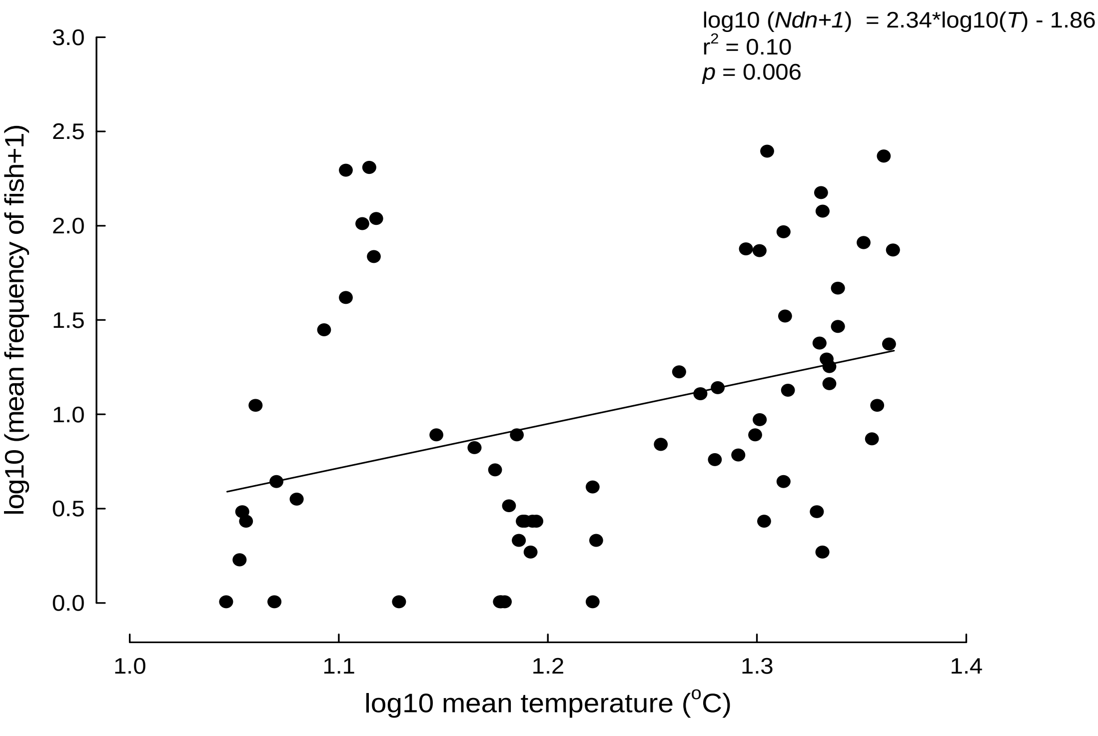


Figure 23 Relationship between the mean strength of downstream movements of Freshwater Cobbler in the Blackwood River main channel with water temperature in all sampling months between 2005 and 2008. N.B. Data were log10 transformed and migration number was standardised for effort; see text for details.

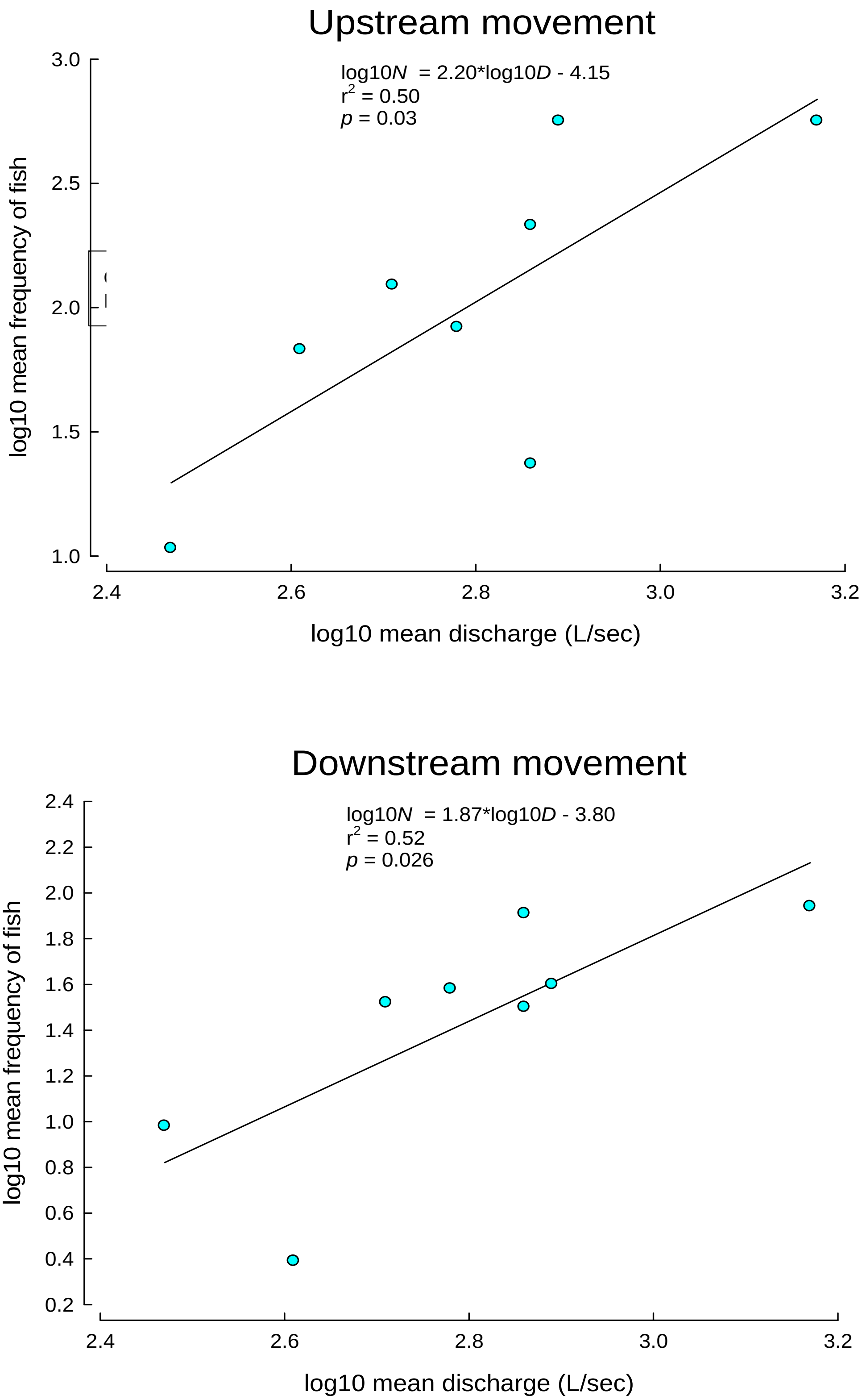


Figure 24 Relationships between the mean strength of upstream movement of Freshwater Cobbler and the mean discharge in the Blackwood River main channel between December and April 2005-2006 and 2007-2008. N.B. Data were log10 transformed and migration number was standardised for effort, see text for details.

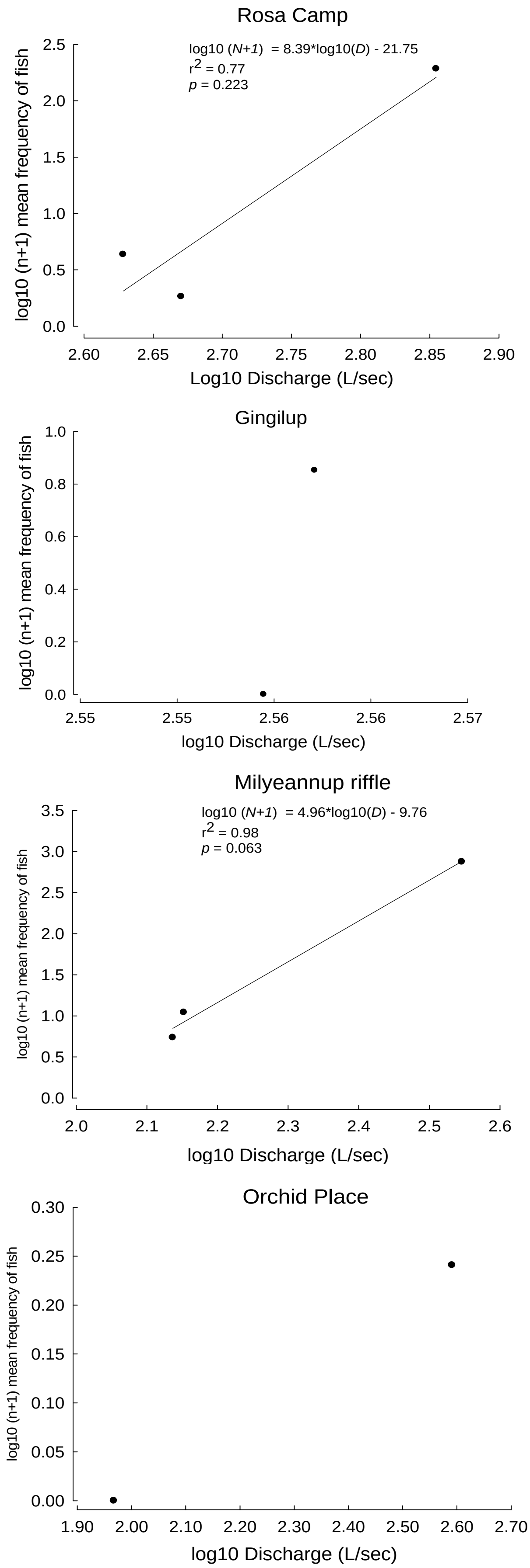


Figure 25 Relationship between mean upstream Freshwater Cobbler movement over Denny Road, Gingilup, Milyeannup Pool and Orchid Place riffles during March 06, 07 and 08 and mean discharge during those months

Table 4 Maximum depths (discharge in parenthesis) across the various riffle cross-sections at the four riffle sites monitored during base-flows in 2007 and 2008. N.B Also included is the shallowest riffle depths (on the cross-sections) that Freshwater Cobbler negotiated during each base-flow month. Preliminary (extrapolated) estimates of minimum discharges over riffles (and depths based on minimum cross-section depths) required for upstream movement (based on linear regressions (Figure 25) in March 2006, 2007, and 2008). Hydrological data provided by Department of Water, Bunbury.

		2007		2008		Estimate minimum discharge (L/sec) (and depth (m)) for upstream movement
Site	**Riffle location**	**March**	**May**	**March**	**April**	
Denny Road	Upstream	0.211	0.306	0.267	0.365	
	Mid-riffle	0.436	0.472	0.453	0.508	
	Downstream	0.418	0.521	0.466	0.515	
	Minimum depth negotiated	0.211	0.306	0.267	0.365	**391 (0.19)**
Gingilup	Upstream	0.248	0.325	0.27	0.318	
	Downstream	10.149	10.277	0.363	0.427	
Milyeannup	Upstream	0.239	0.349	0.272	0.343	
	Mid-riffle	0.139	0.2	0.155	0.196	
	Downstream	0.091	0.16	0.119	0.159	
	Minimum depth negotiated	0.091	0.16	0.119	0.159	**92 (0.05)**
Orchid Place	Upstream	ns	ns	0.12	0.25	
	Mid-riffle	ns	ns	0.12	ns	
	Downstream	ns	ns	0.24	ns	

Western Minnow

Habitat associations

The Western Minnow was captured at the majority of sites sampled on most occasions, with large numbers recorded in both the main channel sites and in the tributaries. This widespread distribution, being present in nearly all habitats sampled, reflects this species tolerance to a wide range of salinities; having previously been recorded in salinities up to ~24 ppt or ~two thirds the salinity of seawater (Morgan & Beatty 2004). However, recent rapid change salinity trials on the species from the Blackwood River have revealed a LD_{50} (length at 50% of individuals showed severe stress that would lead to death) at ~14 ppt (Beatty *et al*. 2008). Furthermore, larval stages of the species may have an even lower tolerance to salinity.

Migration patterns

There were limited movements of Western Minnow in the most upstream main channel site compared to the more downstream sites, i.e. Denny Road, Gingilup and Milyeannup Pool (Figure 26). The upstream movement of Western Minnow was generally strongest during winter; peaking in June and August 2006. The majority of these fish were large adults that were likely to be moving as a precursor to spawning (Figures 27-31). In general the numbers of Western Minnows captured within the main channel was greater over 2007/2008 than 2005/2006.

There are substantial differences in the population demographics of Western Minnows in the main channel sites. Specifically, fish captured in the three most downstream sites (i.e. Denny Road, Gingilup and Milyeannup Pool) grew to a substantially larger size, implying that the species had greater longevity (and/or faster grow) at the downstream sites compared to the two upstream sites. For example, of the fish that were greater than 100 mm TL, almost all were found at the Denny Road, Milyeannup Pool and Gingilup sites (within zone of Yarragadee Aquifer discharge).

The migration pattern of the Western Minnow within tributaries exhibited considerable interannual variation (Figures 32-36). Migration within the

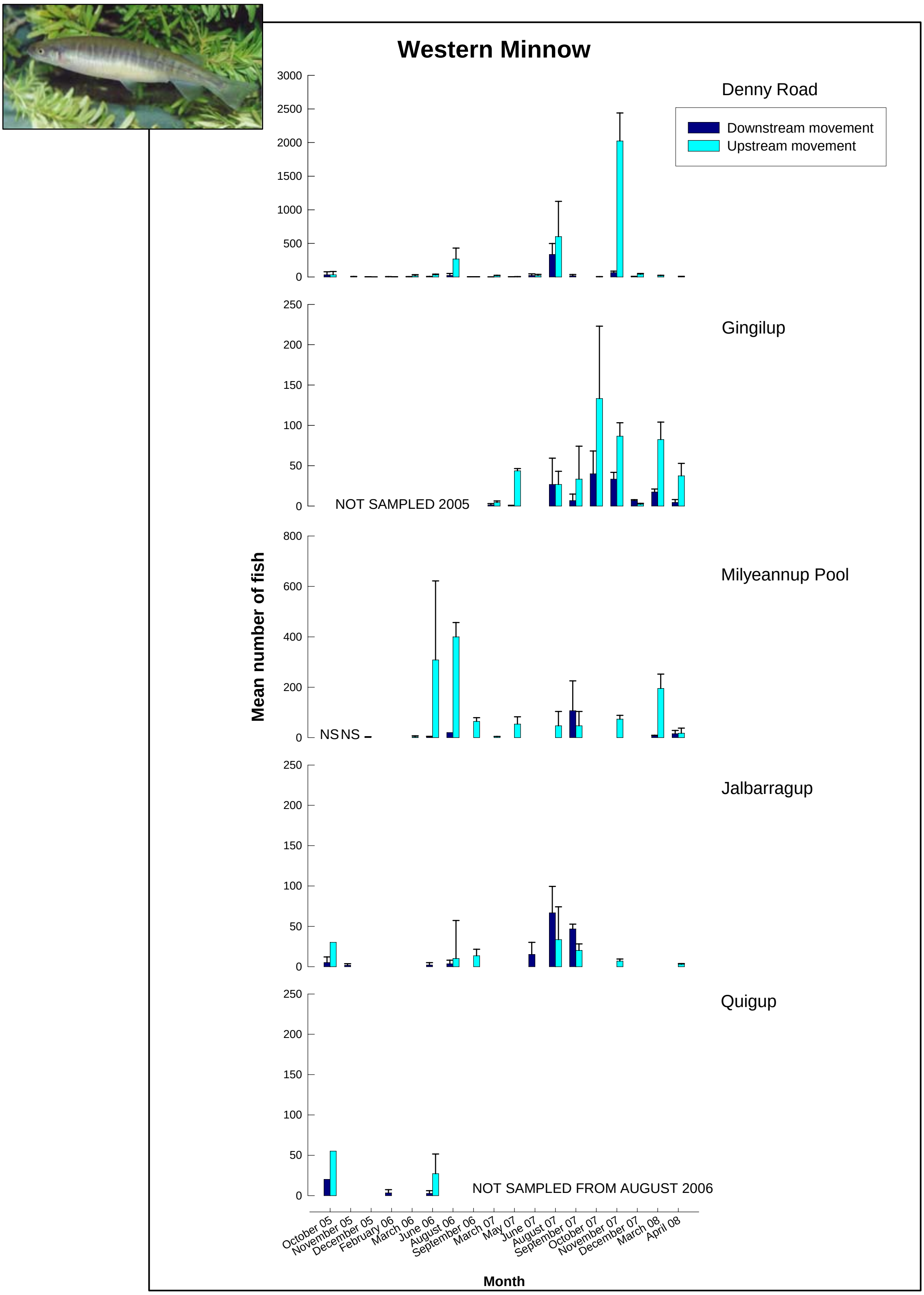


Figure 26 Upstream and downstream movement of Western Minnow in the Blackwood River main channel.

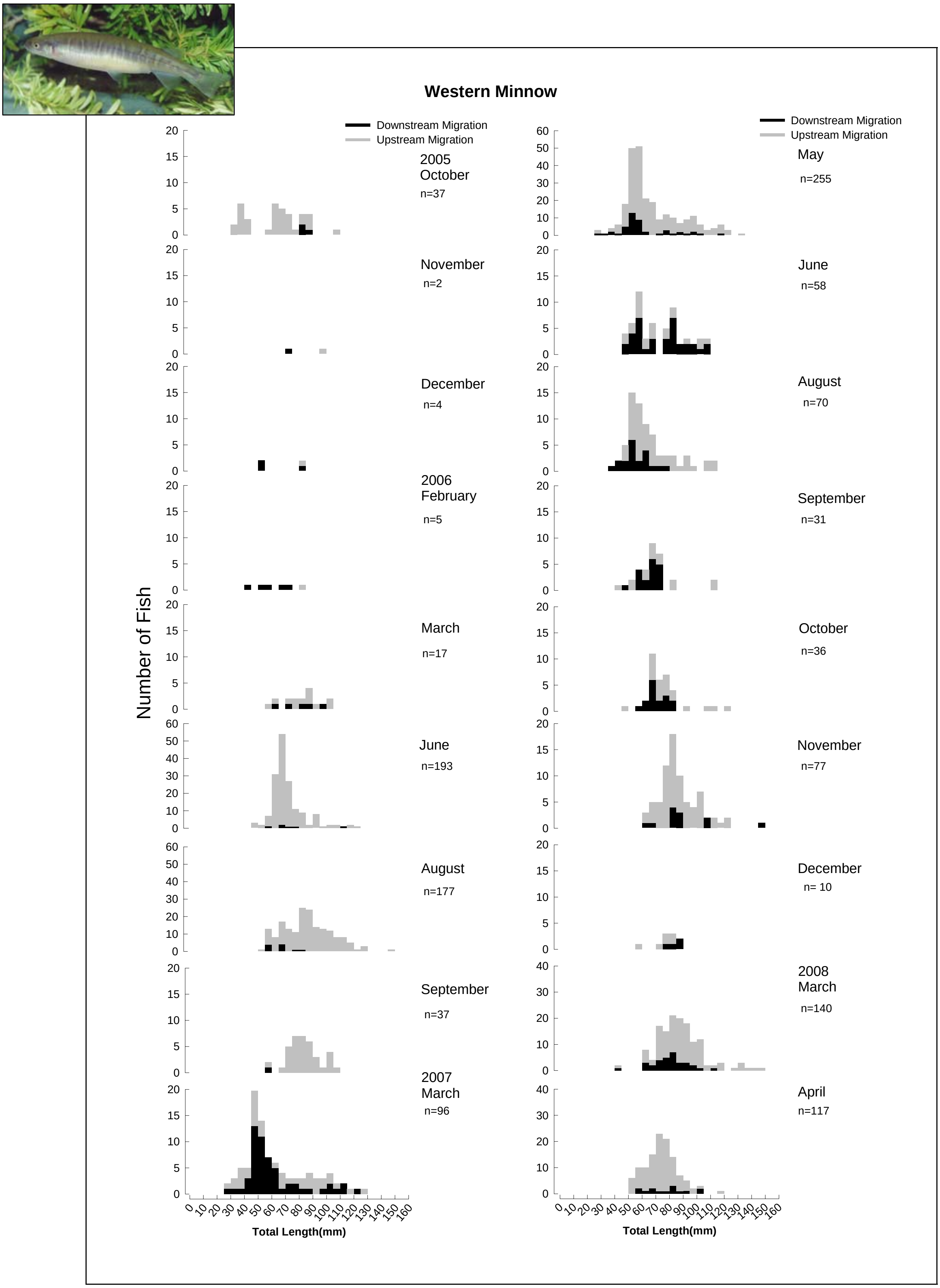


Figure 27 Length-frequency histograms, differentiated by upstream and downstream movement, of the Western Minnow in the Blackwood River main Channel.

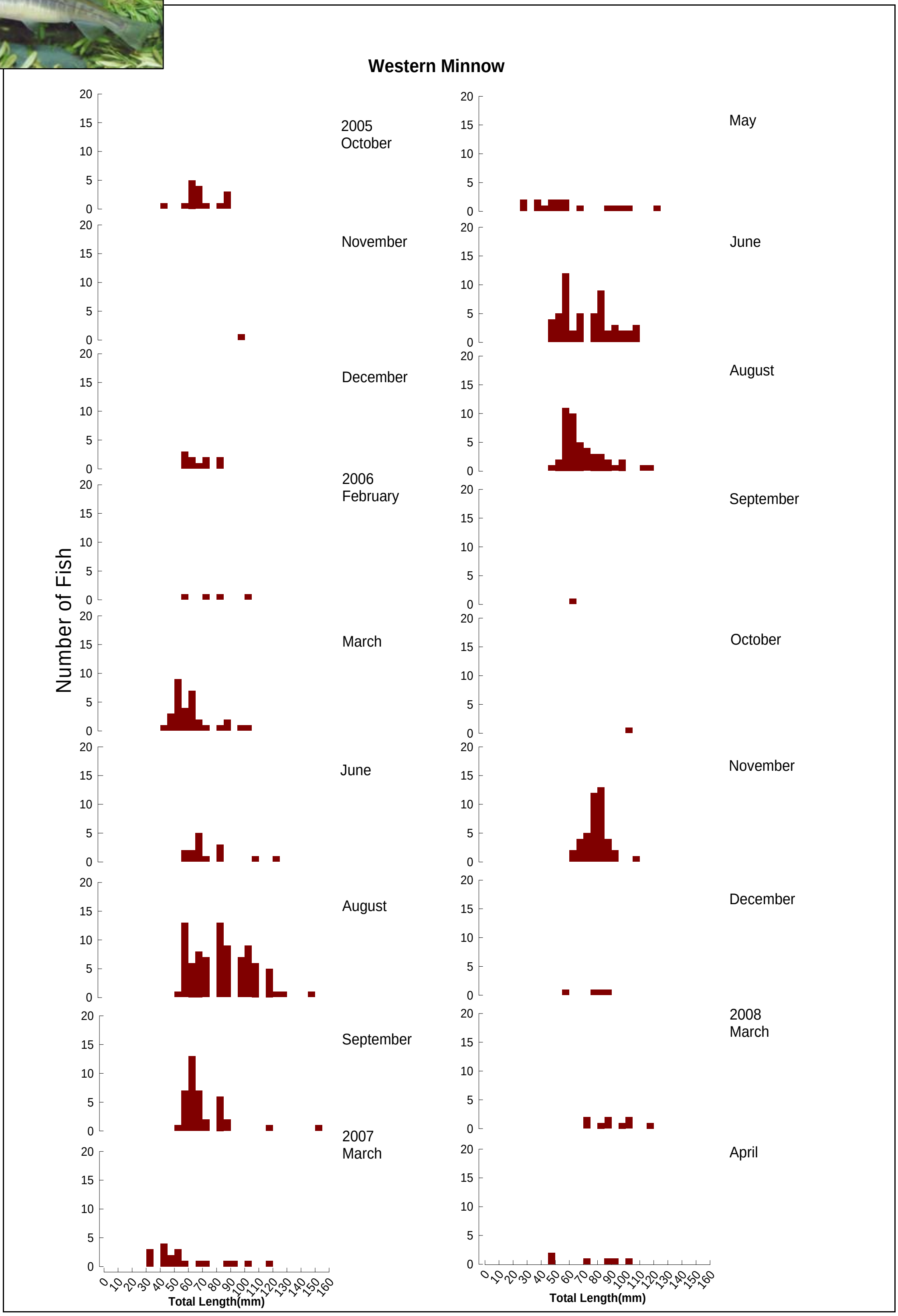


Figure 28 Length-frequency histograms of Western Minnow from Denny Road in the Blackwood River main channel.

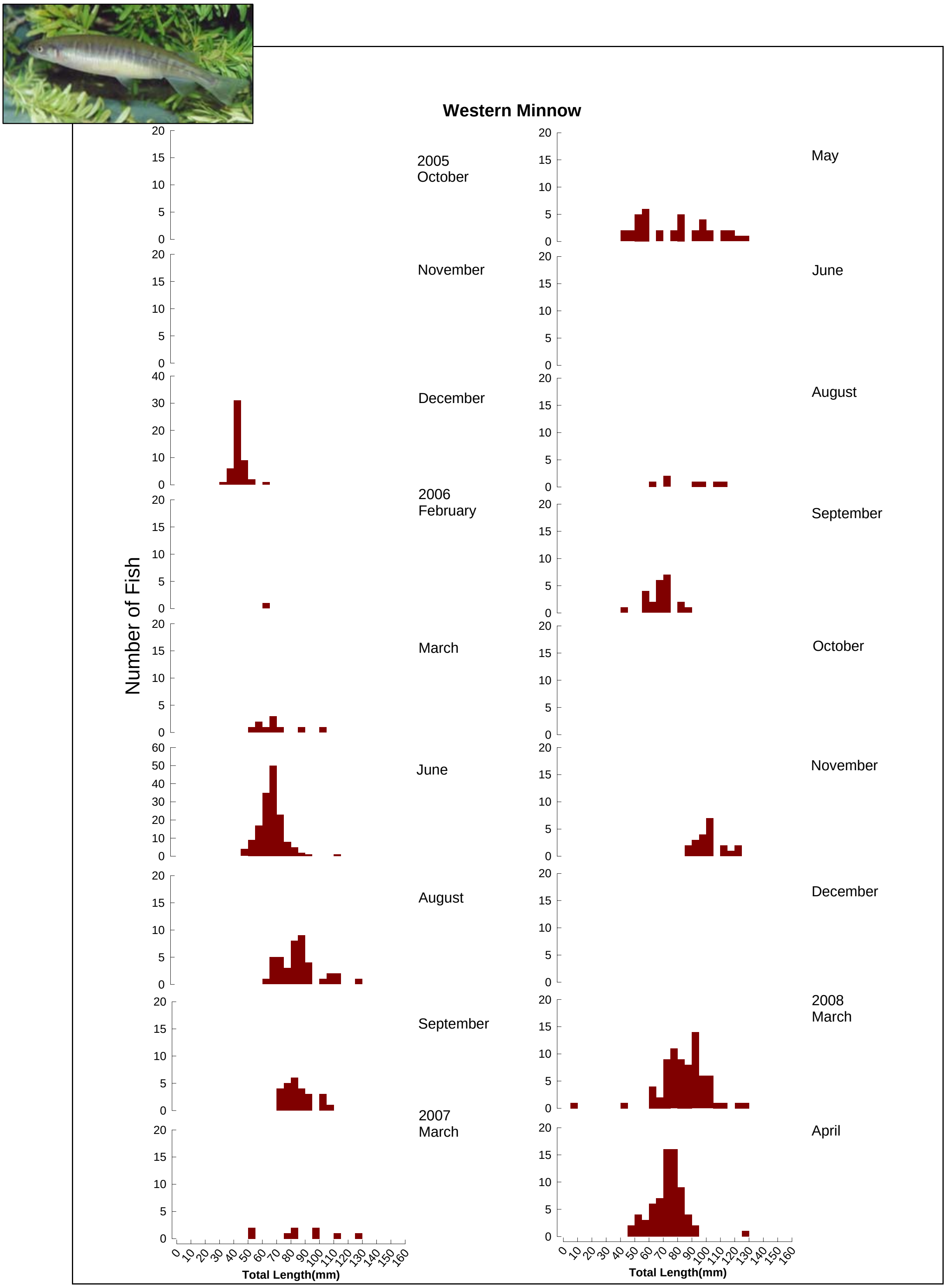


Figure 29 Length -frequency histogram of Western Minnow from Milyeannup Pool in the Blackwood River main channel.

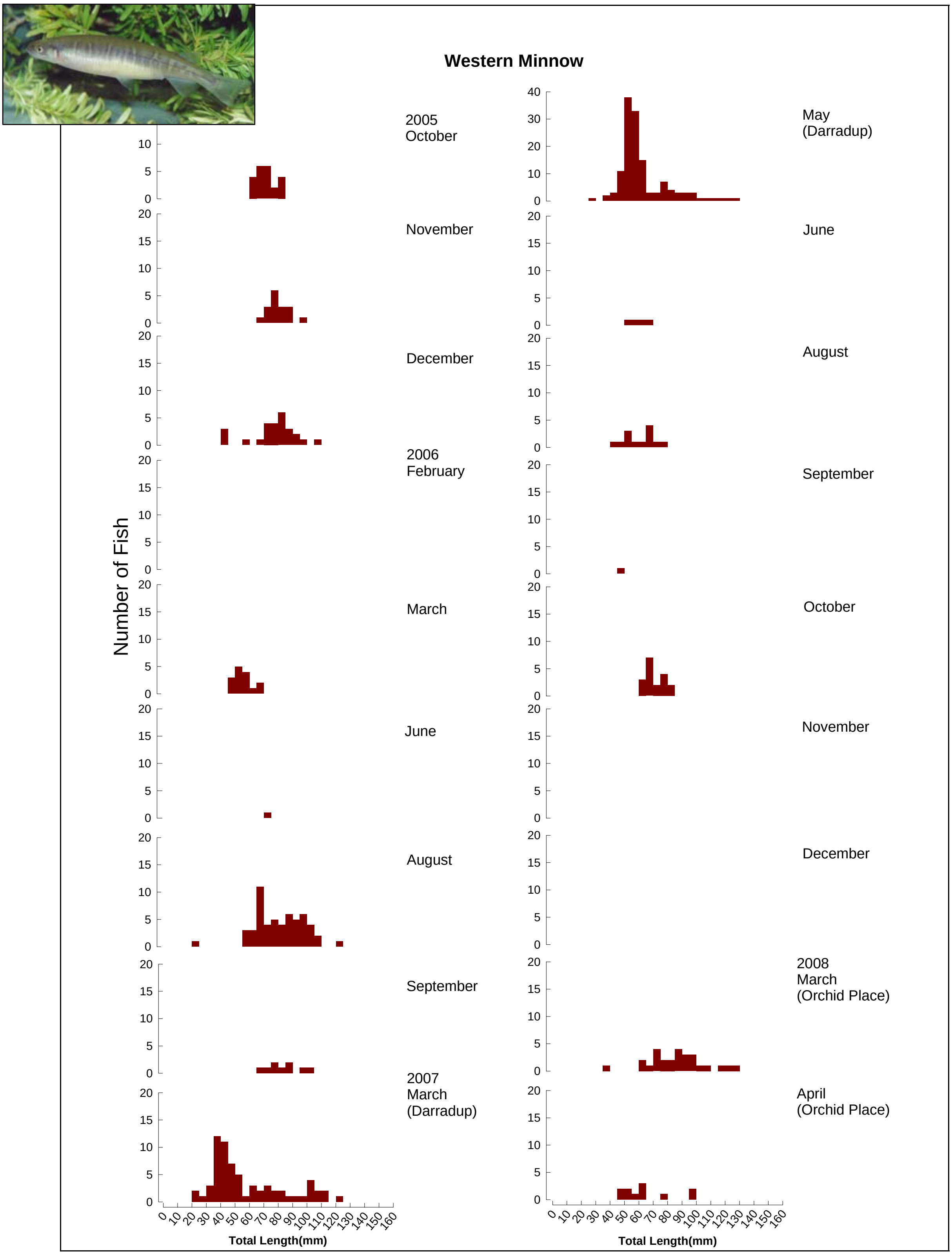


Figure 30 Length-frequency histograms of minnows captured at Jalbarragup/Darradup/Orchid Place in the Blackwood River main channel.

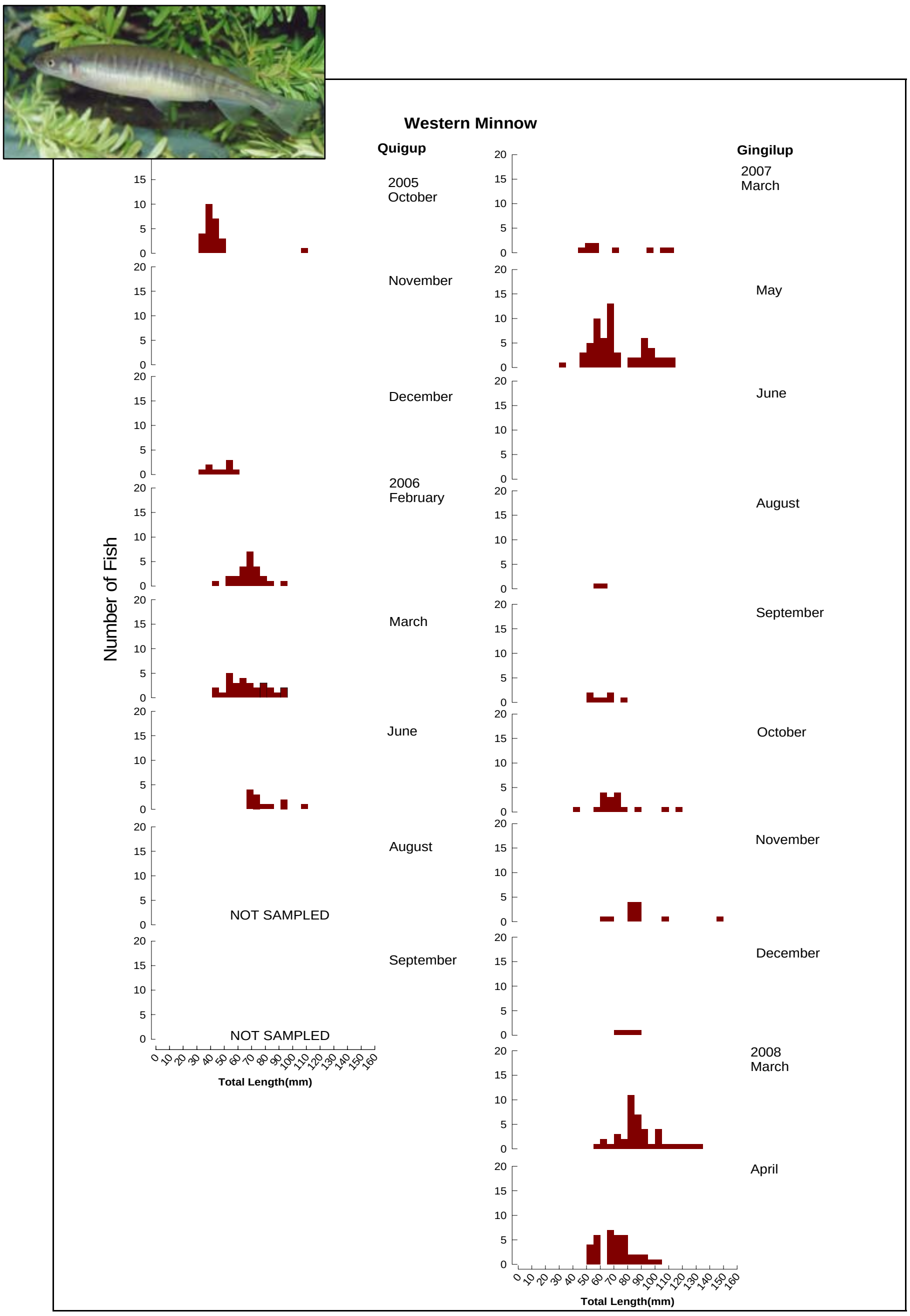


Figure 31 Length-frequency histograms of Western Minnow at Quigup and Gingilup in the Blackwood River main channel.

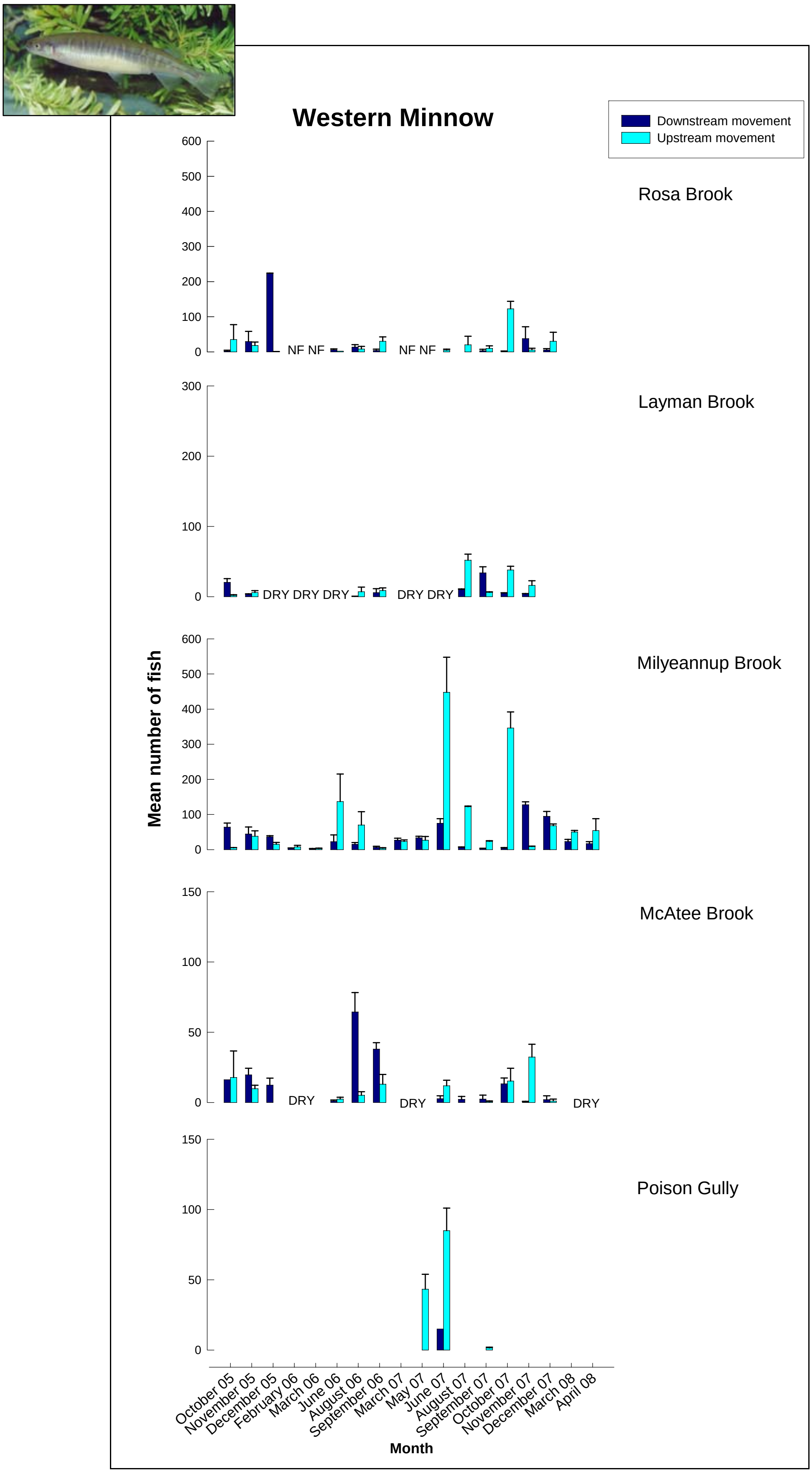


Figure 32 Upstream and downstream movement of Western Minnow in the tributaries.

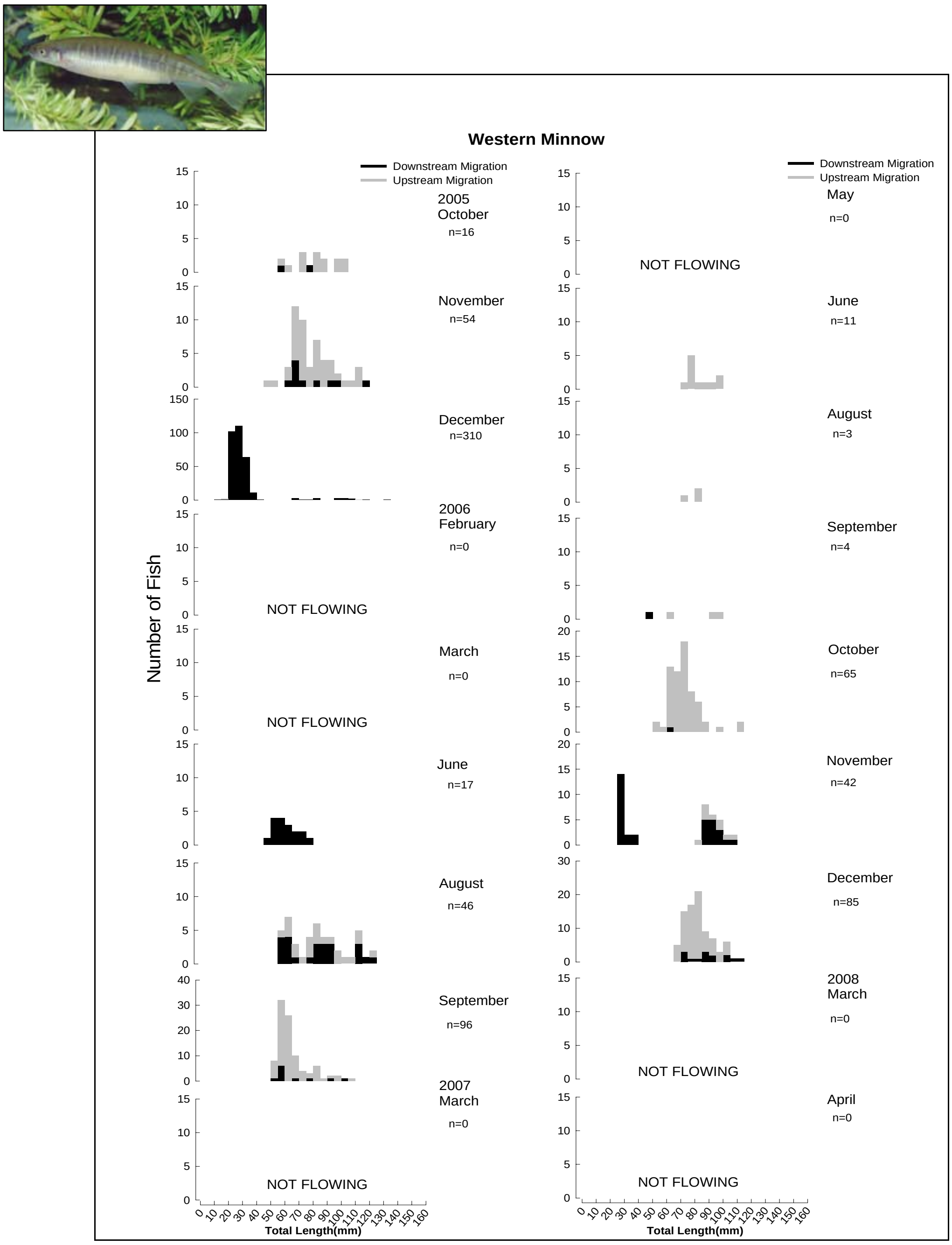


Figure 33 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Minnow in Rosa Brook.

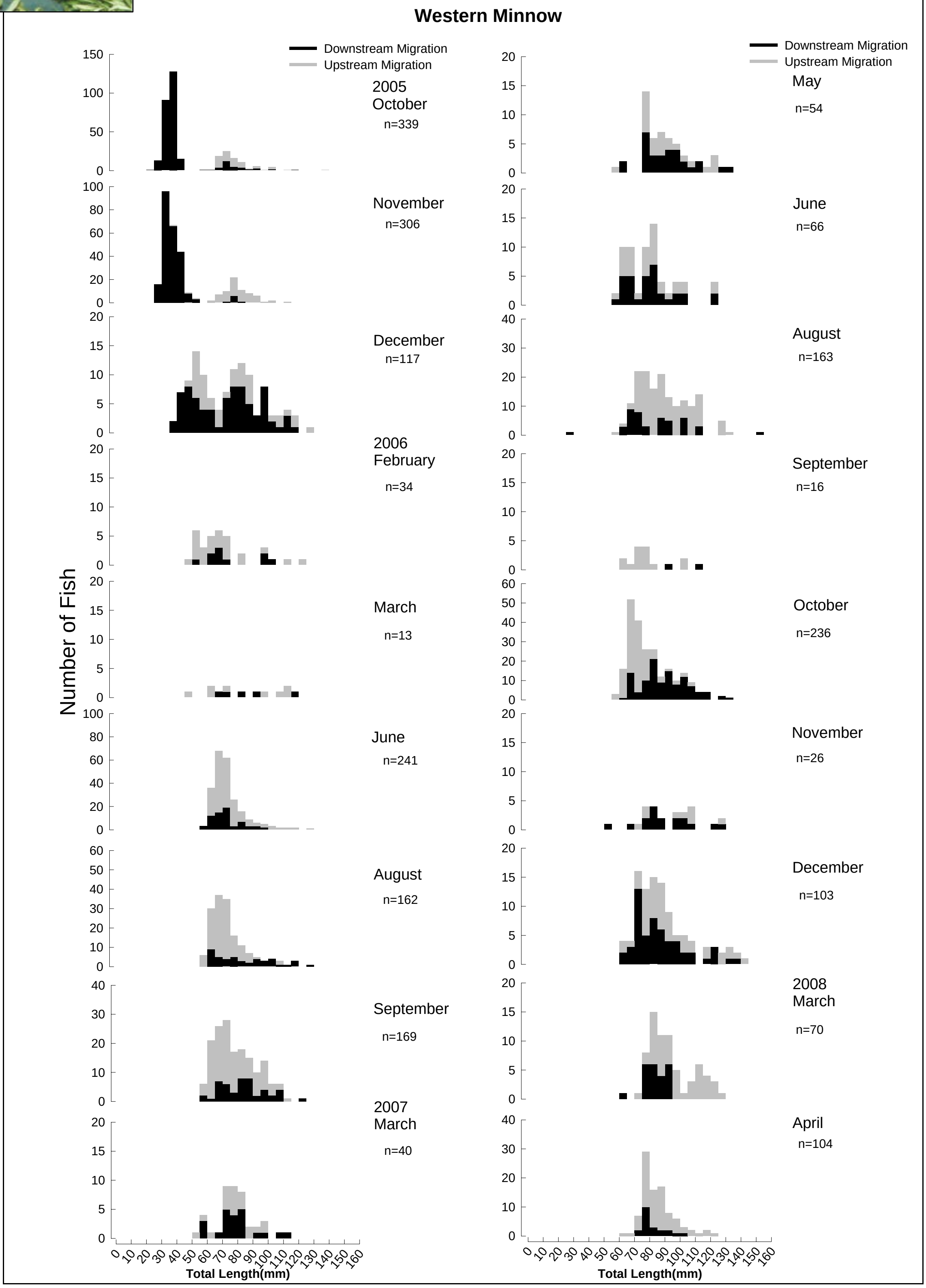


Figure 34 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Minnow in Milyeannup Brook.

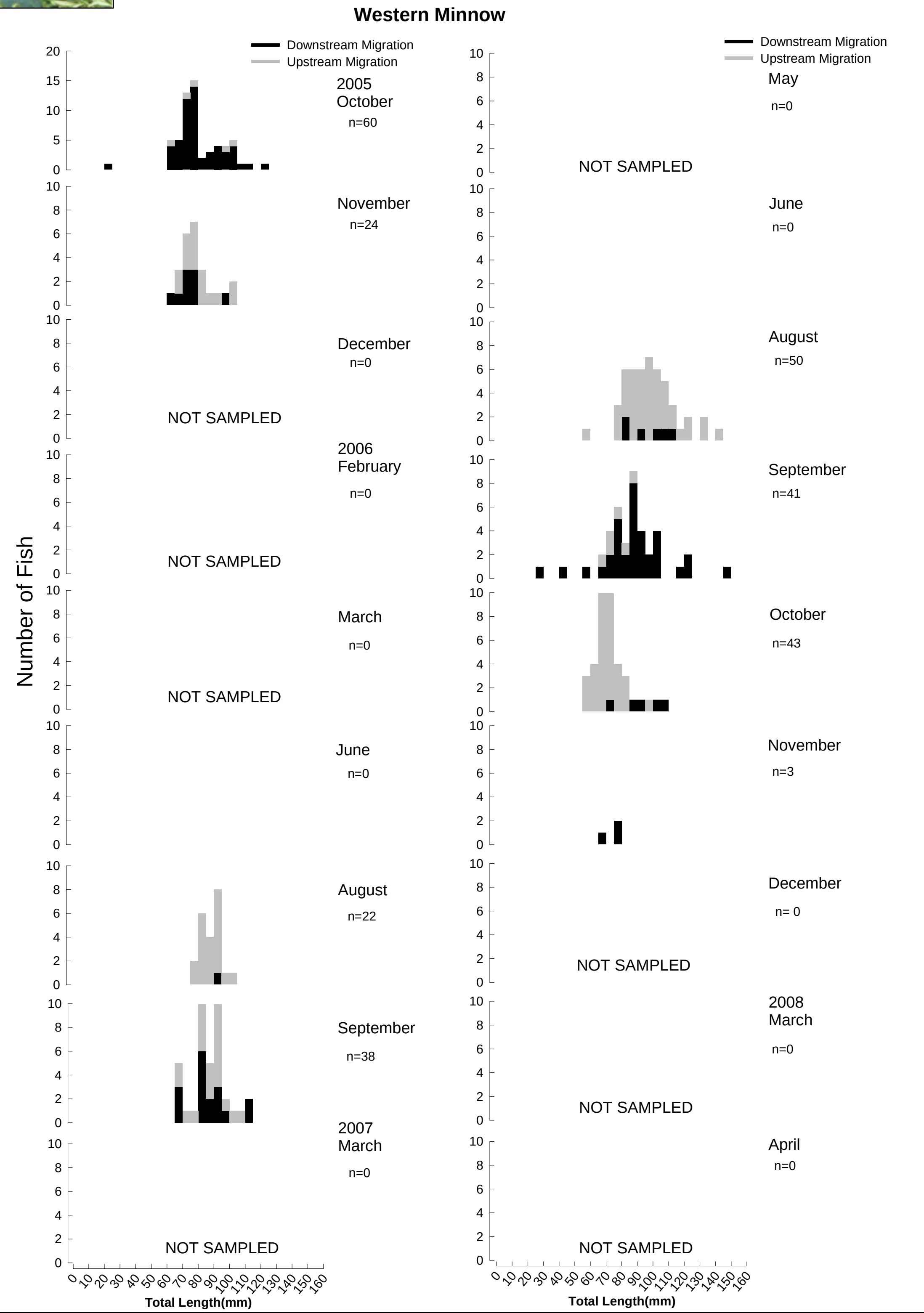


Figure 35 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Minnow in Layman Brook.

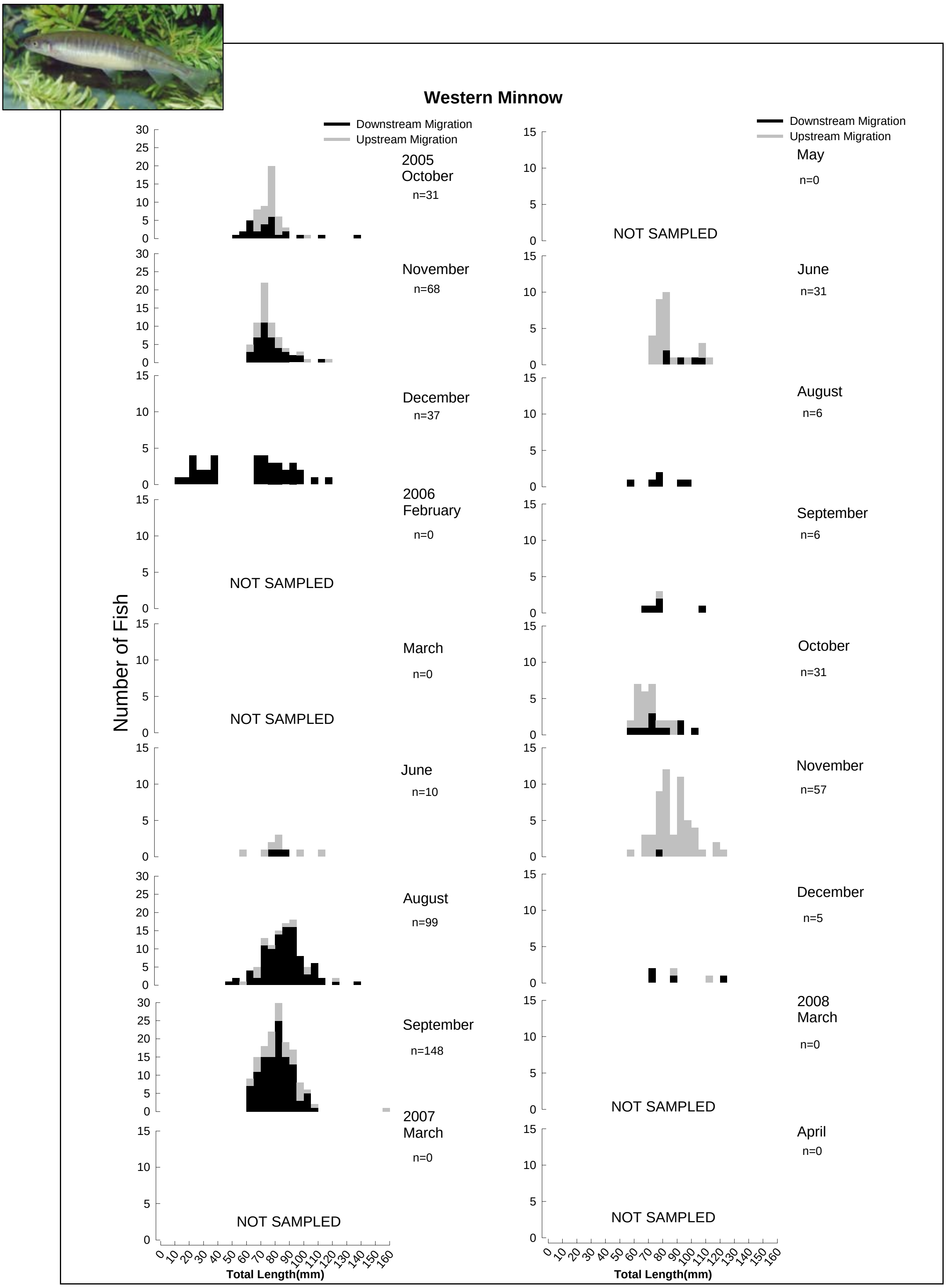


Figure 36 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Minnow in McAtee Brook.

perennial Milyeannup Brook occurred at least one month earlier in both 2006 and 2007 than in Rosa Brook (Figure 32). Similarly, in Poison Gully, in May and June 2007, there was considerable movement into this system by the species. There was limited movement of adults into the other tributaries at this time. Within Milyeannup Brook, there were large scale downstream movements in late spring and early summer (Figure 32). Adults also left the stream in early summer.

Examination of length-frequency histograms of fish caught in main channel sites compared to tributary sites again revealed that the vast majority of Western Minnows captured less than 40 mm TL were only found within the tributaries (Figures 33-36). This, in combination with the strong upstream migration of adults prior to the known spawning period (i.e. winter/early spring) strongly suggests that breeding takes place within tributaries and that these habitats are therefore vital spawning areas for this species. The authors are currently undertaking micro-chemical examination of the otoliths of this species (and also Balston's Pygmy Perch and the Mud Minnow) to compare with the water chemistry of the tributaries (undertaken by Edith Cowan University). This research aims to provide additional evidence of the relative importance of the different systems to in terms of providing spawning habitats for these species.

The upstream and downstream migration of the Western Minnow in the tributaries were both previously found to be positively correlated with the mean discharge from the tributaries during the major flow period (Beatty *et al.* 2006). With the addition of the 2007 migration period, this relationship was still evident; however, no longer significant at $p < 0.05$ (although upstream was significant at $p < 0.1$, and downstream at $p = 0.12$, see Figures 37, 38, Table 5). The relationship between the strength of upstream and downstream migrations of Western Minnow into the tributaries and the mean discharge out of those tributaries during the major flow periods will be further tested during the additional sampling scheduled for 2008 and 2009.

The strength of upstream and downstream movement of the Western Minnow during this major migration period in tributaries was positively and significantly related ($r^2 = 0.71$, $p = 0.009$, Figure 39). This indicates that upstream movement of Western Minnows into tributaries can be used to predict the subsequent downstream movement of the species; that is, the return of those mature individuals moving back down into the main channel of the Blackwood River and also the subsequent degree of downstream recruitment of juveniles back into the Blackwood River.

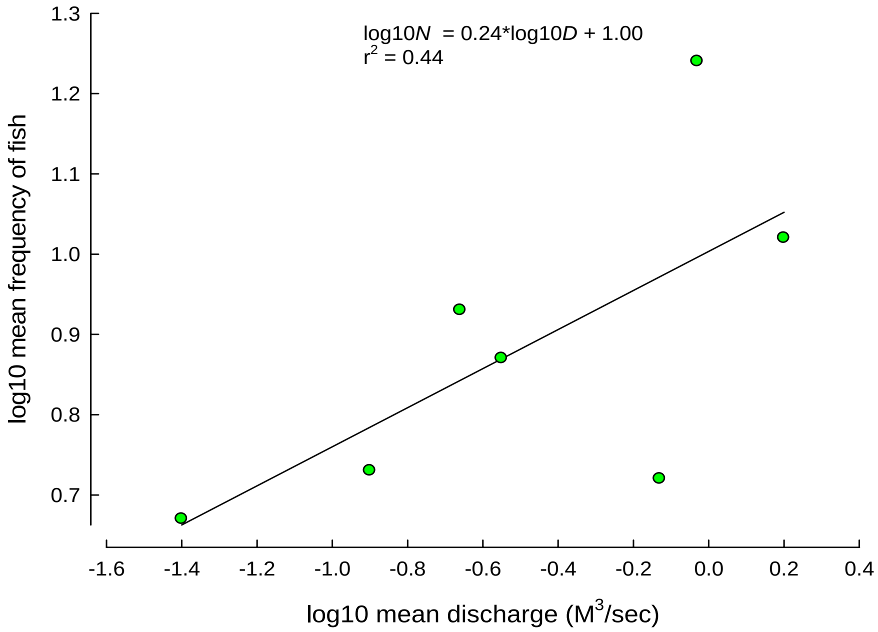


Figure 37 Relationship between the mean strength of upstream migration of Western Minnows within the major flow period (August and December 2005/06-2007) and the mean discharge in the four tributaries during that period. N.B. Data were log10 transformed and migration was standardised for effort, see text for details.

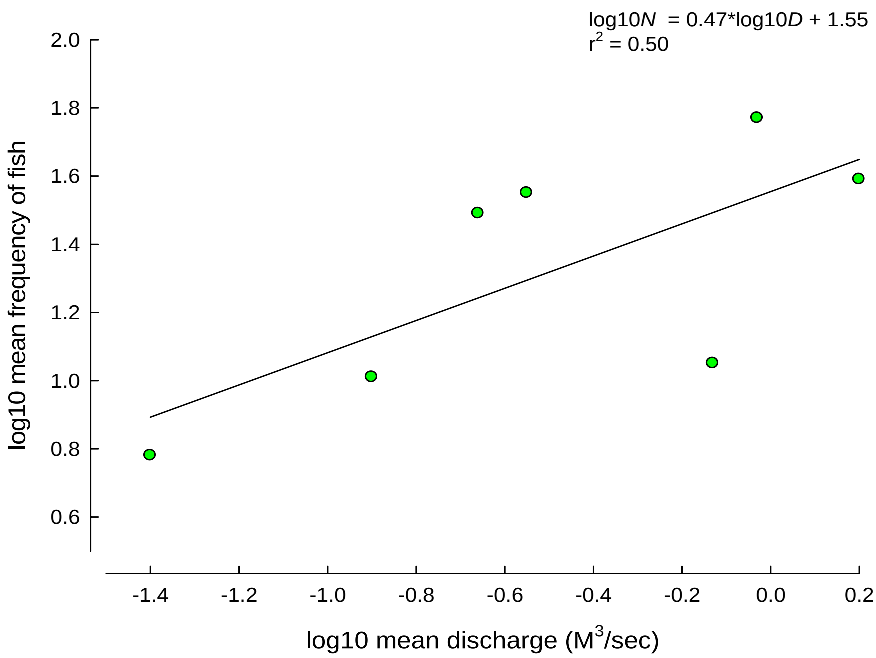


Figure 38 Relationship between the mean strength of downstream migration of Western Minnows within the major flow period (August to December 2005/06-2007) and the mean discharge in the four tributaries during that period. N.B. Data were log10 transformed and migration was standardised for effort, see text for details.

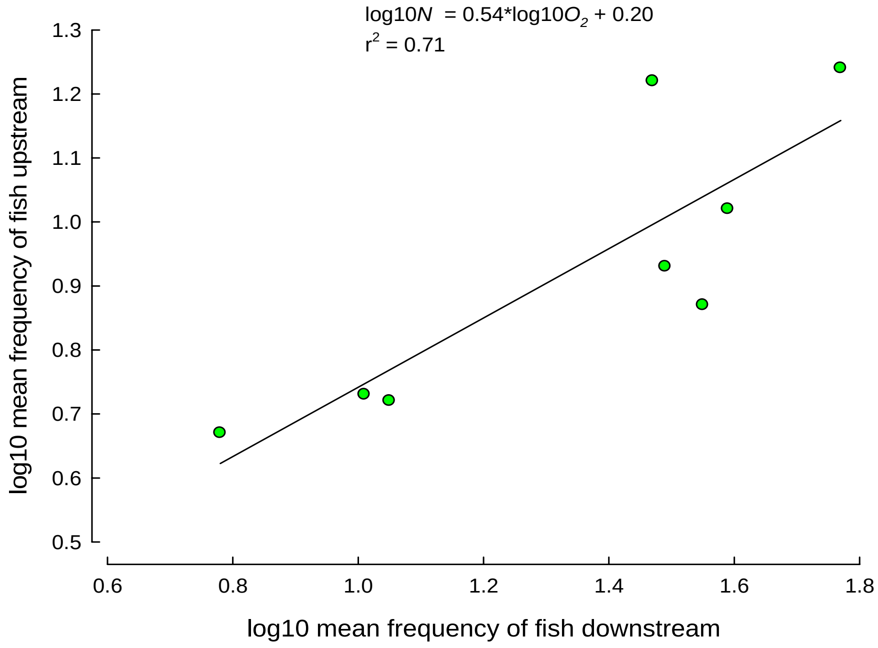


Figure 39 Relationship between the mean upstream and downstream migration of Western Minnows in the four tributaries within the major flow period (August to December 2005/06-2007) N.B. Data were log10 transformed and migration was standardised for effort, see text for details.

Table 5 Correlations between upstream and downstream movement of Western Minnows in the tributaries of the Blackwood River and prevailing environmental variables during the major migration periods in 2005/06 and 2007. N.B. Data were log10 transformed, * denotes correlation is significant at the 0.05 level ** at 0.01 level (2-tailed).

		Log temperature	Log conductivity	Log pH	Log O2	Log discharge	Log NTU	Downstream movement
Log conductivity	Pearson Correlation	.560						
	Sig. (2-tailed)	.149						
Log pH	Pearson Correlation	.127	-.311					
	Sig. (2-tailed)	.764	.453					
Log O2	Pearson Correlation	.022	.301	-.580				
	Sig. (2-tailed)	.958	.469	.132				
Log discharge	Pearson Correlation	.140	.731	.022	-.174			
	Sig. (2-tailed)	.765	.062	.963	.709			
Log NTU	Pearson Correlation	.292	.951(*)	-.311	-.033	.999(*)		
	Sig. (2-tailed)	.708	.049	.689	.967	.023		
Log downstream movement	Pearson Correlation	-.251	.453	-.419	.017	.708	.465	
	Sig. (2-tailed)	.549	.260	.301	.968	.075	.535	
Log upstream movement	Pearson Correlation	-.345	.220	-.265	-.016	.666	.045	.841(**)
	Sig. (2-tailed)	.402	.601	.527	.971	.102	.955	.009

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Mud Minnow

Habitat associations

The Mud Minnow was only captured in the tributaries of the Blackwood River indicating that isolation of the populations in these systems may be occurring with the main channel effectively acting as a barrier. This is also evidenced by the substantial genetic differences between these tributary populations (Phillips *et al*. 2007). Currently, otolith and water microchemistry analysis (in conjunction with Edith Cowan University) is being conducted to further confirm that each of these populations complete their lifecycle within these systems.

As with the previous sampling period (Beatty *et al.* 2006), the species was again recorded in Poison Gully, Milyeannup Brook, Rosa Brook and McAtee Brook. Mud Minnows naturally exist in low abundances compared to other native species (such as the Western Minnow) as was the case in this study with the species being recorded in lower numbers than any other native freshwater fish. Morgan & Beatty (2005) also reported this species in the nearby St John Brook and Red Gully. The upper reaches of Rosa Brook, which receive Leederville Aquifer discharge, are a known refuge for the species in that system (Morgan *et al.* 2004a) and this population has the greatest genetic diversity (Phillips *et al*. 2007).

Migration patterns

While the overall numbers of Mud Minnows captured remained low a large downstream migration of recently metamorphosed Mud Minnows, 82 in total occurred during November 2007 in Milyeannup Brook similar to that in October and November 2005 (Figures 40 & 41). These juveniles, ranging from 16 to 23 mm TL, were captured at the uppermost sampling point i.e. Milyeannup Road, in Milyeannup Brook (Figure 41). This further reinforces the hypothesis proposed in the previous report (Beatty *et al.* 2006) that the upstream habitats of Milyeannup Brook are indeed utilised for spawning. This species is known to have a one year lifecycle (Pen *et al*. 1991) and in the case of Rosa Brook, the breeding period is between August and October (Morgan *et al*. 2004a).

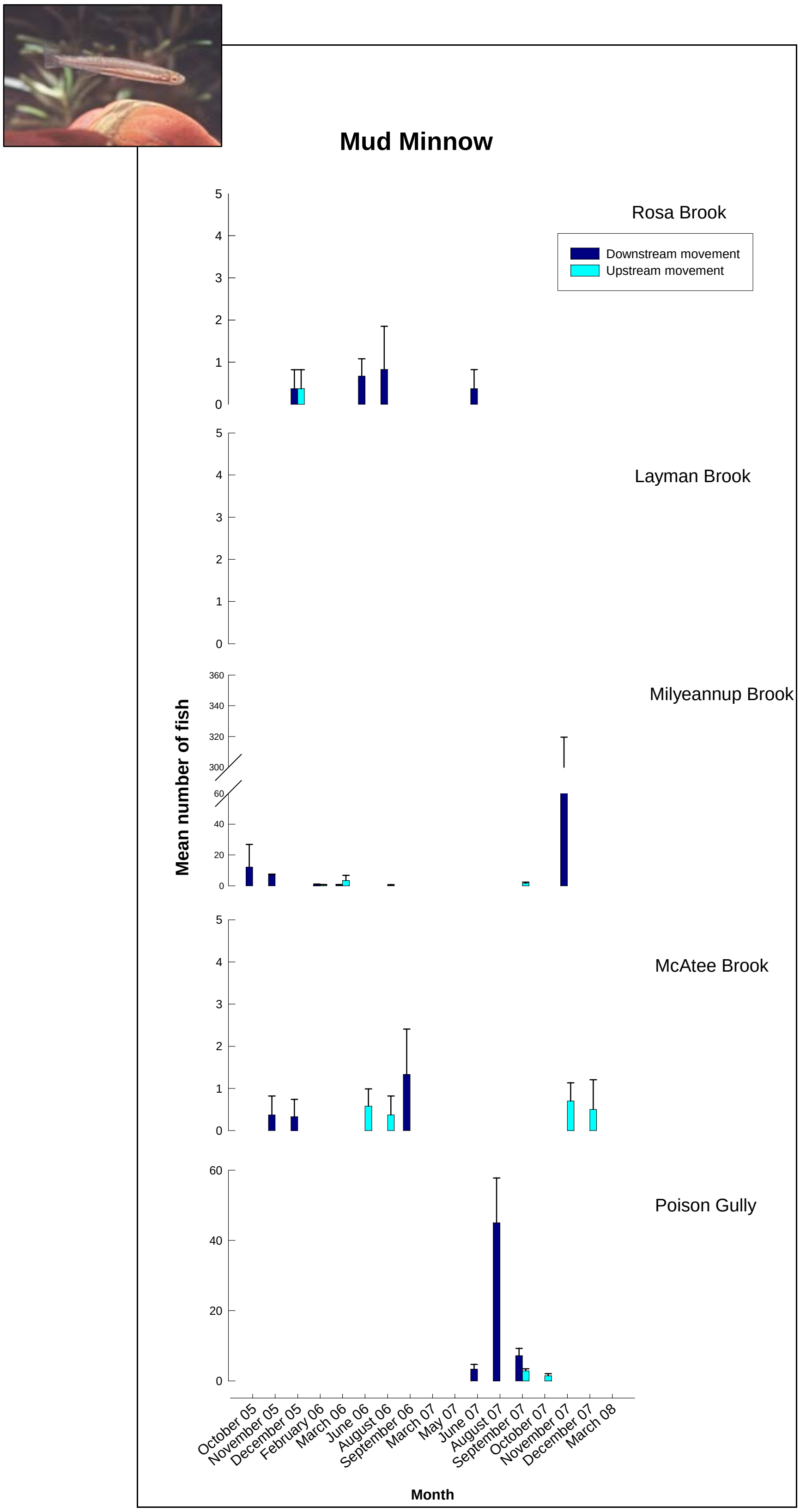


Figure 40 Upstream and downstream movement of Mud Minnow in the tributaries.

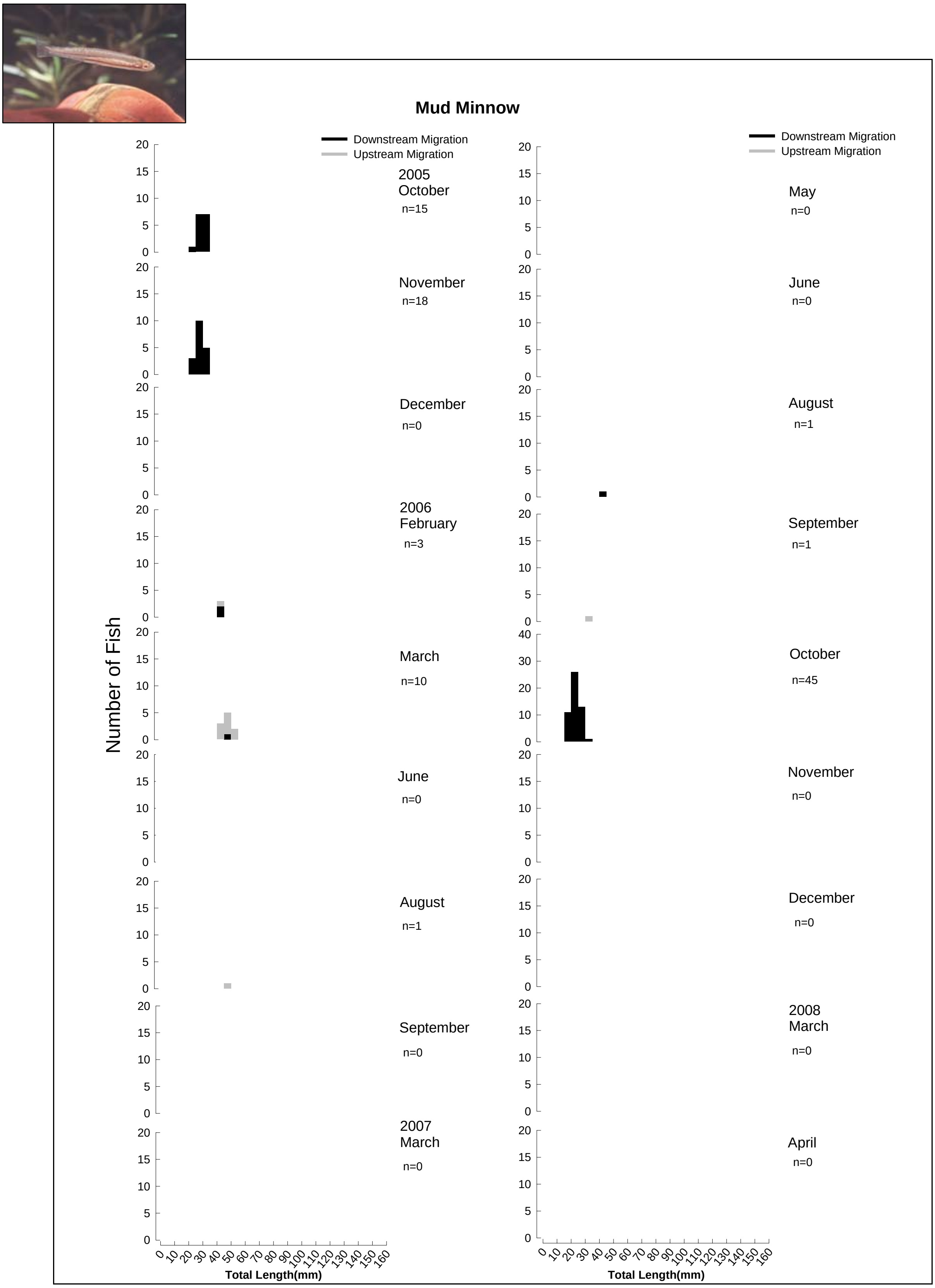


Figure 41 Length-frequency histograms, differentiated by upstream and downstream movement, of Mud Minnow in Milyeannup Brook.

Balston's Pygmy Perch

Habitat associations

Balston's Pygmy Perch is the most restricted fish species found within the Blackwood River catchment and has recently (2006) been listed as *Vulnerable* under the *EPBC* Act and listed as Schedule 1 at State level (*Wildlife Conservation Act*, 1950). Balston's Pygmy Perch was almost entirely captured within Milyeannup Brook with 3160 of the 3177 fish (or 99.46%) being recorded in this stream during 2005/2006 and 1841 of 1897 (97.05%) in 2007/2008. Milyeannup Brook is the critical breeding habitat for this species in the Blackwood River catchment; probably due to the consistency of suitable available habitat facilitated by the permanency of flow due to groundwater discharge in this system. Recent salinity trials conducted by the authors on this species has revealed an acute tolerance of ~8 ppt; compared with ~14 ppt for Western Minnow and Western Pygmy Perch (Beatty *et al.* 2008). This suggests that much of the upper catchment of the Blackwood River is now unsuitable for this endangered species. Furthermore, the tolerance of earlier life history stages of these species (i.e. larvae) is as yet unknown; however, they may have an even lower tolerance of salinity (Beatty *et al.* 2008).

Eight, seven and one individual were captured in McAtee Brook, Rosa Brook and Poison Gully respectively during the 2007/2008 period while a further 46 fish were captured in the Blackwood Main channel at Milyeannup Pool and Gingilup. The lengths recorded for this species Milyeannup Brook were considerably greater than has previously been reported for the species (see Morgan *et al*. 1995). The length-frequency distribution of this species suggest that the modal length of the fish captured in August (50-70 mm TL) are likely to be 1 year old; while those fish greater than 70 mm TL are most likely at the end of their second or third year of life (Figure 43). The relatively high longevity of the Milyeannup Brook population contrasts with those elsewhere that have only been found to live for just over one year (see Morgan *et al*. 1995).

Migration patterns

This species was captured in all but one month in Milyeannup Brook. The major migration patterns of 2007 in Milyeannup Brook i.e. upstream during

June for adult Balston's Pygmy Perch, downstream movement of presumably spent (recently spawned) adults in August and September and downstream migration of juveniles occurring in November and December 2007 (Figure 42). As with the Mud Minnow, the juvenile Balston's Pygmy Perch were captured at the uppermost sampling site Milyeannup Brook, further supporting the conjecture that these species uses the upper reaches for spawning. Visual surveys of the flooded vegetation in the uppermost reaches of the Milyeannup Brook catchment showed habitats similar to those that the species is known to prefer for spawning (Morgan *et al.* 2005).

During 2007 and 2008 larger numbers were captured in the main channel than in the previous year; highlighting the importance of sampling for interannual variations in migration patterns. The bulk of these were captured in Milyeannup Pool (below the mouth of Milyeannup Brook) and Gingilup, thus the species appears to utilise the main channel within the major groundwater intrusion zone downstream from Milyeannup Brook (Figure 43).

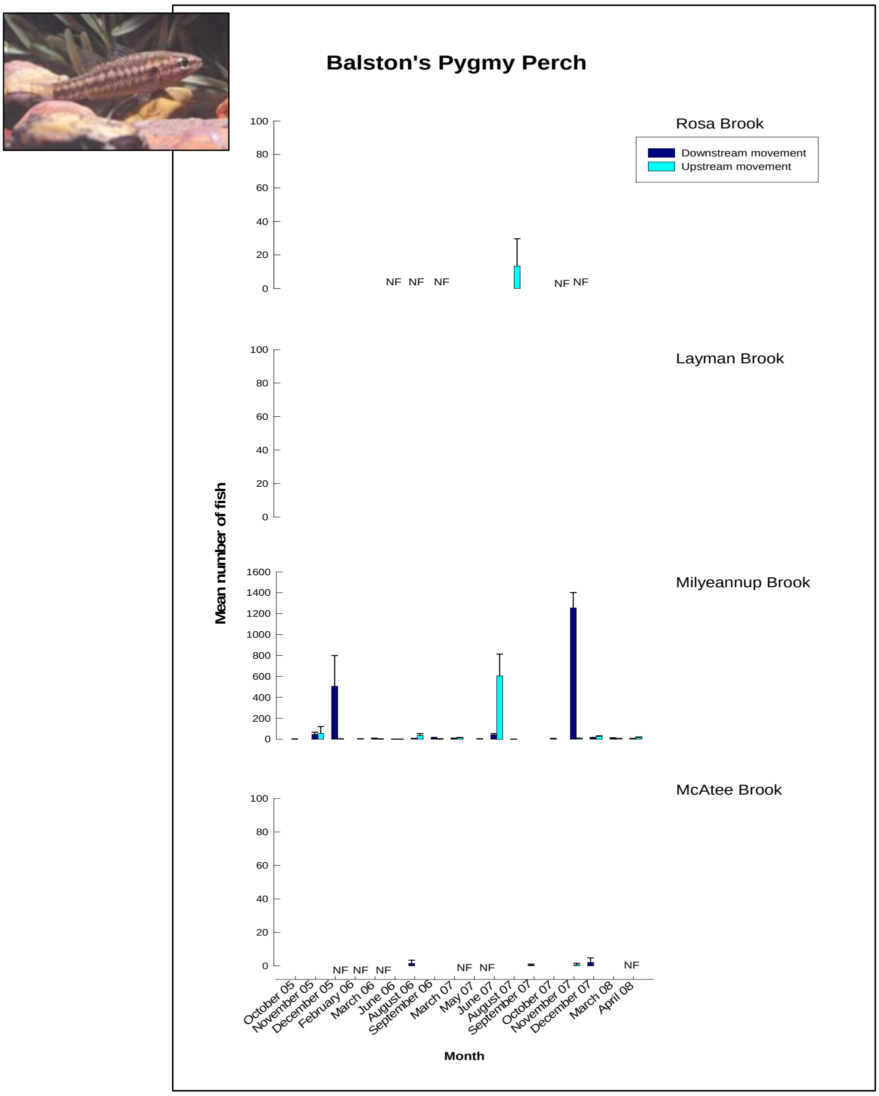


Figure 42 Upstream and downstream movement of Balston's Pygmy Perch in the tributaries.

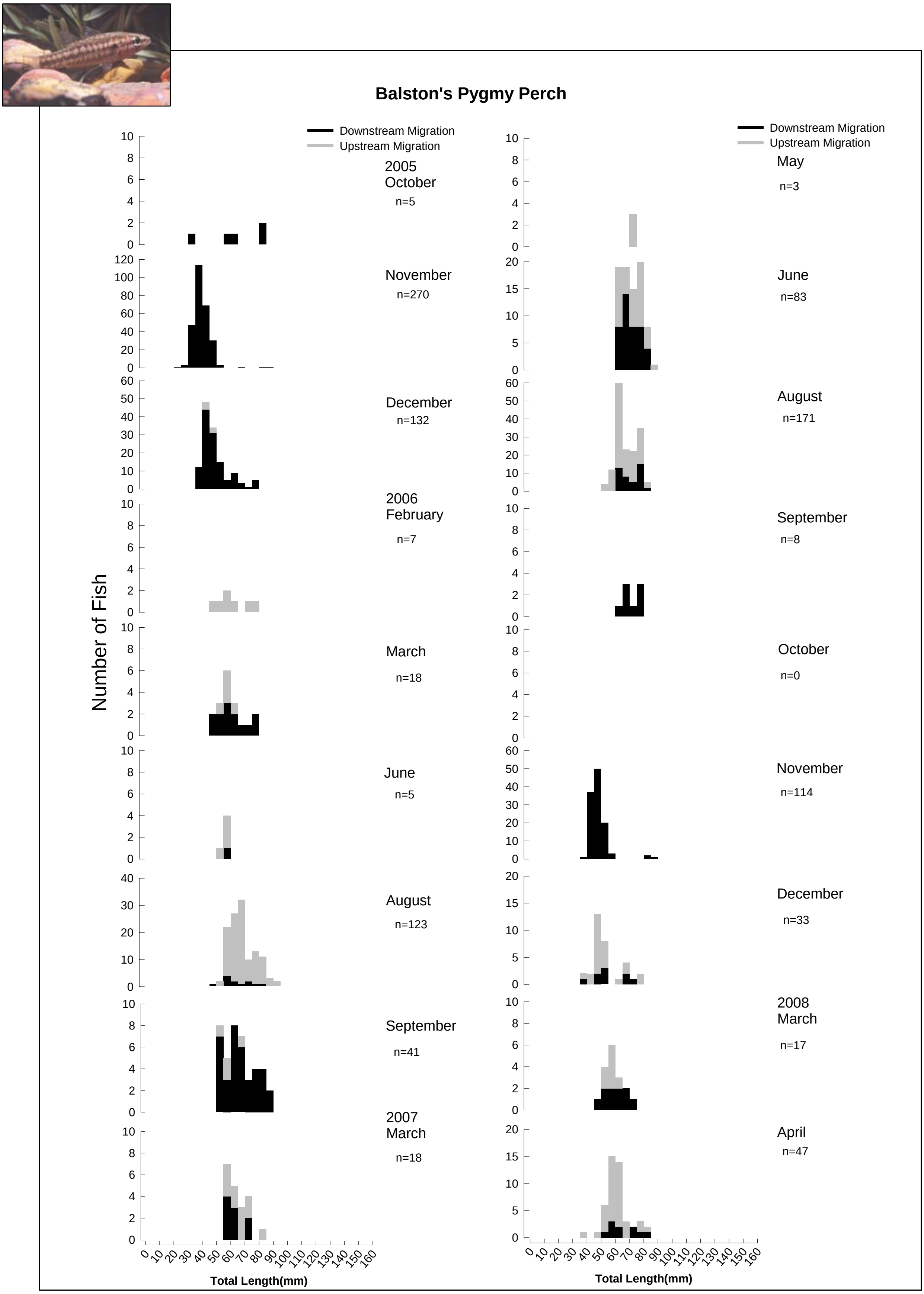


Figure 43 Length-frequency histograms, differentiated by upstream and downstream movement, of Balston's Pygmy Perch in Milyeannup Brook.

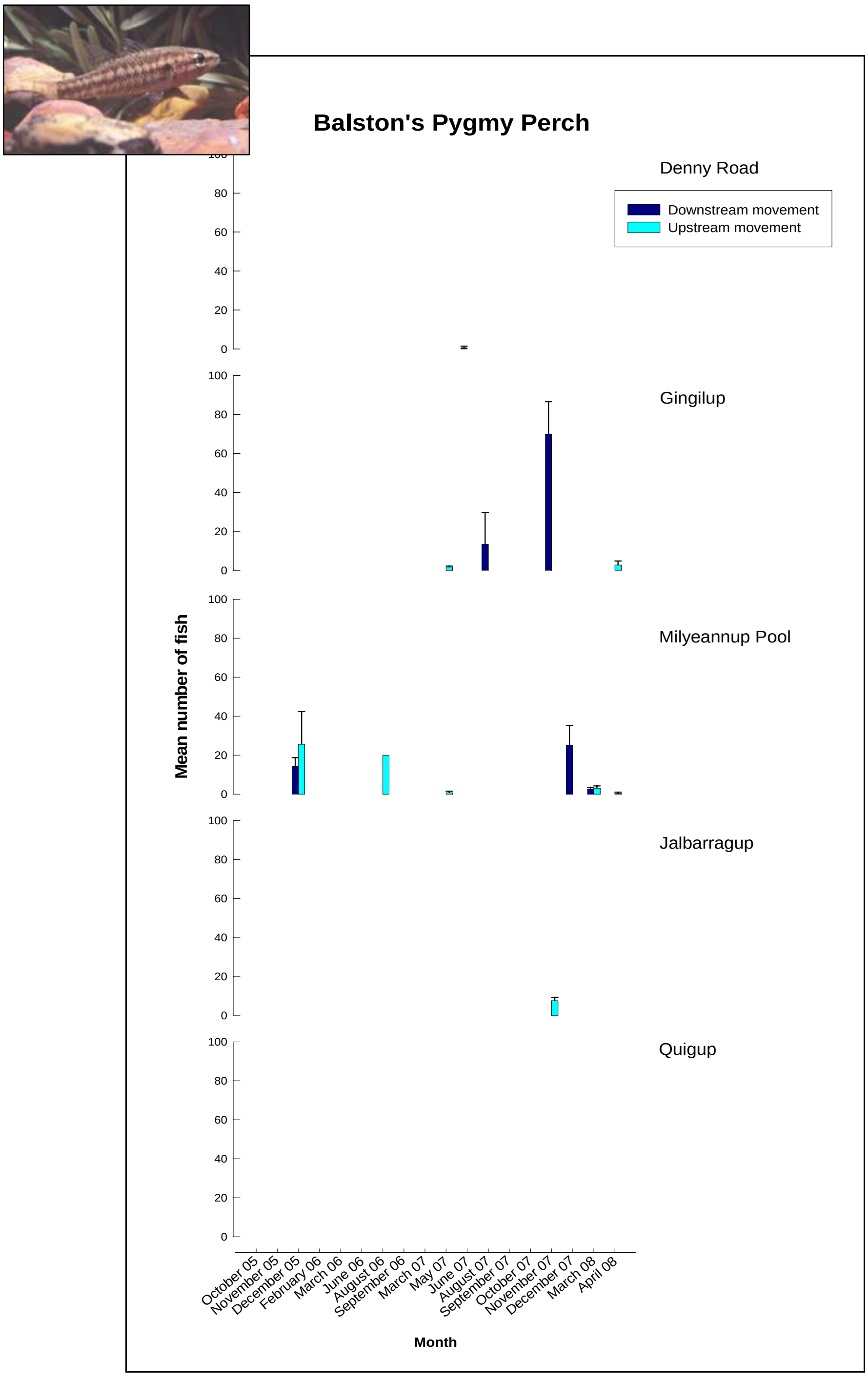


Figure 44 Upstream and downstream migration of Balston's Pygmy Perch in the Blackwood River main channel.

Western Pygmy Perch

Habitat associations

Western Pygmy Perch were recorded moving at each site within Rosa Brook, Milyeannup Brook and McAtee Brook on each sampling occasion (Figure 45). This species was not captured in Layman Brook. In contrast to 2006, larger numbers of Western Pygmy Perch were captured in the main channel during 2007/2008. Increased spring discharges in the tributaries during 2007 compared to 2006 may have resulted in greater movement of fish into the main channel from the tributaries.

The predominant and consistent captures of this species in the tributaries compared to the main channel suggests a preference tributary habitats. For example, a relatively low tolerance to saline conditions may have been expected, however, salinity trials (Beatty *et al.* 2008) found that the adults of the species are as tolerant as Western Minnow to sudden changes in salinity (LD_{50} = ~14ppt). Therefore, other life stages of the species (e.g. sperm viability or juvenile tolerances) may be less tolerant to elevated salinities that exist in the main channel (that is planned to be evaluated by the authors) and/or there exist other relatively unfavourable conditions in the main channel to the species.

Migration patterns

In contrast to main channel captures, where fish were invariably captured moving downstream, both upstream and downstream movements of Western Pygmy Perch were recorded at most tributary sites on most sampling occasions (Figures 45 and 46). Migration strength was greatest within Rosa Brook; which appeared to support the largest population of Western Pygmy Perch of any system.

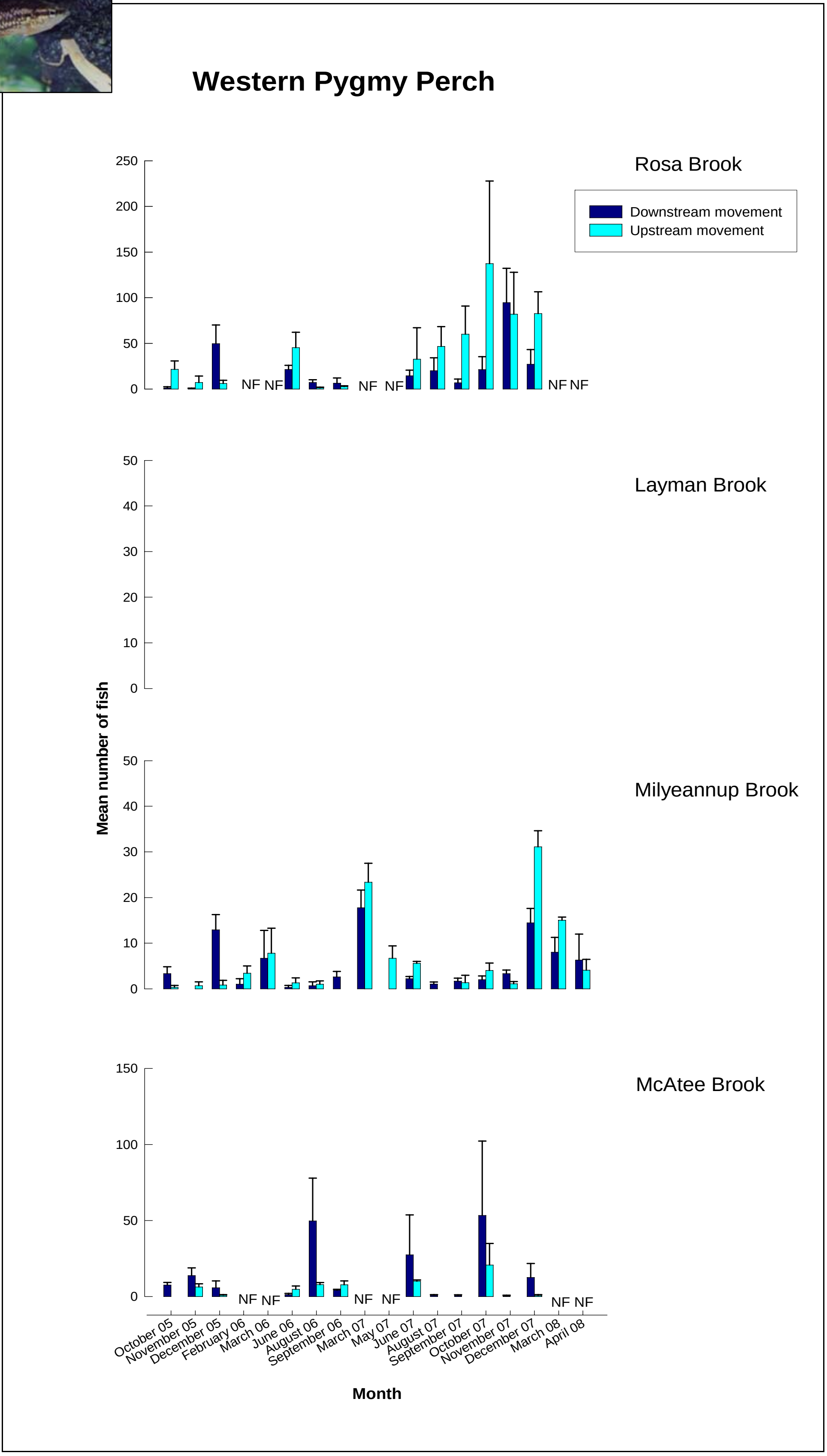


Figure 45: Upstream and downstream migration of Western Pygmy Perch in the tributaries.

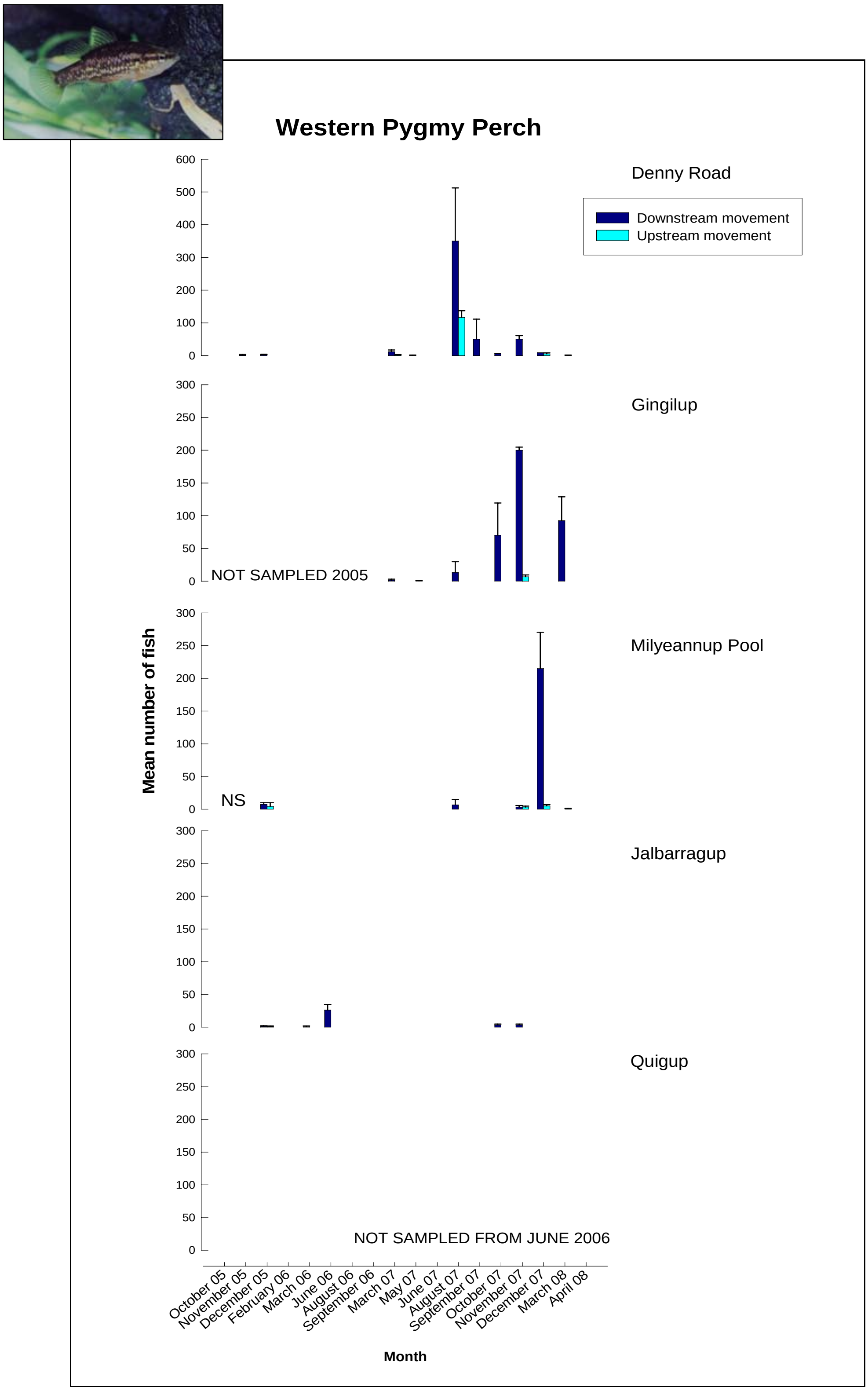


Figure 46: Upstream and downstream migration of Western Pygmy Perch in the Blackwood River main channel.

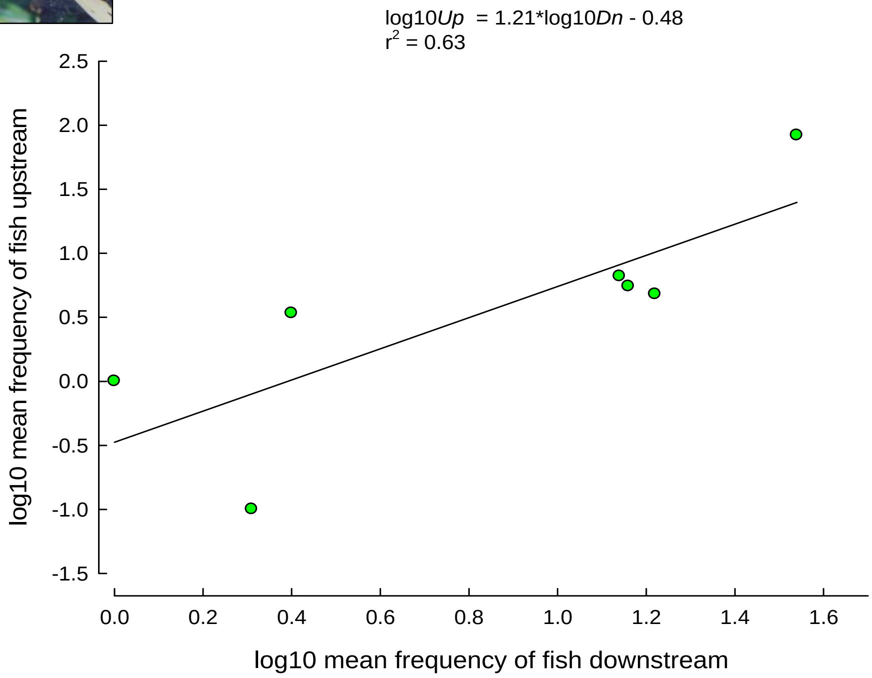


Figure 47 Relationship between the mean upstream and downstream migration of Western Pygmy Perch in the four tributaries within the major flow period (August to December 2005/06-2007) N.B. Data were log10 transformed and migration was standardised for effort, see text for details.

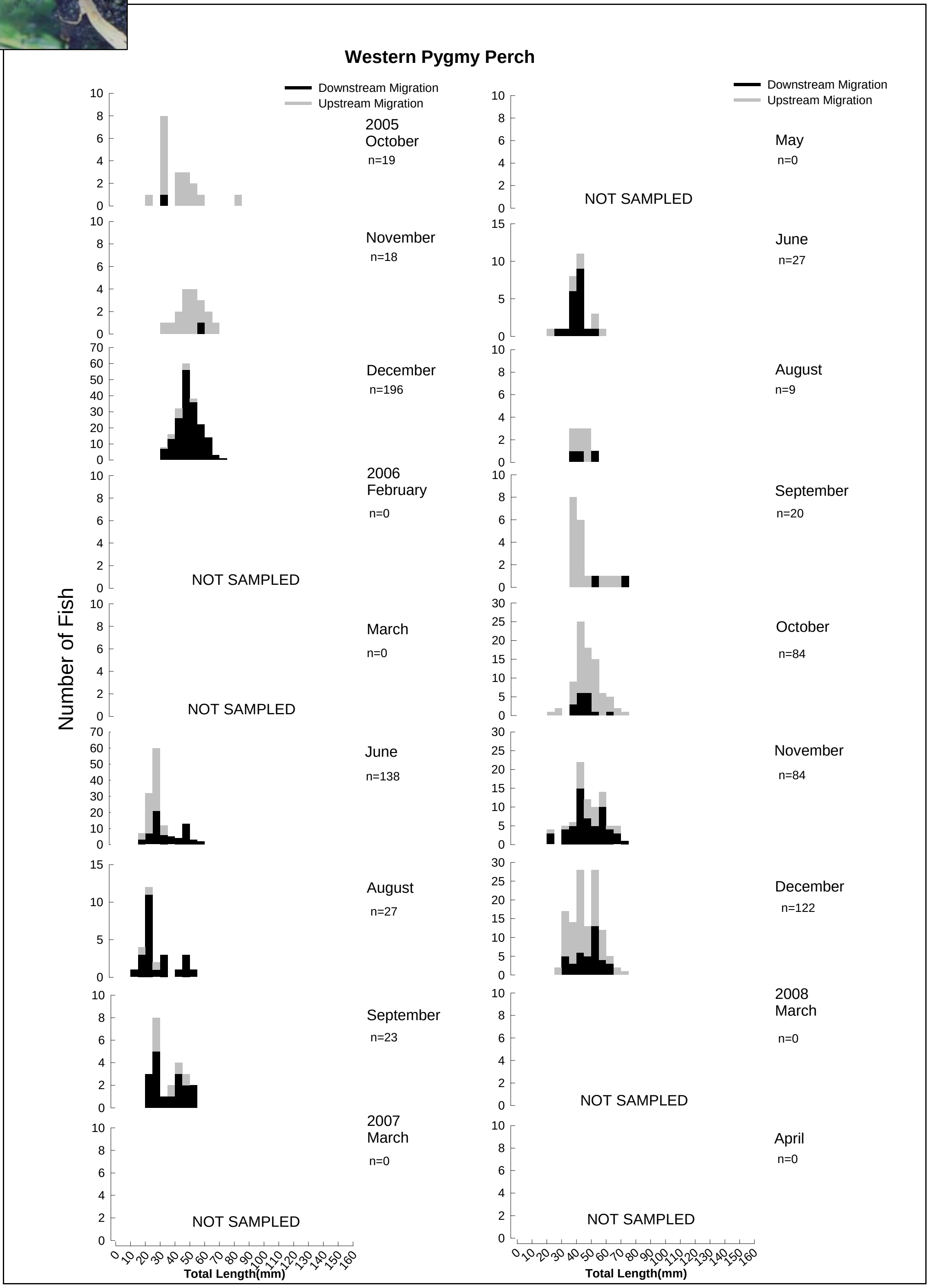


Figure 48 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Pygmy Perch in Rosa Brook.

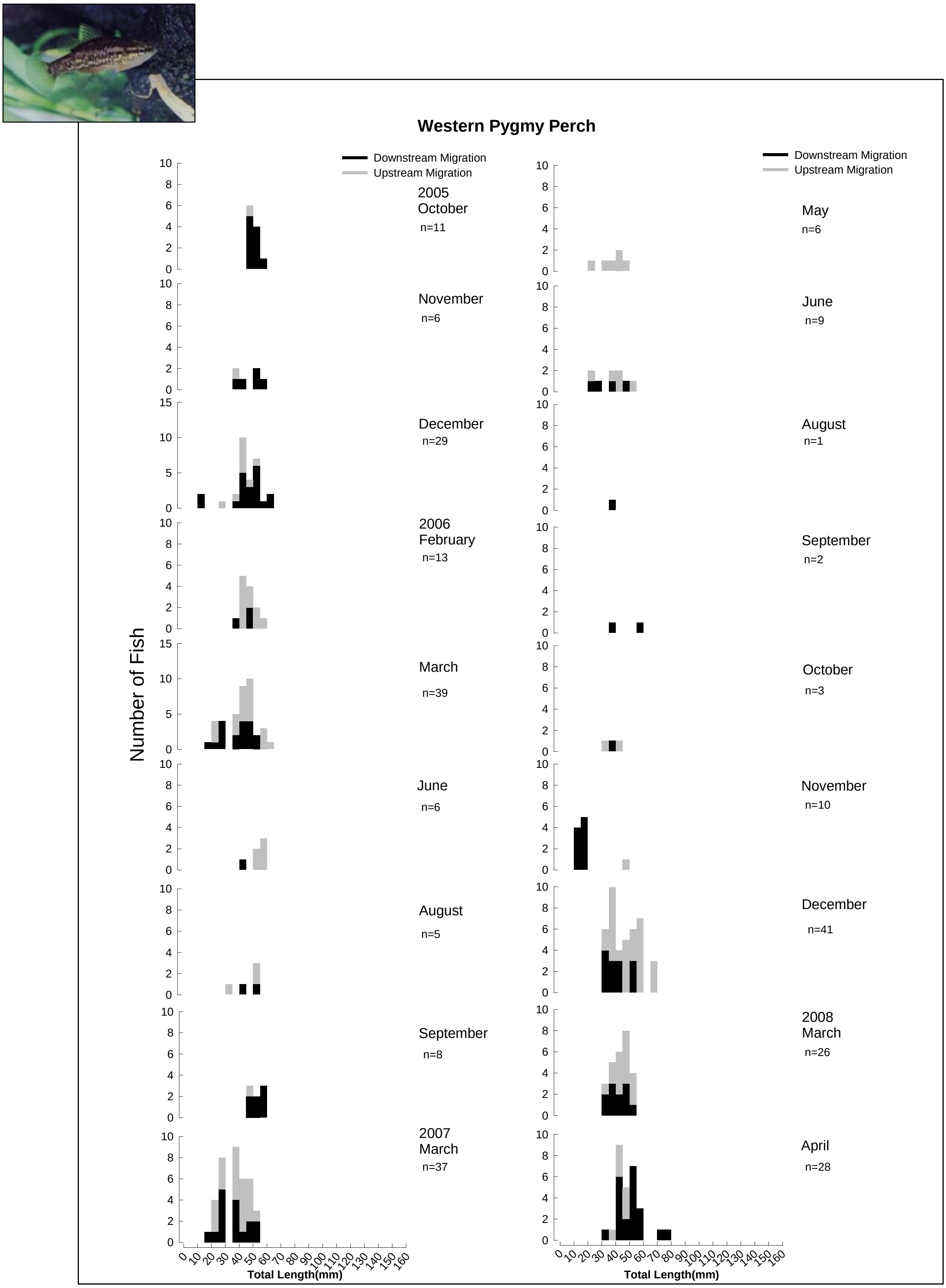


Figure 49 Length-frequency distributions, differentiated by upstream and downstream movement, of Western Pygmy Perch in Milyeannup Brook.

In contrast to other tributaries, within the perennial Milyeannup Brook, there continued to be upstream and downstream migrations throughout summer and early autumn; facilitated by the continuation of flows in this system resulting from direct groundwater discharge (Figure 49).

Previously, the upstream movement of the Western Pygmy Perch in tributaries was positively correlated with mean dissolved oxygen levels during the flow period. However, this relationship was no longer evident following the additional migration period in 2007 (Table 6). However, relationships between the environmental variables in the tributaries and the upstream and downstream movement of Western Pygmy Perch will be re-analysed following the scheduled sampling in 2008 and 2009.

As was found with the Western Minnow, mean upstream and downstream movement of this species during the major migratory periods was significantly ($p = 0.032$) positively related (Figure 47).

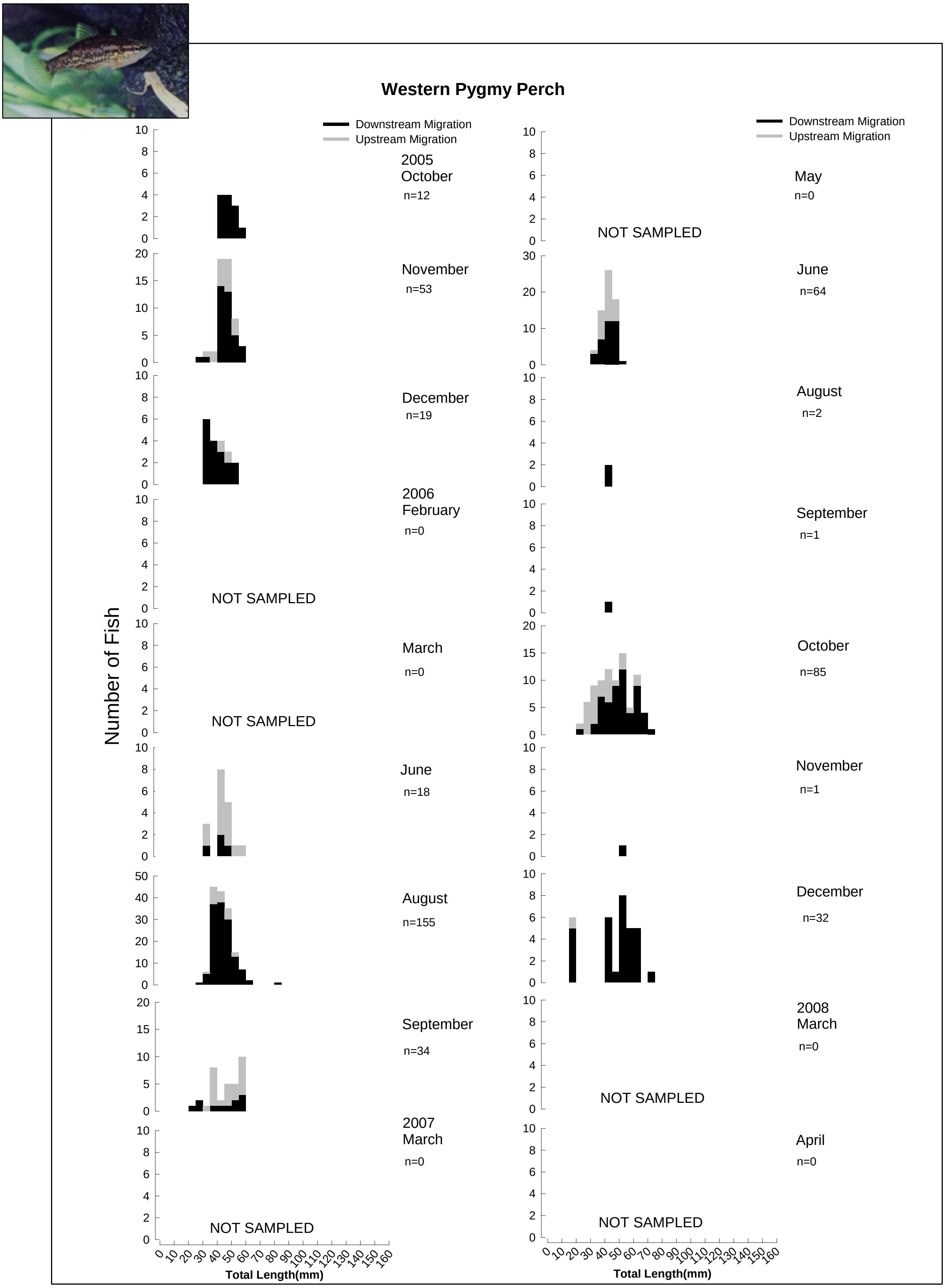


Figure 50 Length-frequency distributions, differentiated by upstream and downstream movement, of Western Pygmy Perch in McAtee Brook.

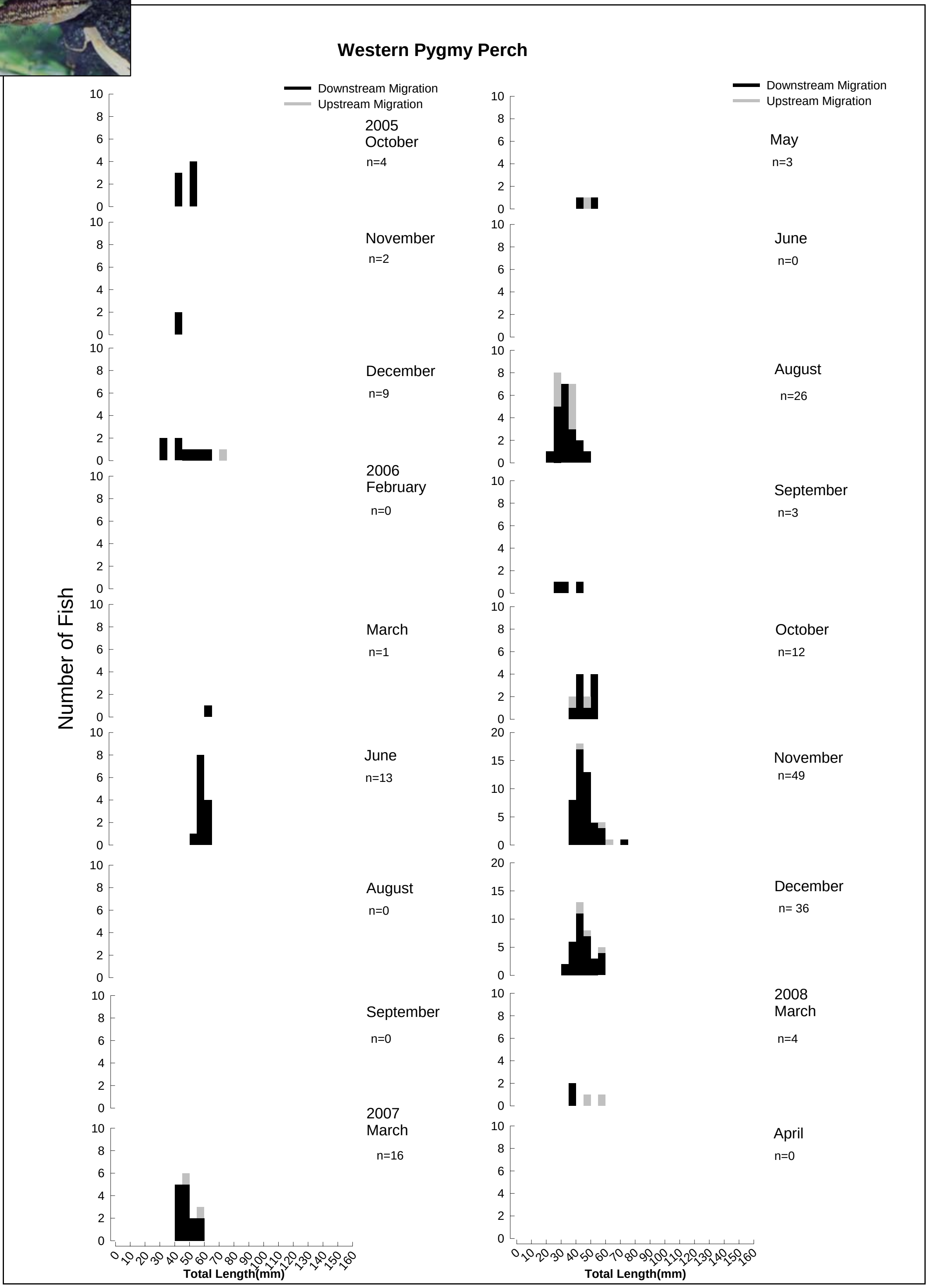


Figure 51 Length-frequency distributions, differentiated by upstream and downstream movement, of Western Pygmy Perch in the Blackwood River main channel.

Table 6 Correlations between upstream and downstream movement of Western Pygmy Perch in the tributaries of the Blackwood River and prevailing environmental variables during the major migration periods in 2005/06 and 2007. N.B. Data were log10 transformed, * denotes correlation is significant at the 0.05 level ** at 0.01 level (2-tailed).

		Log temperature	Log conductivity	Log pH	Log O2	Log discharge	Log NTU	Downstream movement
Log conductivity	Pearson Correlation	.560						
	Sig. (2-tailed)	.149						
Log pH	Pearson Correlation	.127	-.311					
	Sig. (2-tailed)	.764	.453					
Log O2	Pearson Correlation	.022	.301	-.580				
	Sig. (2-tailed)	.958	.469	.132				
Log discharge	Pearson Correlation	.140	.731	.022	-.174			
	Sig. (2-tailed)	.765	.062	.963	.709			
Log NTU	Pearson Correlation	.292	.951(*)	-.311	-.033	.999(*)		
	Sig. (2-tailed)	.708	.049	.689	.967	.023		
Log downstream movement	Pearson Correlation	.301	.946(**)	-.221	.337	.790	1.000(**)	
	Sig. (2-tailed)	.512	.001	.633	.460	.061	.000	
Log upstream movement	Pearson Correlation	.258	.621	.294	-.017	.714	.917	.796(*)
	Sig. (2-tailed)	.577	.137	.522	.971	.111	.083	.032

Nightfish

Habitat associations

The Nightfish was almost exclusively captured within the tributaries of the Blackwood River, which accounted for 99% and 87.91% of captures of this species in 2005/2006 and 2007/2008 respectively. As with the Western Pygmy Perch, the conditions and habitats in the main channel of the Blackwood River appear to be generally less suitable and the Nightfish appears to be reliant on tributary habitats to spawn. The seasonal movement of large numbers of juveniles into the main channel (see below) suggests that considerable mortality of these individuals may occur, with the populations being maintained by those fish that reach adult stage to again spawn in the tributaries.

Migration patterns

A large upstream movement of adult Nightfish occurred in Milyeannup Brook (112) and Layman Brook (23) during August 2007 (Figures 52-56), while the largest downstream migrations was juveniles (10-20 mm TL) during December in 2005 and November 2007 in Laymans Brook (299) (Figure 52 & 55). All tributaries had a downstream migration of juveniles in December 2005 and 2007, with the exception of McAtee Brook in 2005. The downstream migration is presumably a response to a reduction in discharge at that time with associated water level and habitat decline.

Nightfish were captured in greatest numbers during winter 2007/2008 in the main channel, particularly during August 2007 at Milyeannup Pool, Gingilup and Denny Road (Figures 57 & 58). Large fish were moving upstream, while smaller (0+) fish were moving downstream. Upstream movement was probably for spawning purposes while the 0+ fish may have been moving with the flow, noting the female Nightfish don't mature in their 1st year and flows increased during this time.

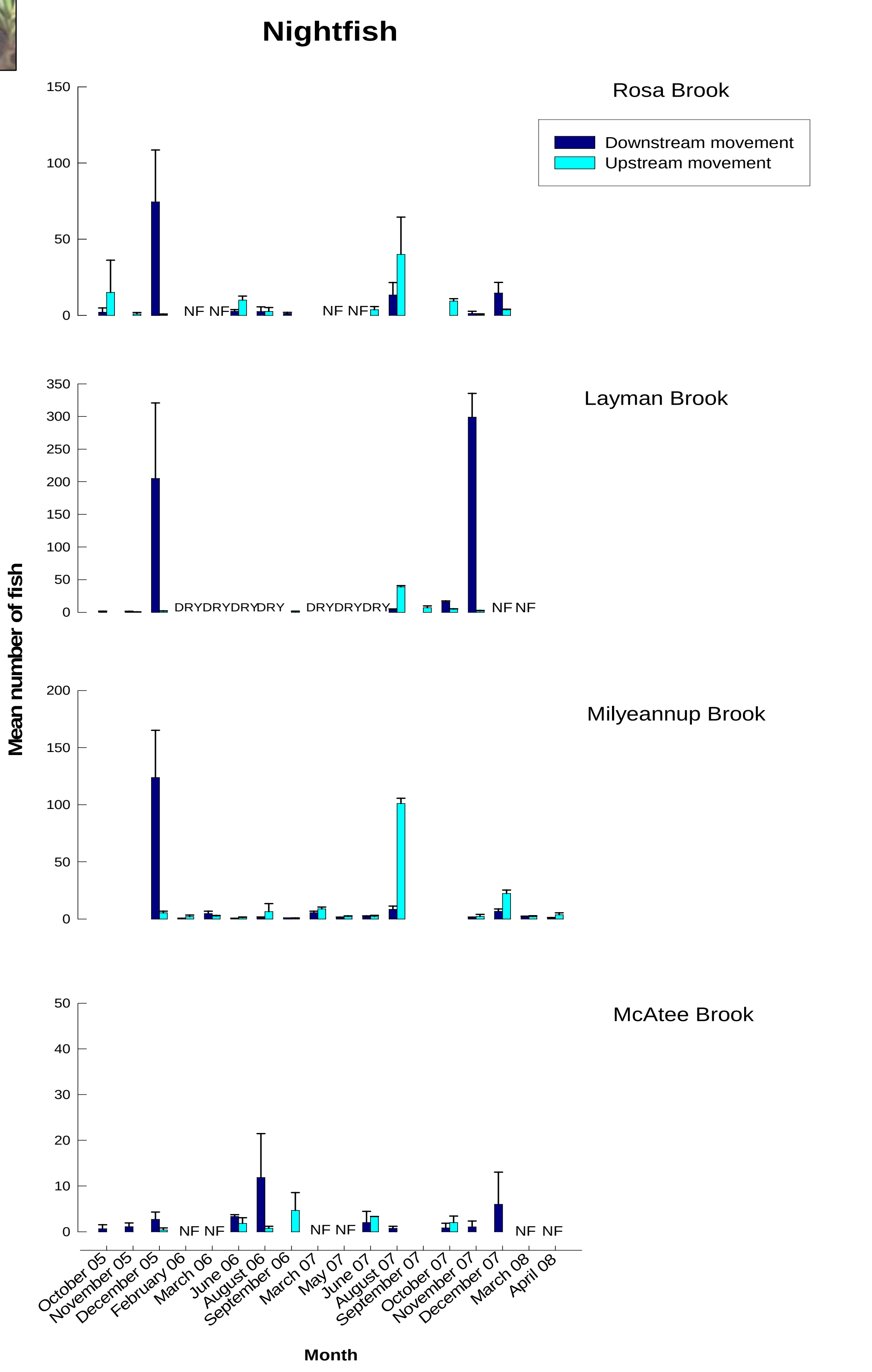


Figure 52 Upstream and downstream migration of Nightfish in the tributaries.

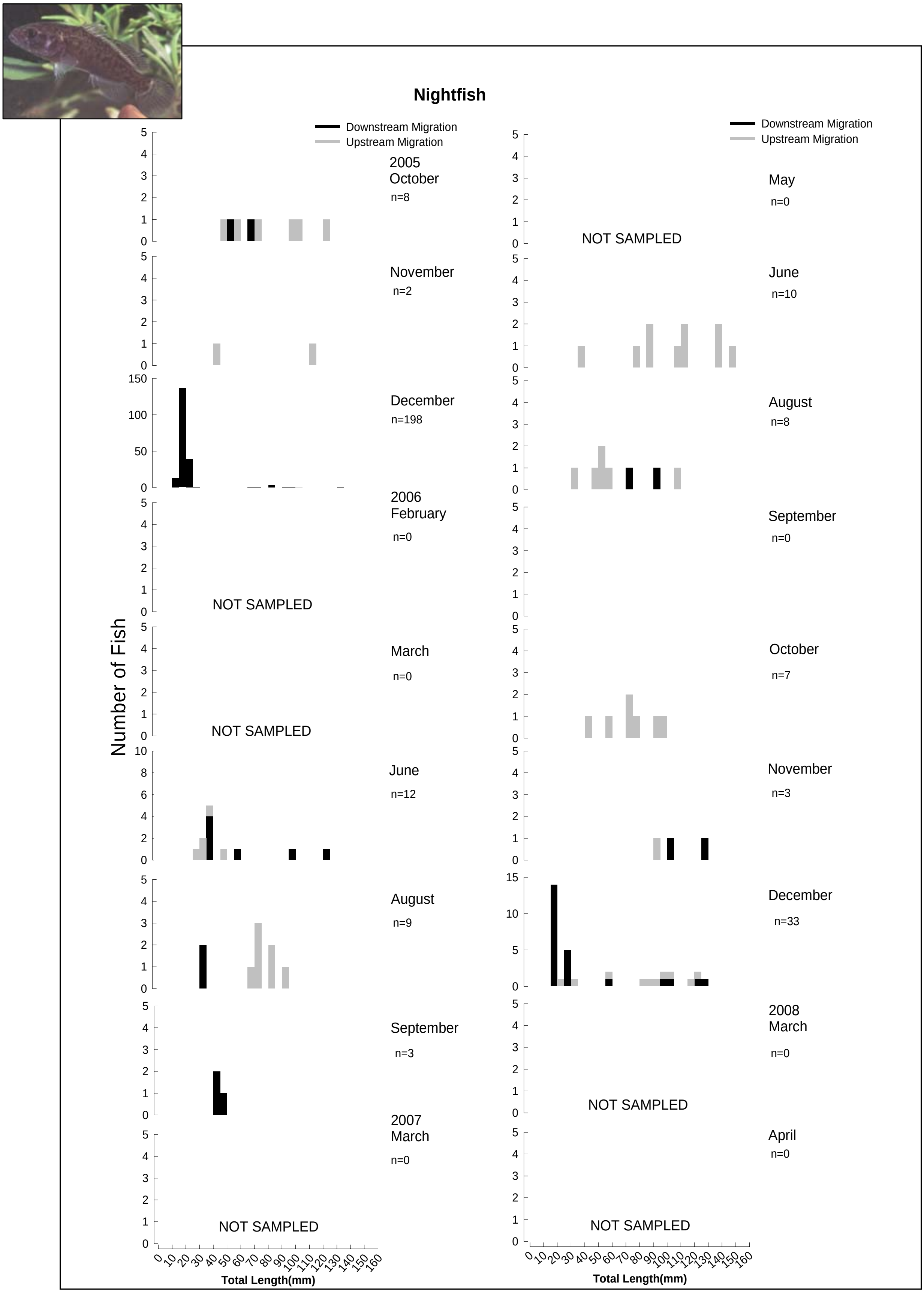


Figure 53 Length-frequency histograms, differentiated by upstream and downstream movement, of Nightfish in Rosa Brook.

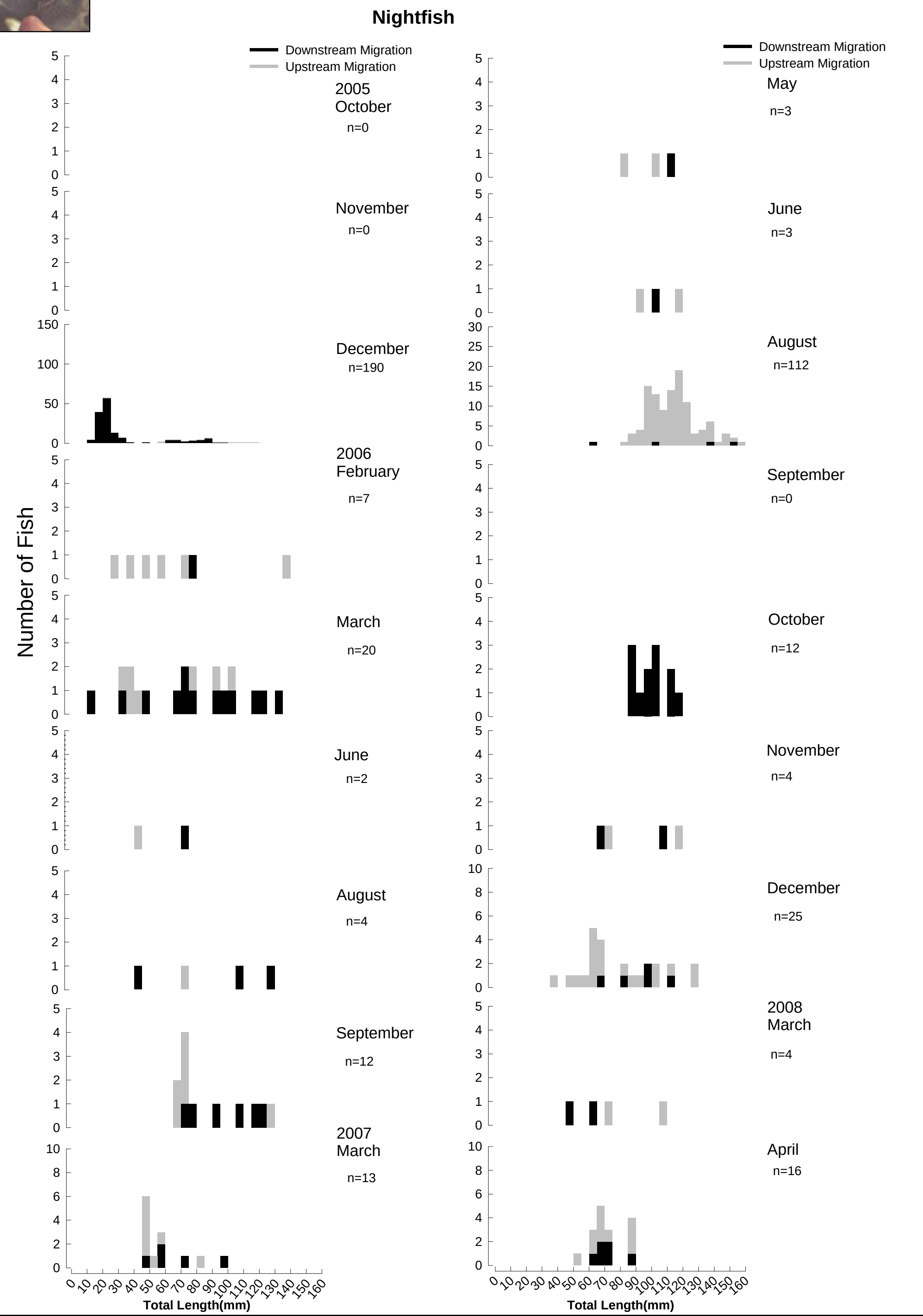


Figure 54 Length-frequency histograms, differentiated by upstream and downstream movement, of Nightfish in Milyeannup Brook

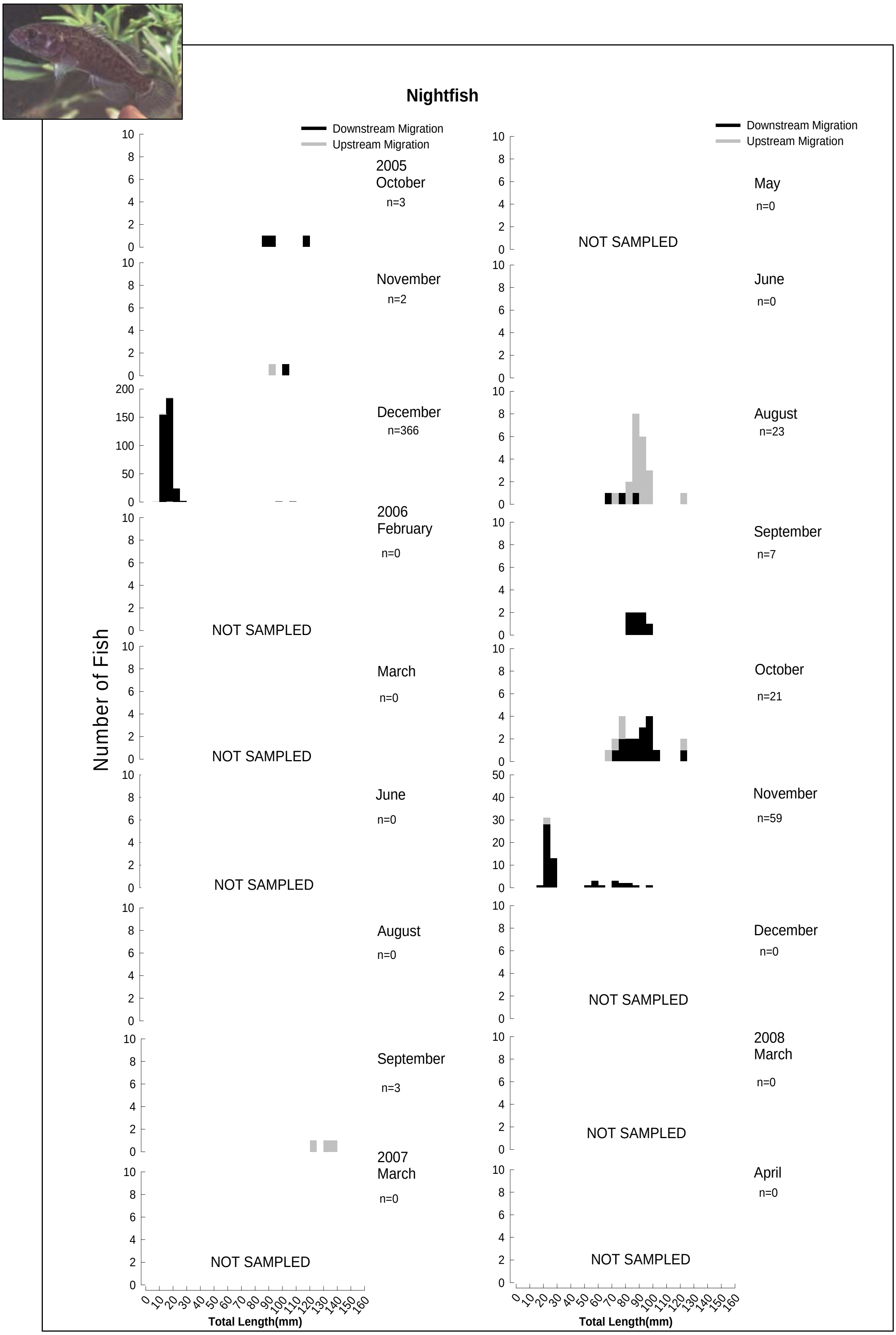


Figure 55 Length-frequency histograms, separated by upstream and downstream migration, of Nightfish in Layman Brook.

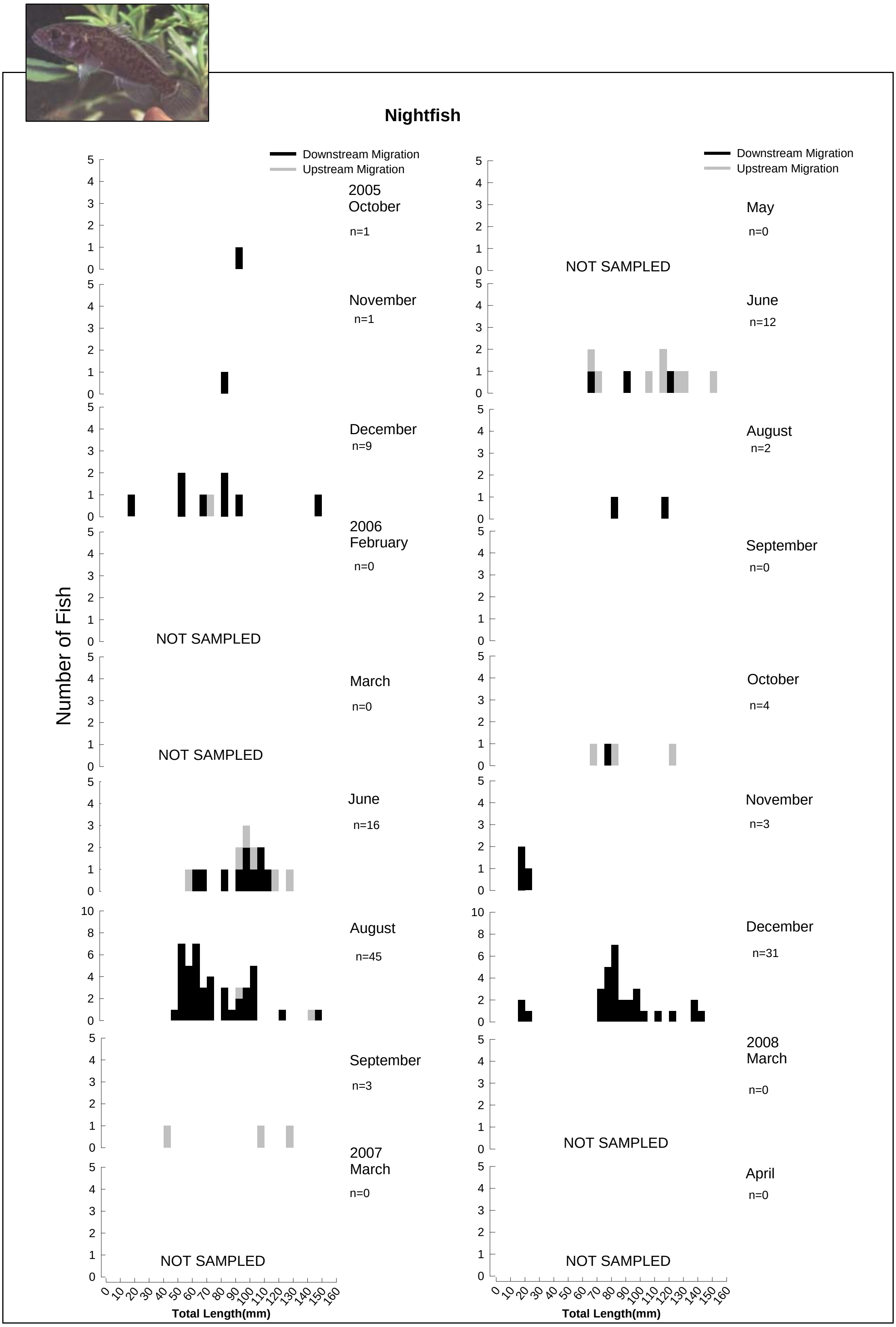


Figure 56 Length-frequency histograms, separated by upstream and downstream migration, of Nightfish in McAtee Brook.

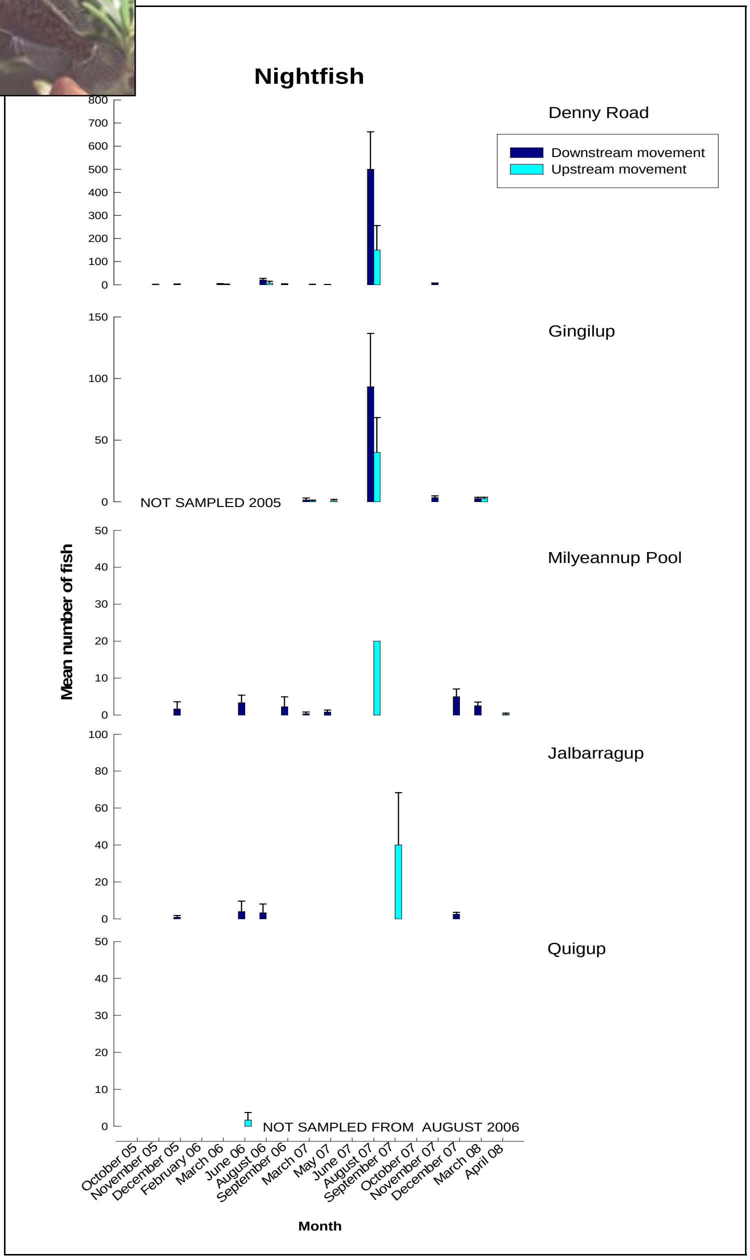


Figure 57 Upstream and downstream movement of Nightfish in the Blackwood River main channel.

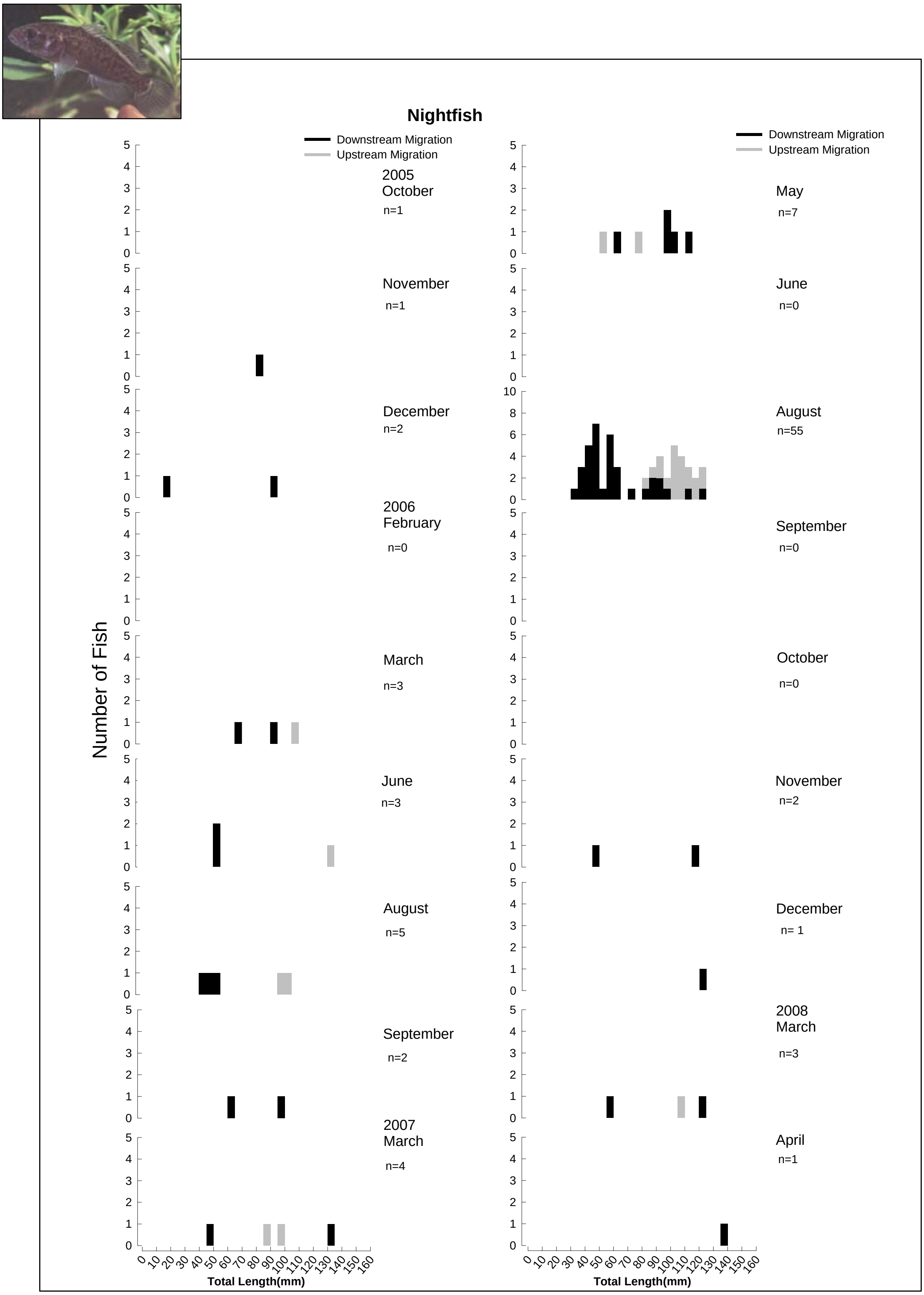


Figure 58 Length-frequency histograms, differentiated by upstream and downstream movement, of Nightfish in the Blackwood River main channel.

The previous study period found that the upstream movement of Nightfish was positively correlated with mean dissolved oxygen levels during the flow period in the tributaries (Beatty *et al.* 2006); however, this relationship was no longer significant (Table 7). Relationships between the environmental variables in the tributaries and the upstream and downstream movement of Nightfish will be re-analysed following the scheduled sampling in 2008 and 2009.

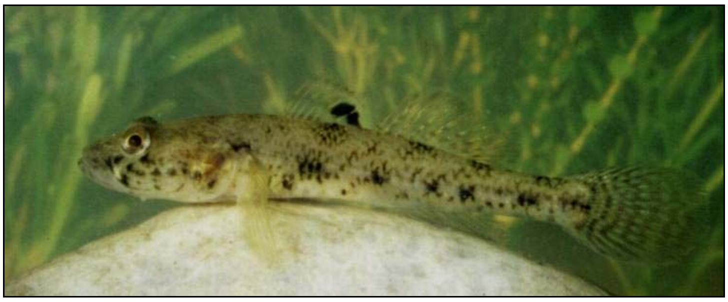
Unlike the Western Minnow and Western Pygmy Perch, the mean upstream and downstream movement of this species during the major migratory periods was not significantly related. This suggests that greater strength of upstream movement of mature fish does not necessarily result in higher downstream movement of recruits (Table 7).

Table 7 Correlations between upstream and downstream movement of Nightfish in the tributaries of the Blackwood River and prevailing environmental variables during the major migration periods in 2005/06 and 2007. N.B. Data were log10 transformed, * denotes correlation is significant at the 0.05 level ** at 0.01 level (2-tailed).

		Log temperature	Log conductivity	Log pH	Log O2	Log discharge	Log NTU	Downstream movement
Log conductivity	Pearson Correlation	.560						
	Sig. (2-tailed)	.149						
Log pH	Pearson Correlation	.127	-.311					
	Sig. (2-tailed)	.764	.453					
Log O2	Pearson Correlation	.022	.301	-.580				
	Sig. (2-tailed)	.958	.469	.132				
Log discharge	Pearson Correlation	.140	.731	.022	-.174			
	Sig. (2-tailed)	.765	.062	.963	.709			
Log NTU	Pearson Correlation	.292	.951(*)	-.311	-.033	.999(*)		
	Sig. (2-tailed)	.708	.049	.689	.967	.023		
Downstream movement	Pearson Correlation	-.660	-.608	.161	.182	-.589	-.388	
	Sig. (2-tailed)	.075	.110	.703	.667	.164	.612	
Upstream movement	Pearson Correlation	.191	.225	.678	-.228	.430	.264	-.187
	Sig. (2-tailed)	.650	.591	.064	.588	.335	.736	.657

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed)

South-western Goby



Habitat associations

Although South-western Goby is typically encountered within estuaries, during this study, it was commonly recorded within most main channel sites (compared to tributary sites); accounting for ~92% and 98% of captures in 2005/2006 and 2007/2008, respectively (Figure 59). In contrast to 2005/2006 no individuals were captured in Milyeannup Brook, but more were captured in Rosa Brook (Figure 65). This species is therefore largely reliant on the main channel habitats; an expected finding given it is a known estuarine species and the main channel has become salinised.

Migration patterns

In most months at the downstream main channel sites (receiving most groundwater discharge), the majority of South-western Gobies were moving downstream (Figure 59-64). Downstream movement was greatest at the Denny Road and Gingilup sites particularly during August 2007 which may have been a result of increased flow at this time. The low catches within tributary sites compared to the main channel suggest that the tributaries have unfavourable conditions for this species.

The general downstream trend in migration may be explained by the fact that this benthic species is not reputed to have a strong swimming ability. This point is highlighted when, during summer and early autumn, there were greater movements upstream at the sites that had negligible discharge, i.e. the two sites that are upstream of the Yarragadee discharge (i.e. Jalbarragup and Quigup) while the greatest downstream migration coincided with the greatest flows.

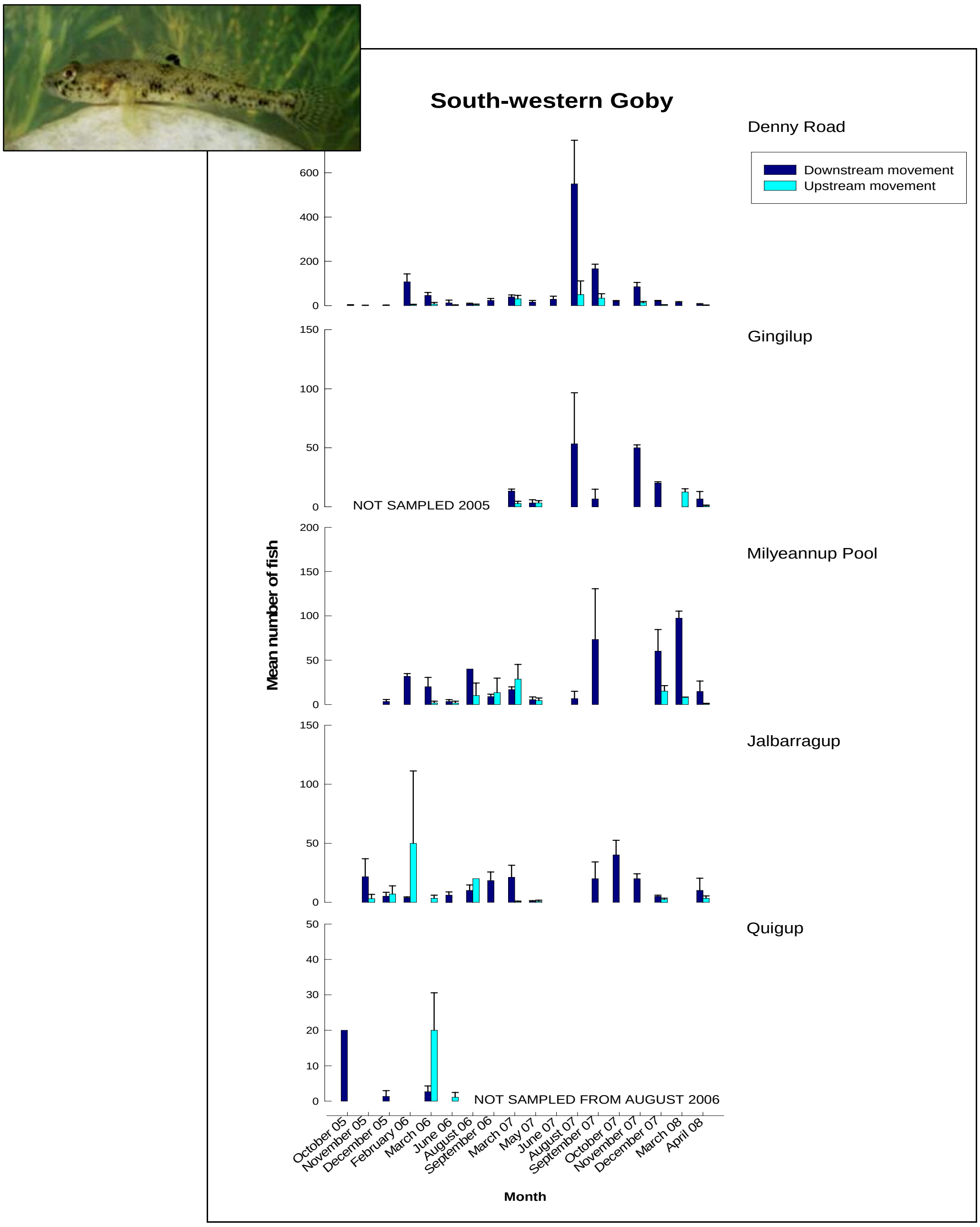


Figure 59 Upstream and downstream migration of South-western Goby in the Blackwood River main channel.

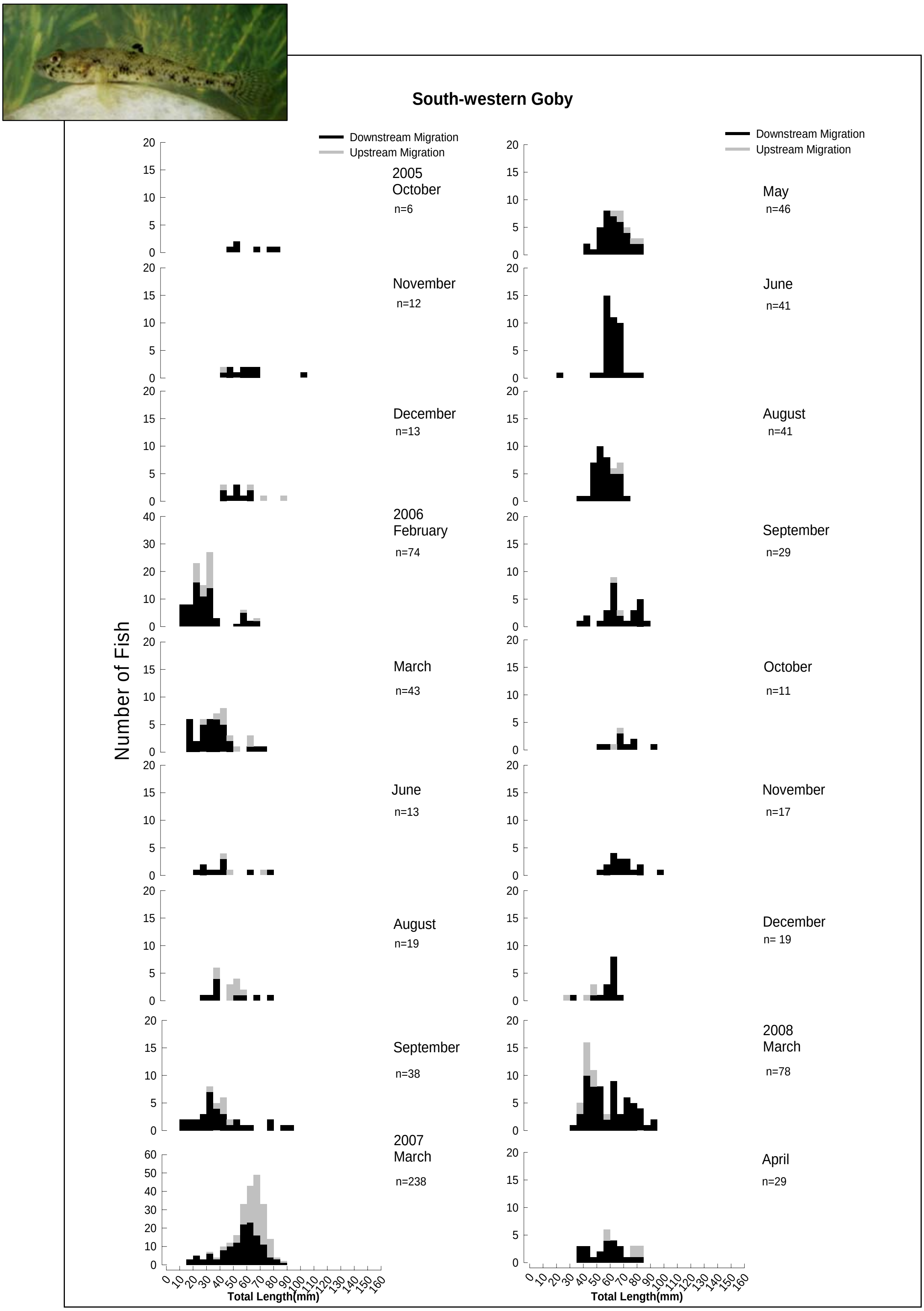


Figure 60 Length-frequency histograms, differentiated by upstream and downstream movement, of South-western Goby in the Blackwood River main channel.

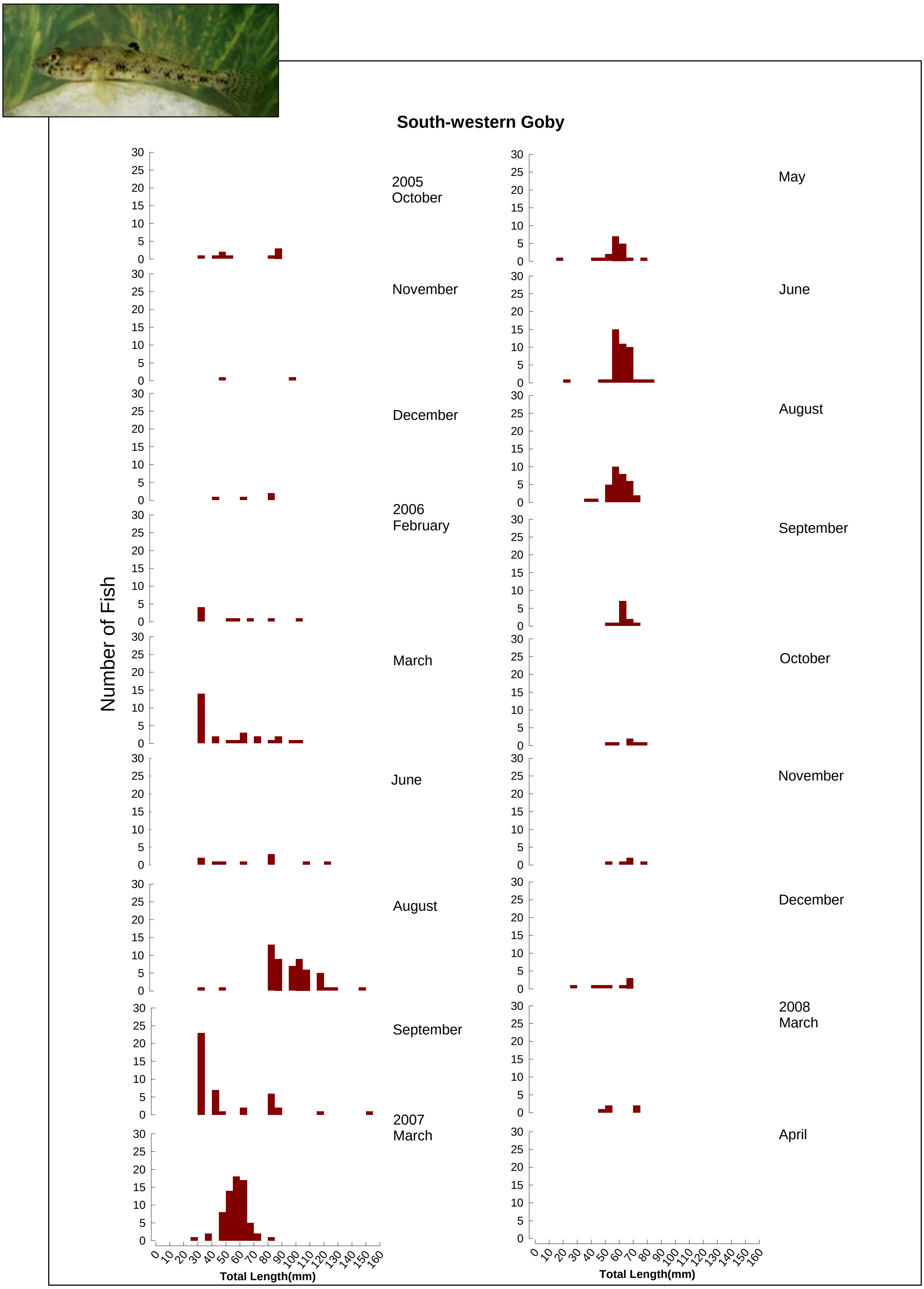


Figure 61 Length-frequency histograms of South-western Goby at Denny Road.

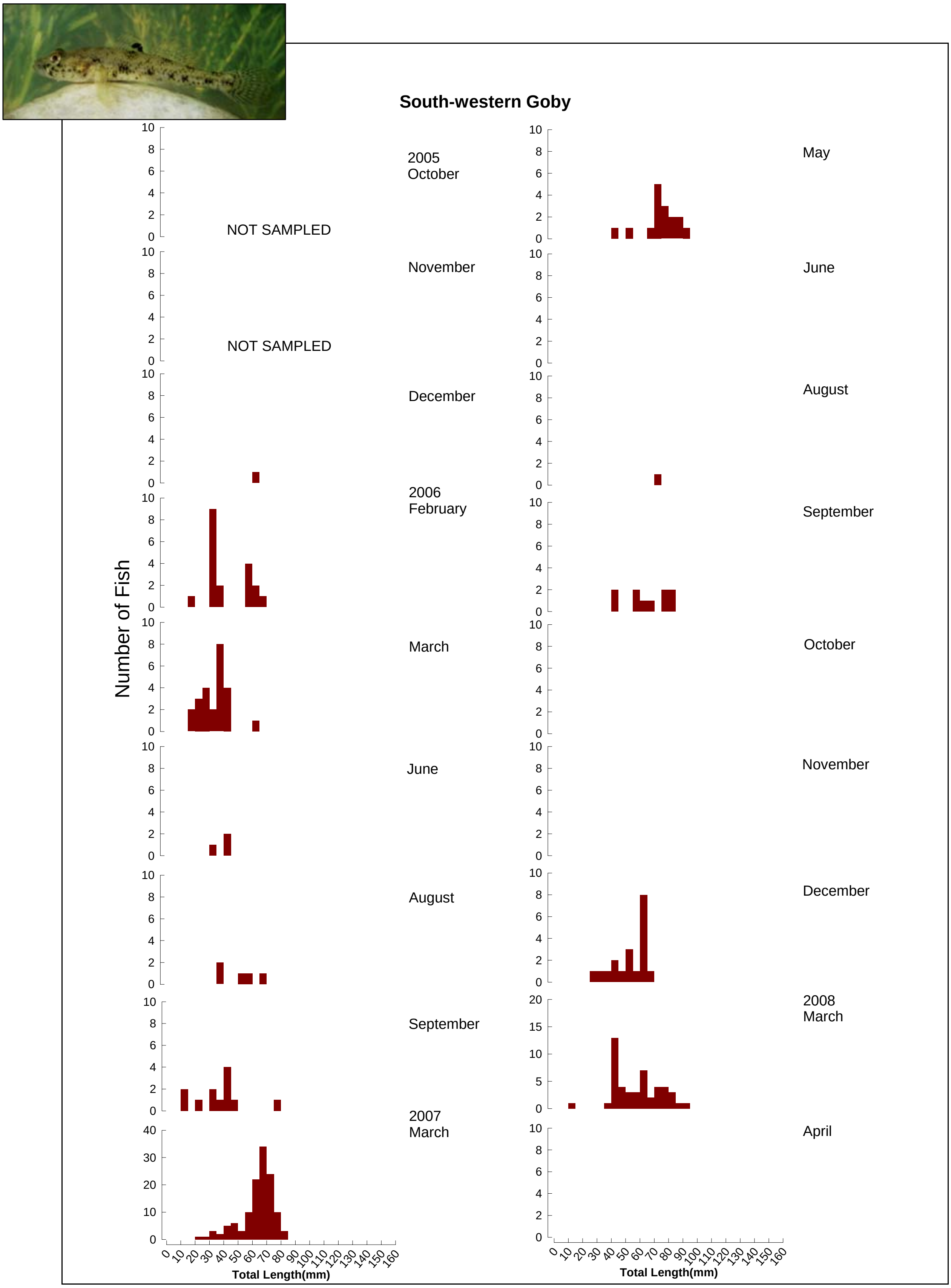


Figure 62 Length-frequency histograms of South-western Goby at Milyeannup Pool.

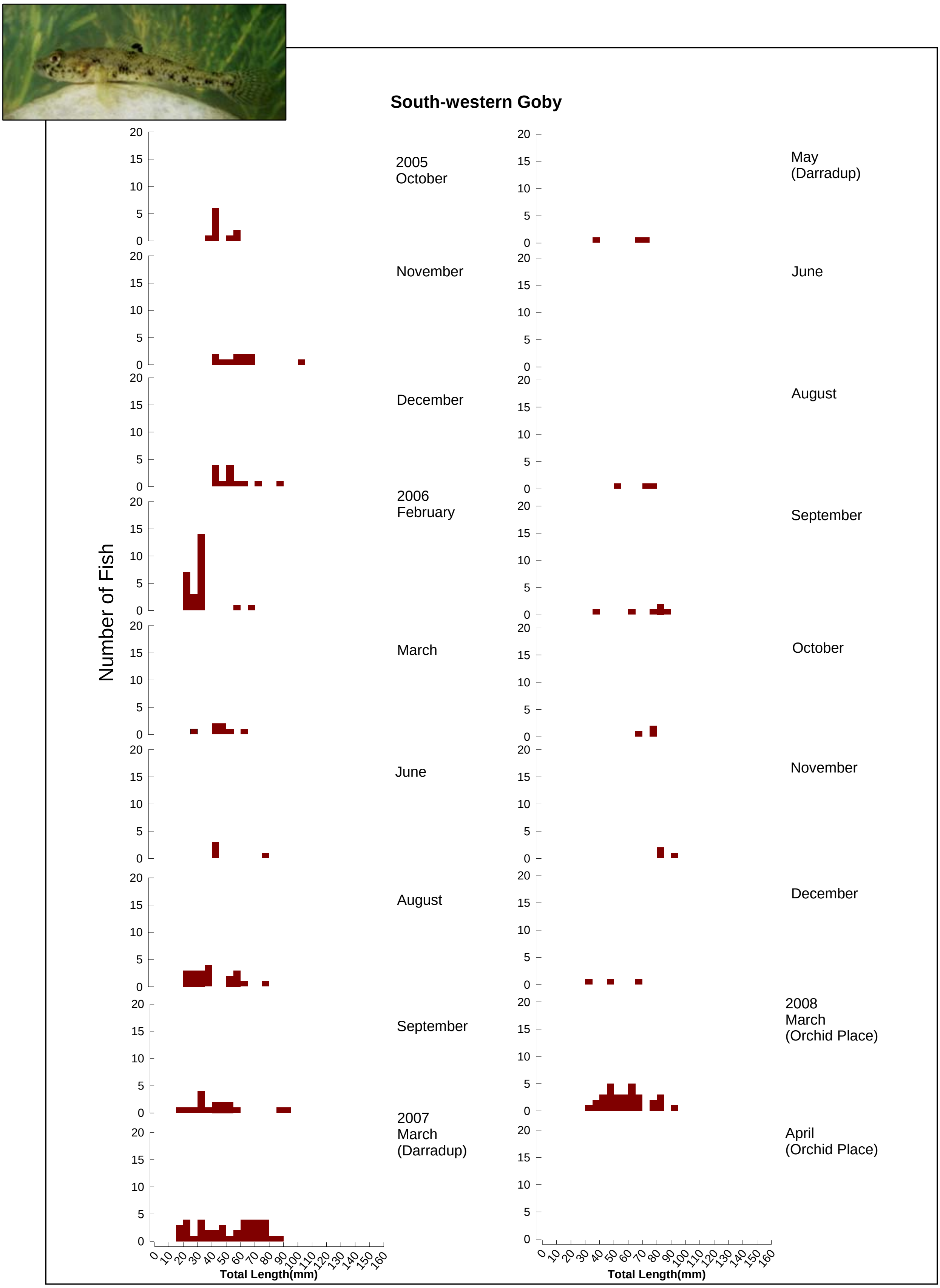


Figure 63 Length-frequency histograms of South-western Goby at Jalbarragup/Darradup/Orchid Place.

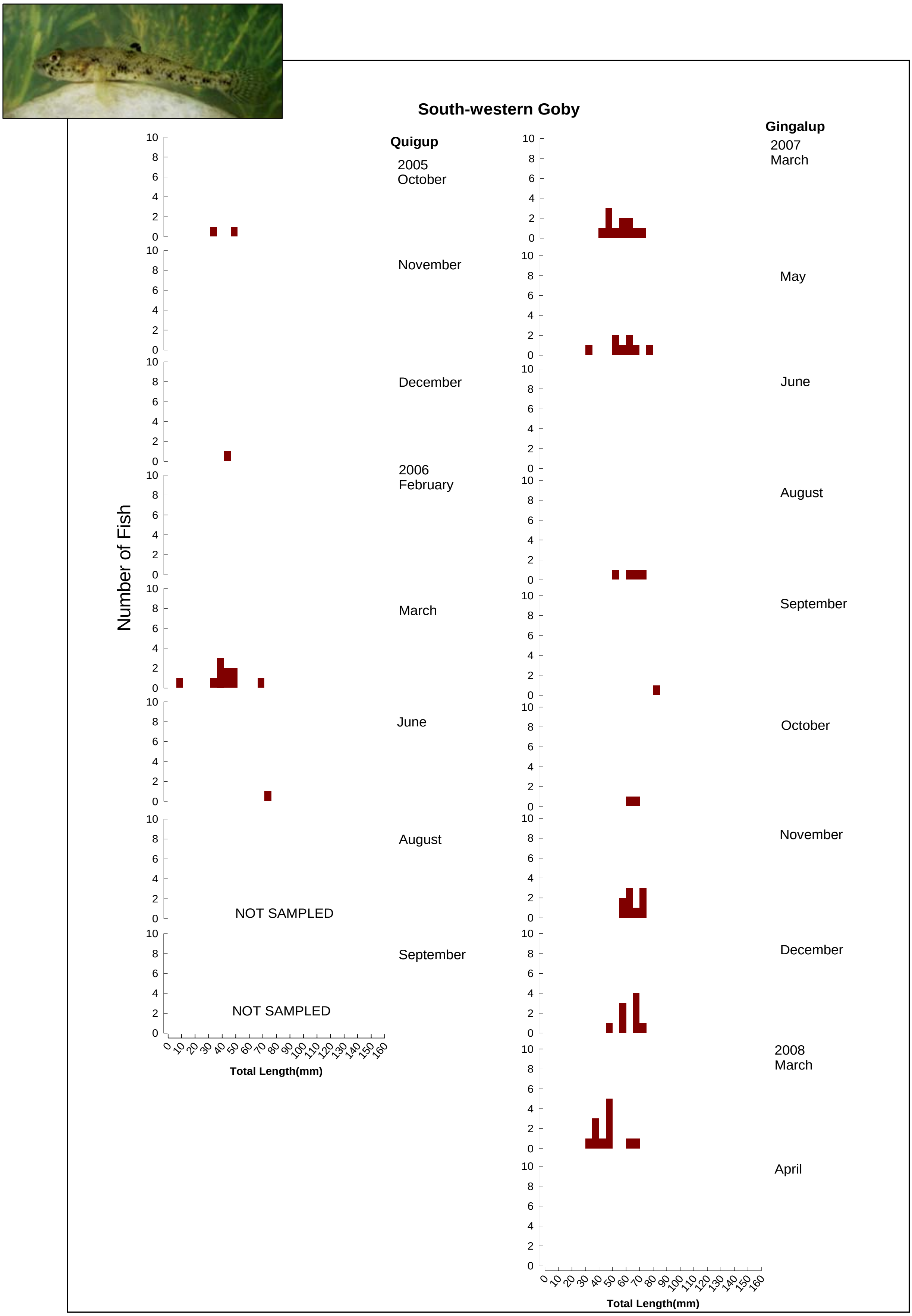


Figure 64 Length-frequency histograms of South-western Goby at Quigup and Gingilup.

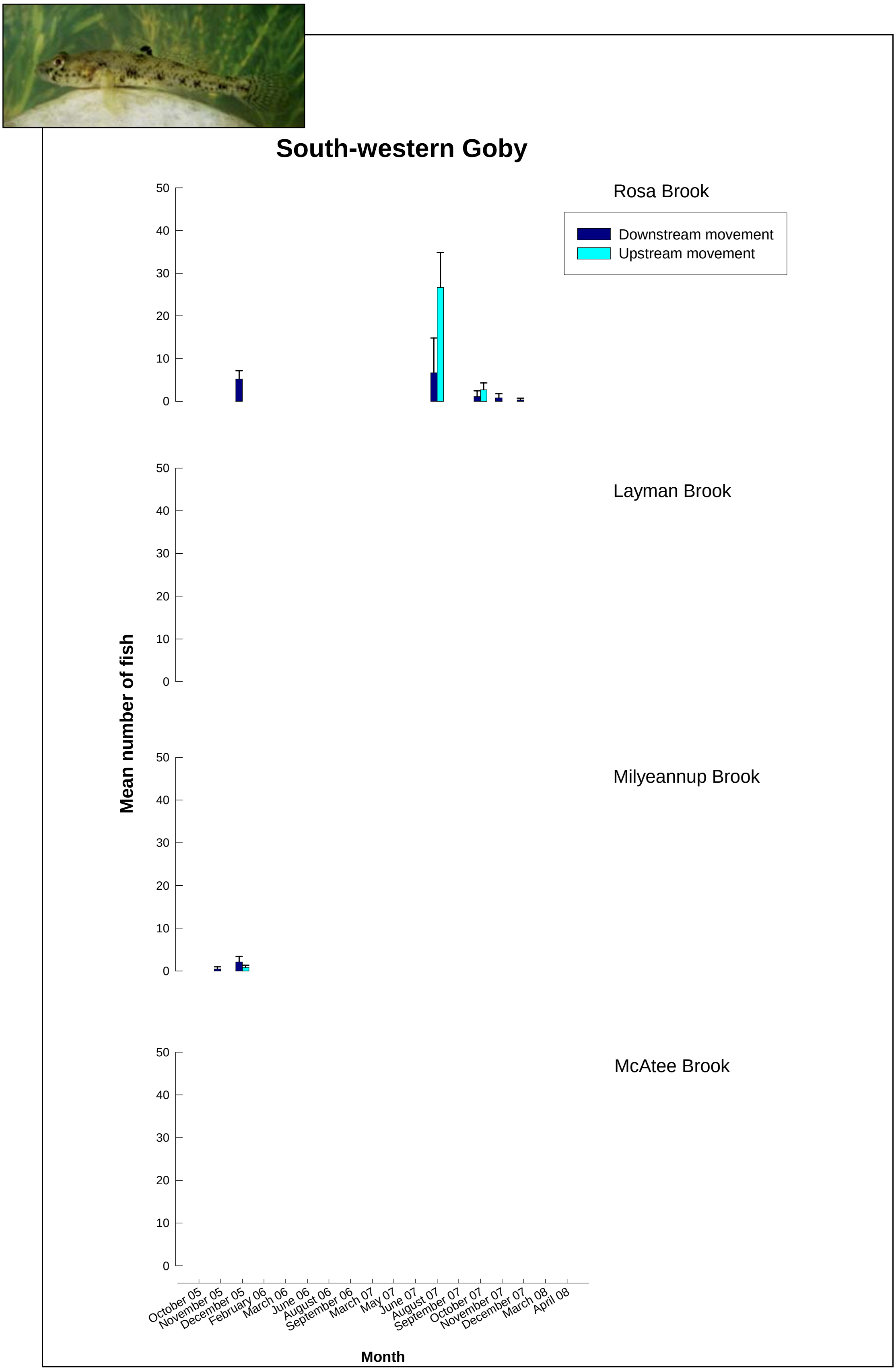


Figure 65 Upstream and downstream movement of South-western Goby in the tributaries.

Swan River Goby

Habitat associations

As with the South-western Goby, the vast majority of captures occurred in the main channel (Figure 66); the absence from the tributaries reflecting the fact that it is a typically estuarine species that has had its inland range increased due to the salinisation of the Blackwood River main channel.

Migration patterns

Catches of the Swan River Goby in fyke nets were sporadic, but the large majority captured were moving downstream in the main channel sites (Figure 66). On all but two months across the four main channel sites, the downstream migration strength was greater than the upstream movement (Figure 66). This is to be expected in such a slow moving benthic species, and the four occasions where upstream movement was greater than downstream movement was during December 2005 at Quigup, March 2006 and 2007 at Jalbarragup, and March 2007 at Milyeannup Pool a period when discharge was reduced and during their known spawning period (Gill *et al.* 1996). The greatest downstream movements of the species occurred during winter 2007; when discharge was substantial. No notable migrations occurred within tributary sites.

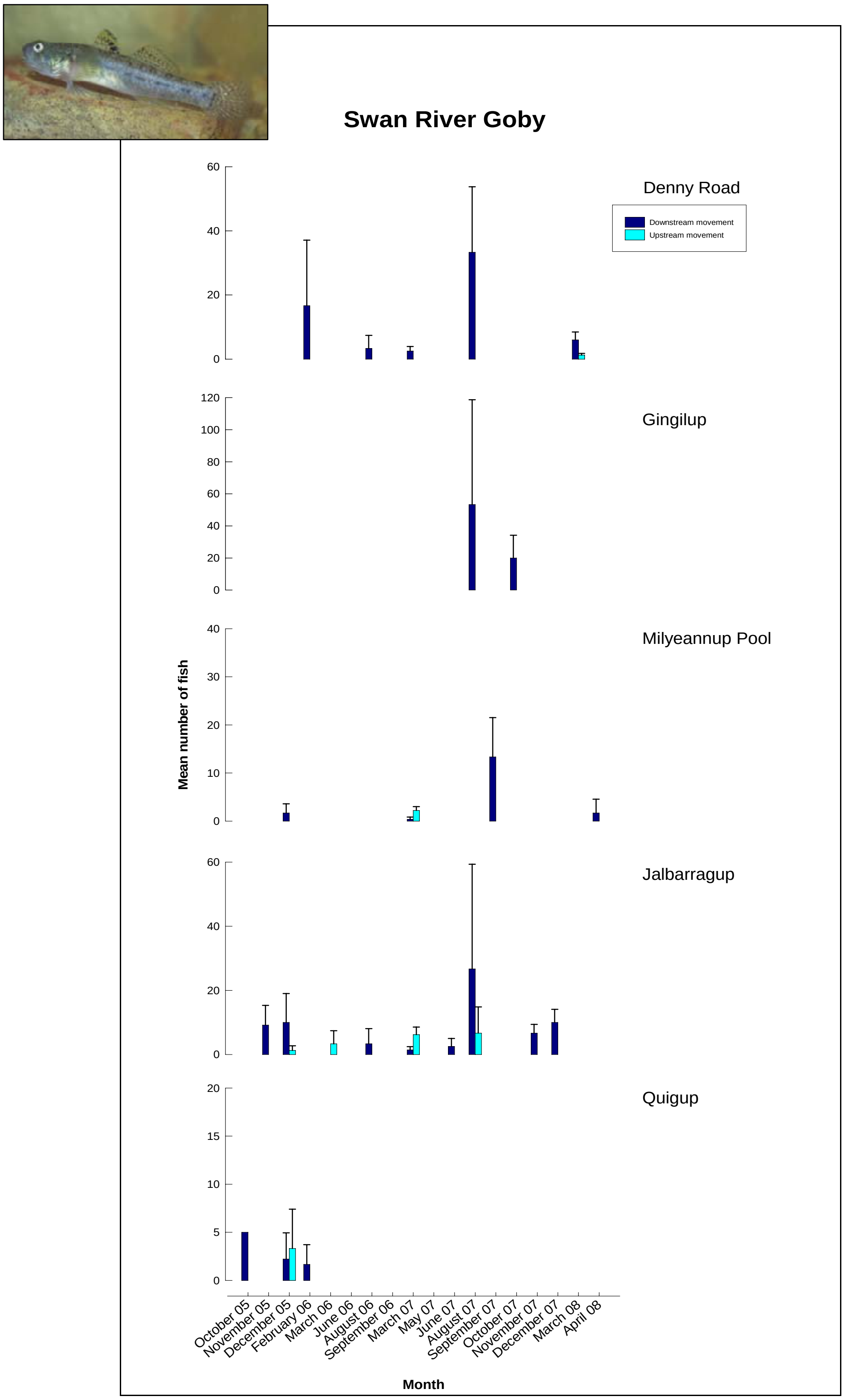


Figure 66 Upstream and downstream movement of Swan River Goby in the Blackwood River main channel.

Western Hardyhead

Habitat associations

As with the other estuarine species that are now found throughout the main channel of the Blackwood River as a consequence of increased salinisation, the Western Hardyhead is common in the main channel (Figures 67-72) but almost completely absent from the tributaries (Figure 73). Of the 9588 captured, only thirty individuals were captured from tributary sites; twenty-nine in Rosa Brook and one in Milyeannup Brook.

Migration patterns

While the species was common at all main channel sites sampled, relatively few were captured in fyke nets at Milyeannup Pool and at Quigup and this method may not be conducive to their capture; noting that Beatty *et al.* (2006) recorded many captures of the species in seine netting. Furthermore, individuals were often sighted near the mouth of nets with few subsequently being captured (Figure 55). However, at the Denny Road site, there were considerable upstream movements of fish in mid-late spring, with both upstream and downstream migrations recorded during summer. Minimal movements were recorded at most sites during autumn and winter (Figure 67-72); but considerable downstream movements of the species in late winter and early spring, particularly during 2007. Similarly, at Jalbarragup, while there was no movement of the species recorded during autumn and winter, there were considerable downstream migrations of fish during late spring and early summer.

Little recruitment of juvenile fish was recorded at the Denny Road site in March 2006whereas considerable numbers of new recruits were captured in late summer and/or early autumn at the other sites as illustrated by clear cohorts in the length-frequency histograms (Figures 68-72). However, new recruits were captured in March 2007 at most sites. During the likely breeding/recruitment period, i.e. late summer/early autumn, the proportion of new recruits in our catches increased from only a few individuals at Milyeannup Pool to being >50% of the population at the two upstream sites.

It is likely that the salinised environment offered by these upstream sites provides this typically estuarine species with more favourable conditions for successful recruitment.

Based on the above findings, an increase in salinity, with a concomitant decrease in discharge in the major groundwater discharge zone, i.e. at sites such as Denny Road and Milyeannup Pool, is likely to increase the recruitment of estuarine species such as the Western Hardyhead as it appears that minimum conductivity favoured for spawning of this species is between ~2000-3000 μS/cm.

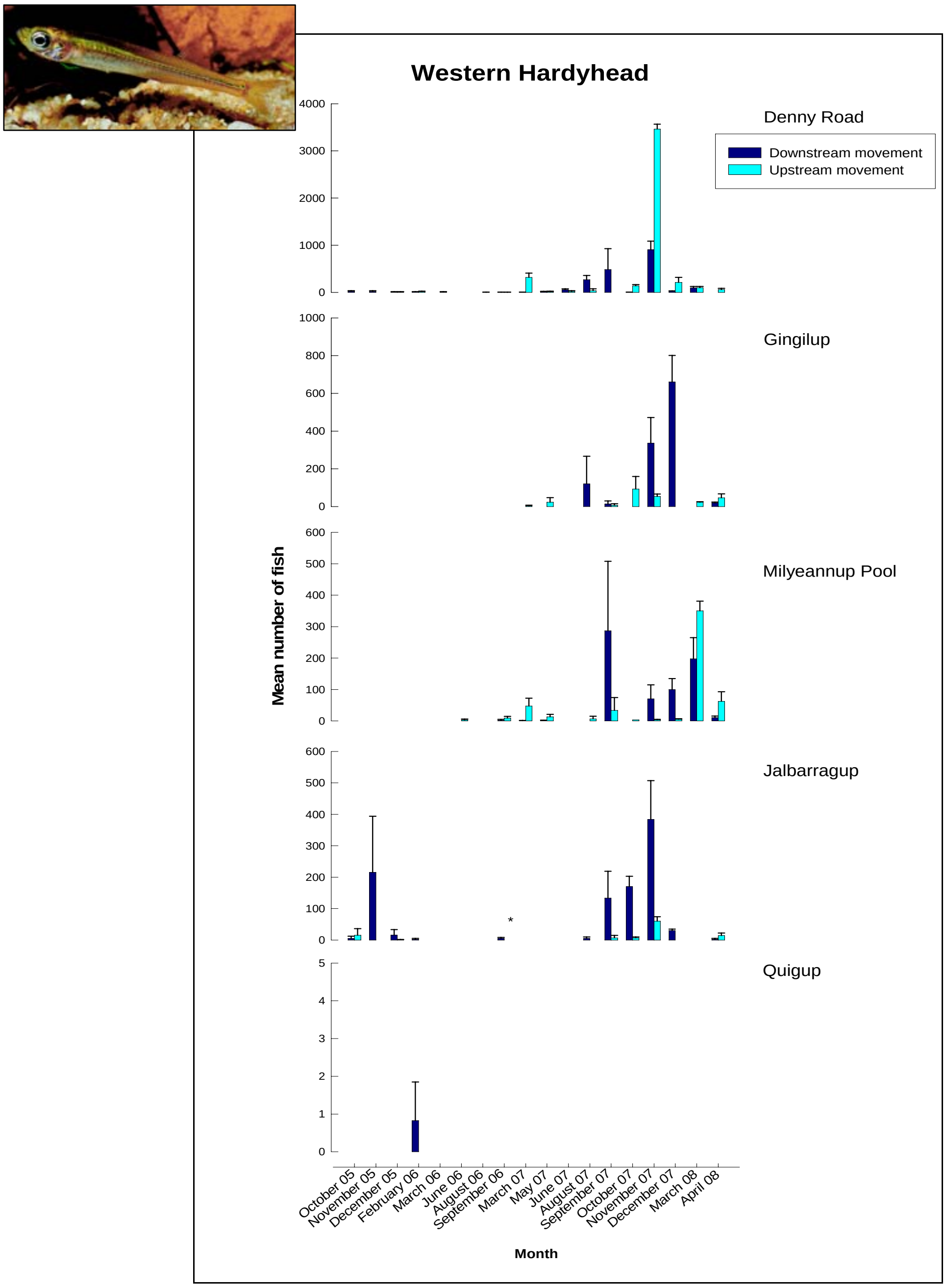


Figure 67 Upstream and downstream movement of Western Hardyhead in the Blackwood River main channel.

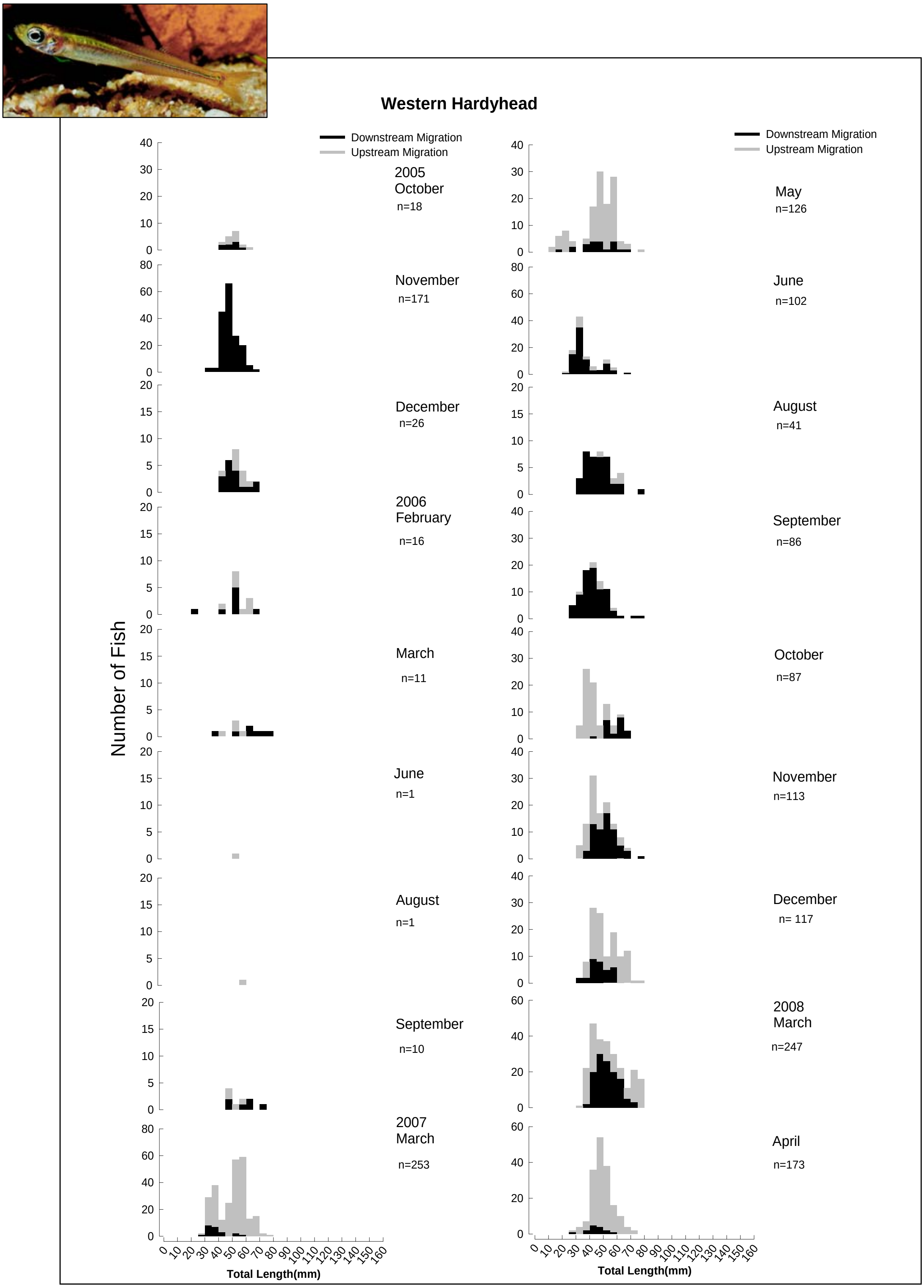


Figure 68 Length-frequency histograms, differentiated by upstream and downstream movement, of Western Hardyhead in the Blackwood river main channel.

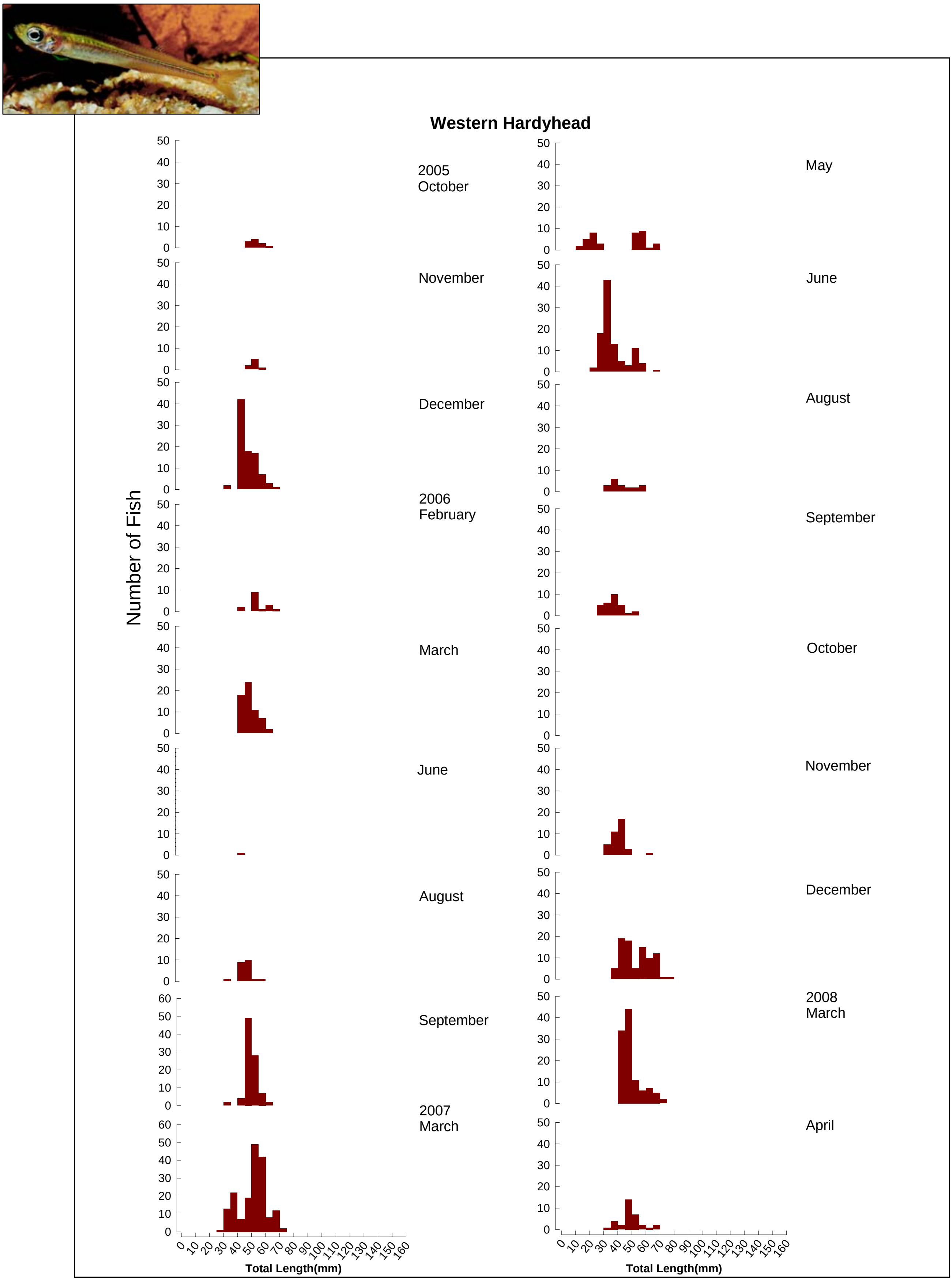


Figure 69 Length-frequency histograms of Western Hardyhead at Denny Road. Note in 2005 and 2006, numbers were supplemented by captures in seine nets.

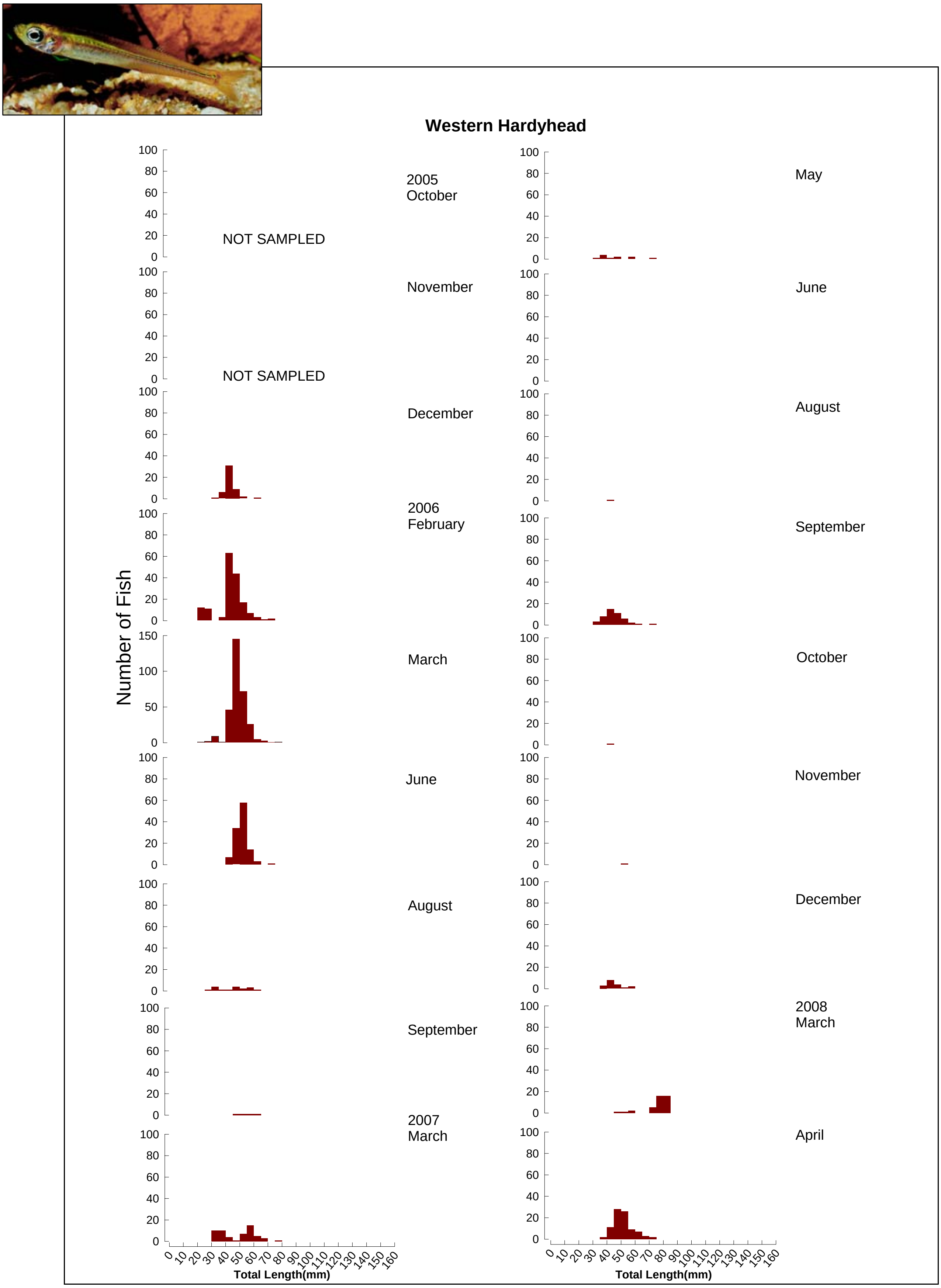


Figure 70 Length-frequency histograms of Western Hardyhead at Milyeannup Pool. Note in 2005 and 2006, numbers were supplemented by captures in seine nets.

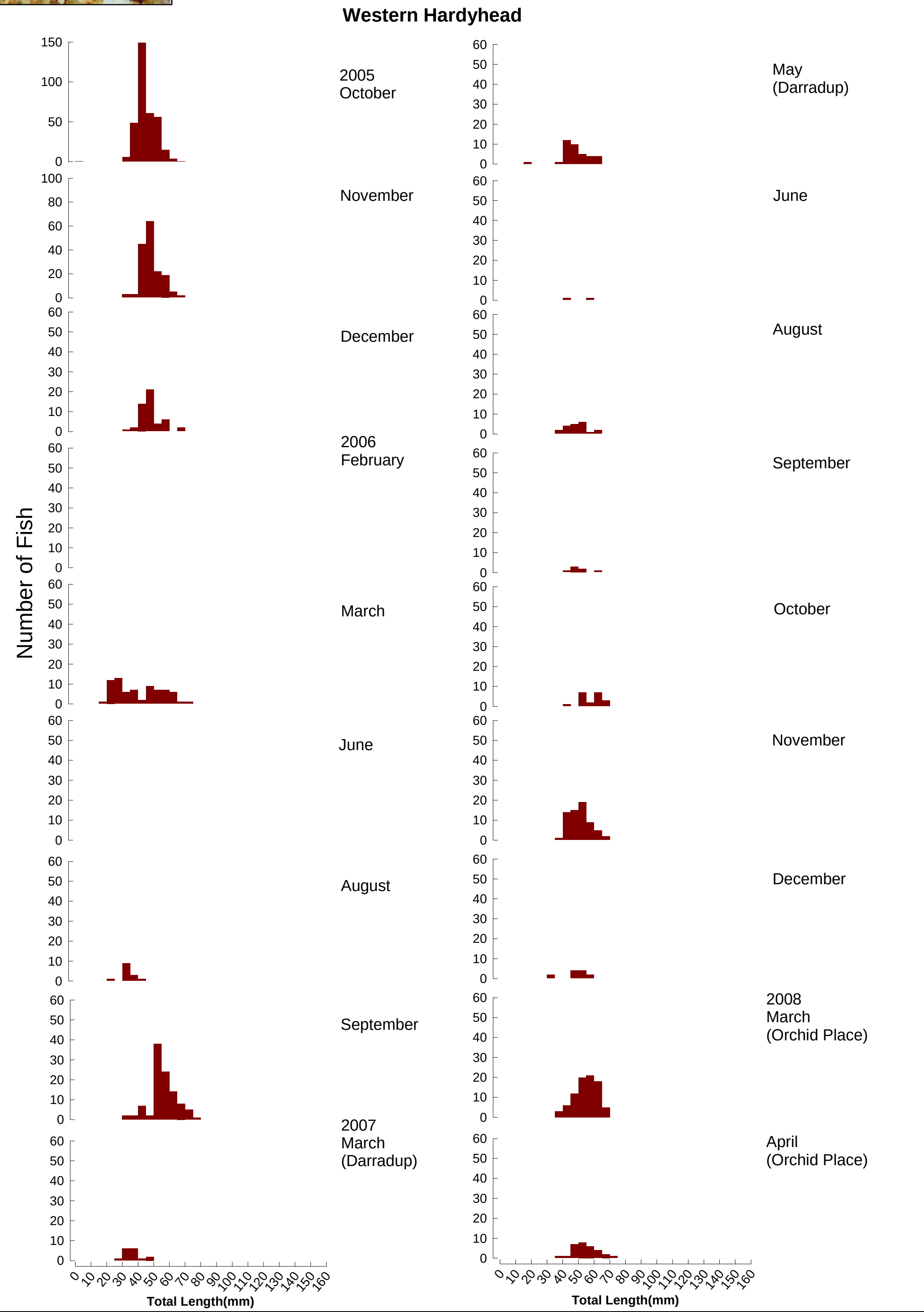


Figure 71 Length-frequency histograms of Western Hardyhead at Jalbarragup/Darradup/Orchid Place. Note in 2005 and 2006, numbers for Jalbarragup were supplemented by captures in seine nets.

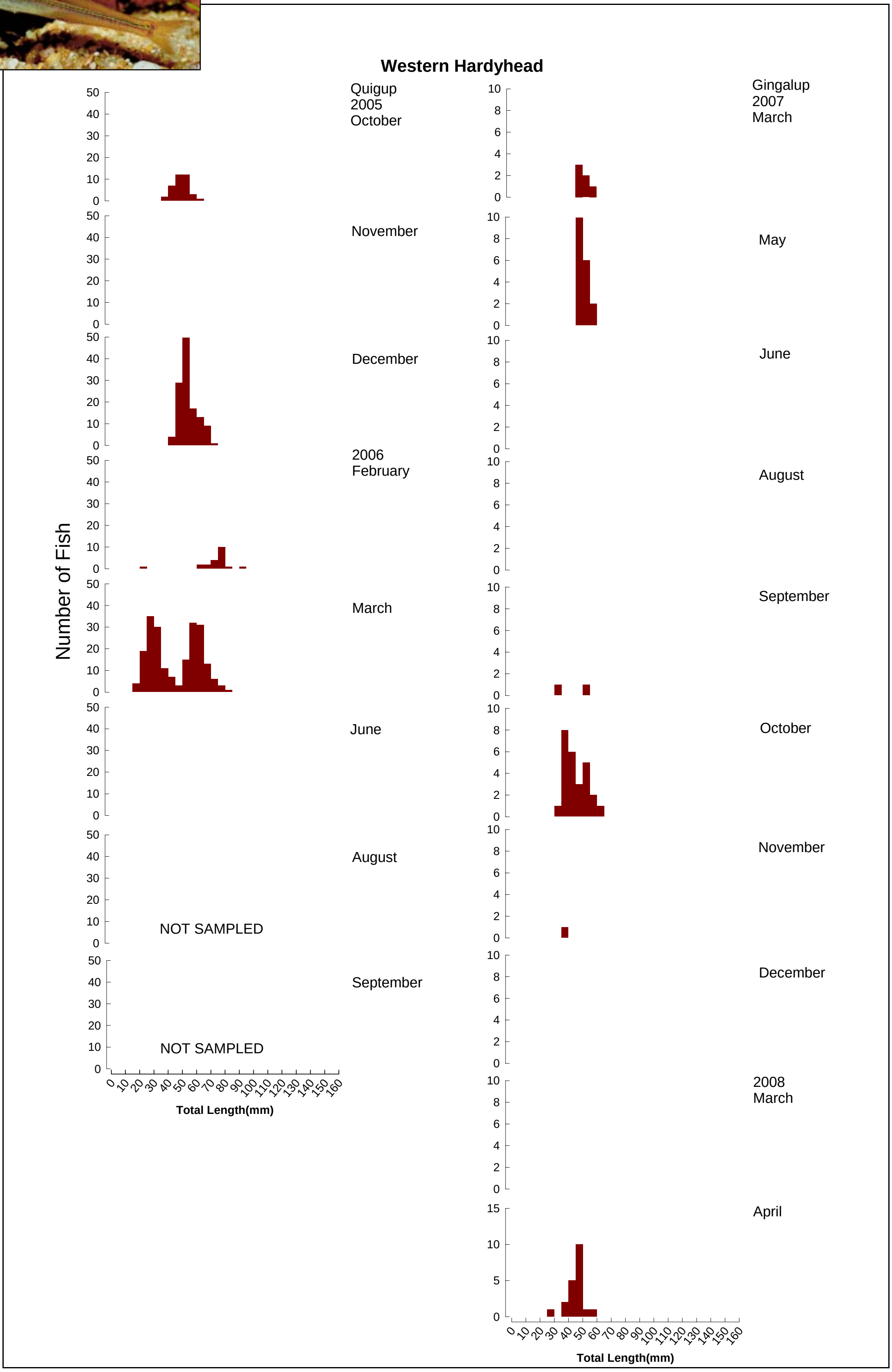


Figure 72 Length-frequency histograms of Western Hardyhead at Quigup and Gingilup. Note in 2005 and 2006, numbers for Quigup were supplemented by captures in seine nets.

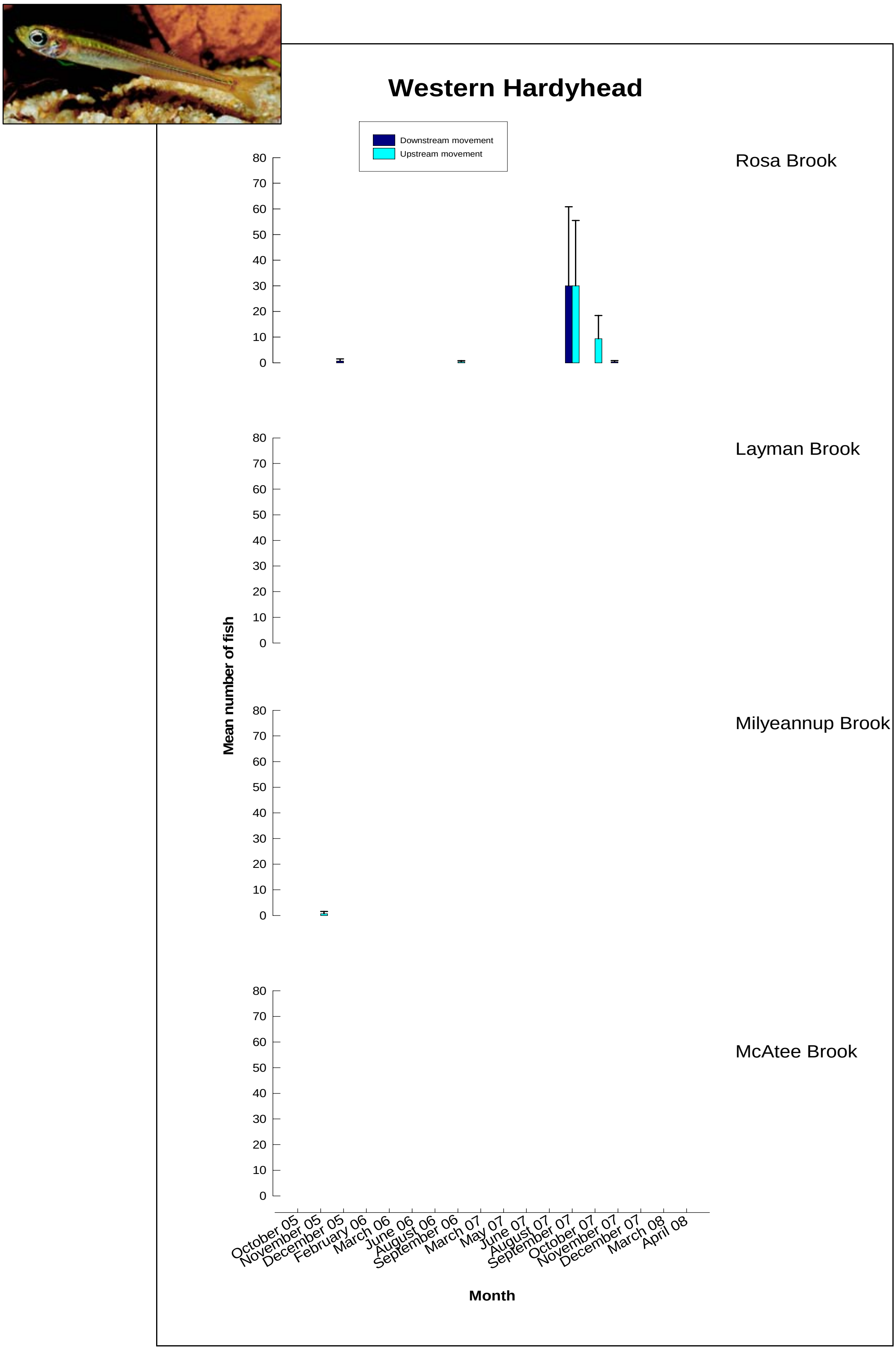


Figure 73 Upstream and downstream movement of Western Hardyhead in the tributaries.

Pouched Lamprey

Habitat associations

Prior to Beatty *et al.* (2006) there had been no reports of larval Pouched Lampreys (*Geotria australis*) in the Blackwood River. During this study, they were captured in Milyeannup Brook, Rosa Brook and St John Brook (Figure 74). Adults were also captured in fyke nets in Rosa Brook (June 2006 and September 2007) and Milyeannup Brook (September 2006), a period that coincides with their upstream migration (see below) (Figure 74).

This species belongs to the Petromyzontiformes, which are one of the only two surviving groups of the jawless (agnathan) stage in vertebrate evolution. The absence of jaws and paired fins separates the agnathans from the cartilaginous (sharks and rays) and bony (teleosts) fishes. While there are 38 species of extant lampreys, the Pouched Lamprey is the sole member of the Geotriidae and one of only four species of Southern Hemisphere lampreys (Potter 1980). The species is known from south-western and south-eastern Australia, Tasmania, New Zealand and south-western and south-eastern South America (Potter *et al*. 1986) and in WA it is found in most of the river systems from the Murray River south to approximately the Waychinnicup River east of Albany (Morgan *et al*. 1998). For further biological information see Potter *et al*. (1980), Potter & Hilliard (1987) and Gill *et al*. (2003).

Ammocoetes require a high degree of shade and a high abundance of organic material on the substrate, factors that are known to influence larval densities (Potter *et al*. 1986). The metamorphosed juveniles (downstream migrants) however are most often associated with (buried in) sandy substrates that occur in well-oxygenated waters (e.g. below riffles).

The larvae are particularly vulnerable to habitat modification and rely on well oxygenated non-saline waters that are characterised by shade and organic matter. There is substantial evidence that lampreys are declining in numbers, particularly as a result of the loss off suitable habitat for the larvae, and this is evident within south-western Australian rivers such as the Blackwood where salinisation and land clearing have resulted in loss of larval beds.

While adults and larvae are relatively common in the main channel of a number of river systems in south-western Australia, e.g. Margaret River, it is likely that the higher salinities within the Blackwood River have reduced habitat availability.

Migration patterns

On almost all occasions, ammocoetes were captured moving downstream, with the species captured during seven sampling events in Milyeannup Brook and one in Rosa Brook. The life-cycle is complex, with the worm–like larval stage (ammocoete) living in 'burrows' below the substrate where they feed on diatoms, detritus and micro-organisms. In south-western Australia at approximately four years of age (and at approximately 90 mm TL) the ammocoete undergoes metamorphosis with the resultant downstream migrant leaving the river during winter. It is thought that there is a one to two year marine trophic phase, where it presumably feeds on fish and their length increases to approximately 500-700 mm TL. The adult then ceases feeding, re-enters rivers and embarks on an upstream migration (moving predominantly at night) during winter and spring. After spending approximately 15-16 months in the river, when they survive off accumulated fat reserves, the adults spawn and die. During this 15-16 month period in the river the adults mature and the males develop a large gular pouch (hence the name pouched lamprey). An enlargement of the oral disc also occurs during this maturation period. The strength of the upstream migration is variable from year to year, and due to their nocturnal migration being in winter they are seldom seen.

From top left (clockwise): A burrowing ammocoete, adults migrating upstream, an adult (upstream migrant) utilising the oral disc to move upstream through a riffle.

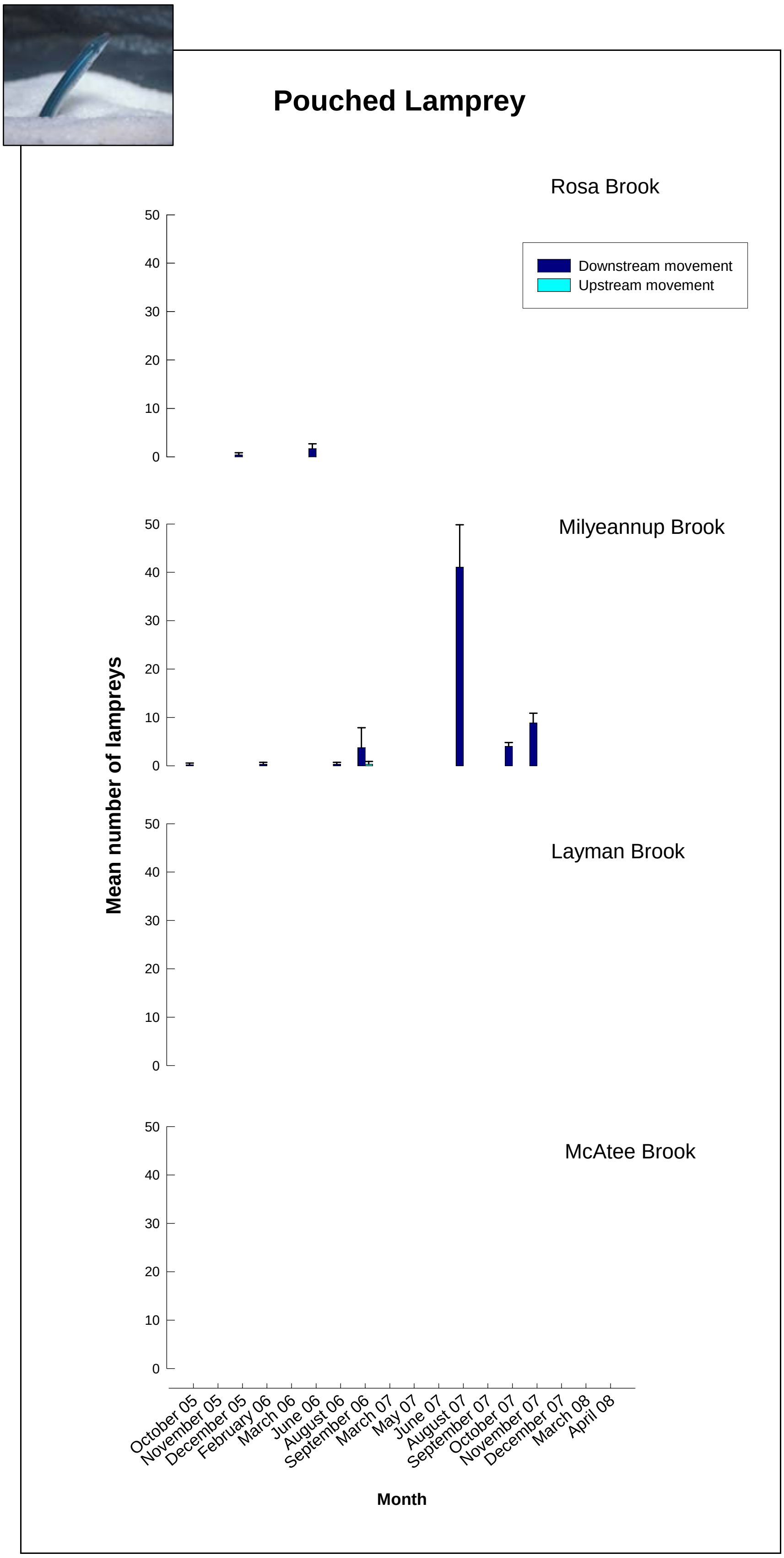


Figure 74 Upstream and downstream movement of the Pouched Lamprey in the tributaries.

Eastern Mosquitofish

Migration patterns

The Eastern Mosquitofish was almost exclusively captured during periods of low flow i.e. late summer and early autumn during both the 2005/2006 and 2007/2008 sampling periods (Figure 75). This is known to be their breeding period in south-western Australia. The increase in numbers captured over the 2007/2008 season may indicate they are not as difficult to capture using fyke nets as previously thought or simply that their numbers have increased (Beatty *et al*, 2006).

The species was almost exclusively captured in the main channel i.e. 99.39% (1307 of 1315). The bulk of these fish were moving downstream with the exception of those in Milyeannup Pool they were often captured moving upstream (Figure 75). Over both 2005/2006 and 2007/2008 fish were recorded migrating both upstream and downstream at Milyeannup Pool. These migrations occurred during summer and early autumn i.e. periods of low flow. The presence of this species in a system is always a concern as, in addition to being a feral species, they are known to fin nip native fish. Certainly some specimens of Western Pygmy Perch captured in the areas were Mosquitofish are known to inhabit have been severely affected.

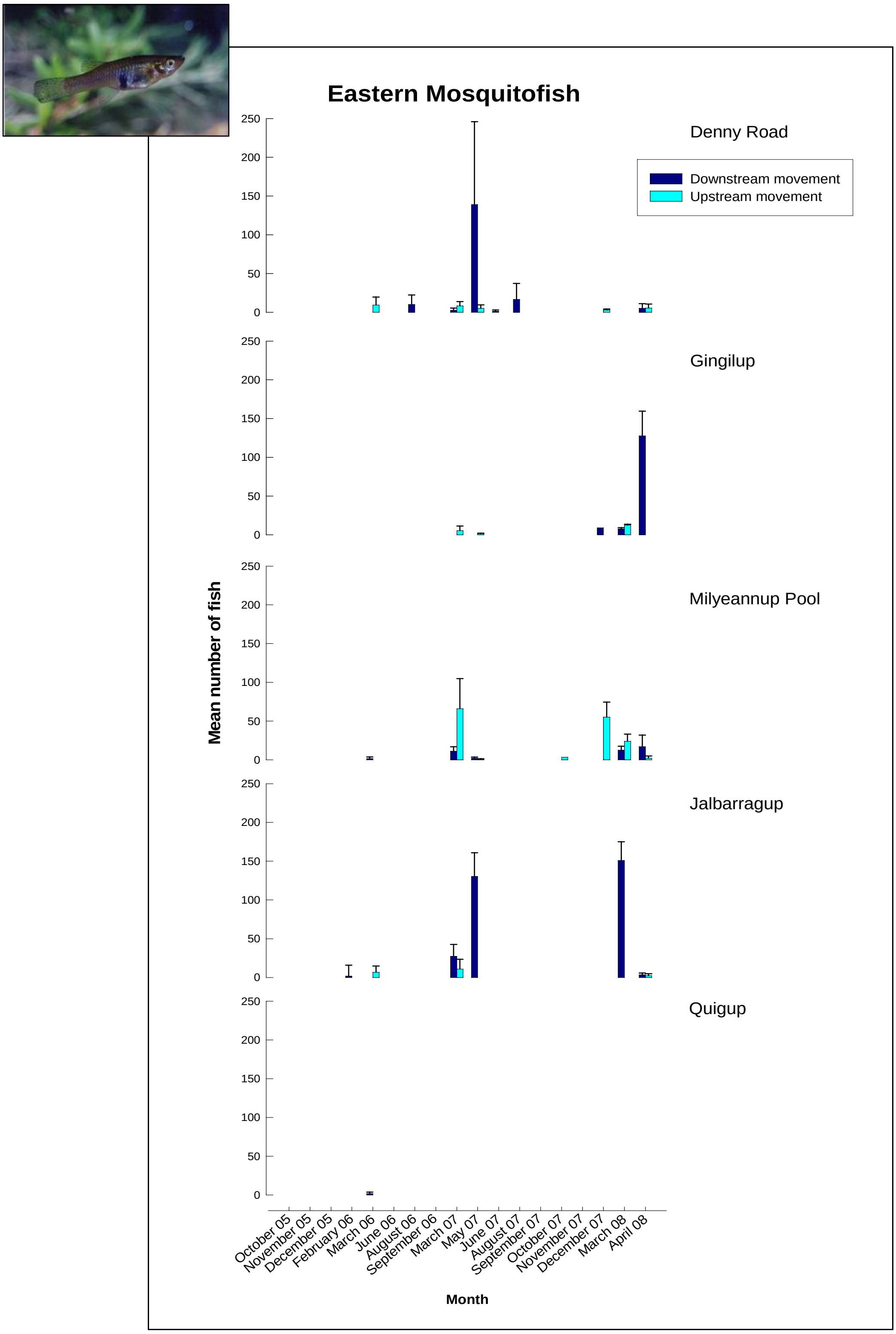


Figure 75 Upstream and downstream movement of Eastern Mosquitofish in the Blackwood River main channel.

Other Species

Feral Species

Goldfish were captured in small numbers during sampling in 2005/2006, however, during 2007/2008 only a single Goldfish was captured in the main channel at Denny Road in September 2007. The absence of captures may indicate a decline in their numbers but more likely reflects that crayfish traps were no longer part of the sampling regime; this being the main method of capture.

Rainbow Trout are no longer stocked in Milyeannup Brook and this is reflected by our sampling which returned no individuals of the species since February 2006 anywhere within the sampling area.

Other Native Species

For the first time since sampling began in October 2005, Sea Mullet were captured upstream of Sue's Bridge. Three individuals were captured moving upstream in March 2008 at Milyeannup Pool, and one individual also moving upstream at Denny Road. This species generally utilises estuaries and are known to be tolerant to large variations in salinity.

Marron

Habitat associations

Although the Marron are found in considerably greater numbers within the main channel of the Blackwood River, they were also captured in all tributaries (Figures 76 and 77). This is a species generally regarded to favour larger, permanent aquatic systems (Austin & Knott 1996) thus explaining its greater abundance in the main channel sites compared to tributaries.

Migration patterns

Both upstream and downstream migrations of Marron were observed during fyke netting in the main channel sites and within the tributaries (Figures 76 and 77). Marron were captured in Milyeannup Brook during most sampling trips and in Rosa Brook in 2005/early 2006 and June to December 2007. Only minimal numbers were captured in McAtee Brook. The species appeared to have distinct upstream movement in Milyeannup Brook in December 2007 and in Rosa Brook in mid-late spring and early summer 2007 (Figure 77).

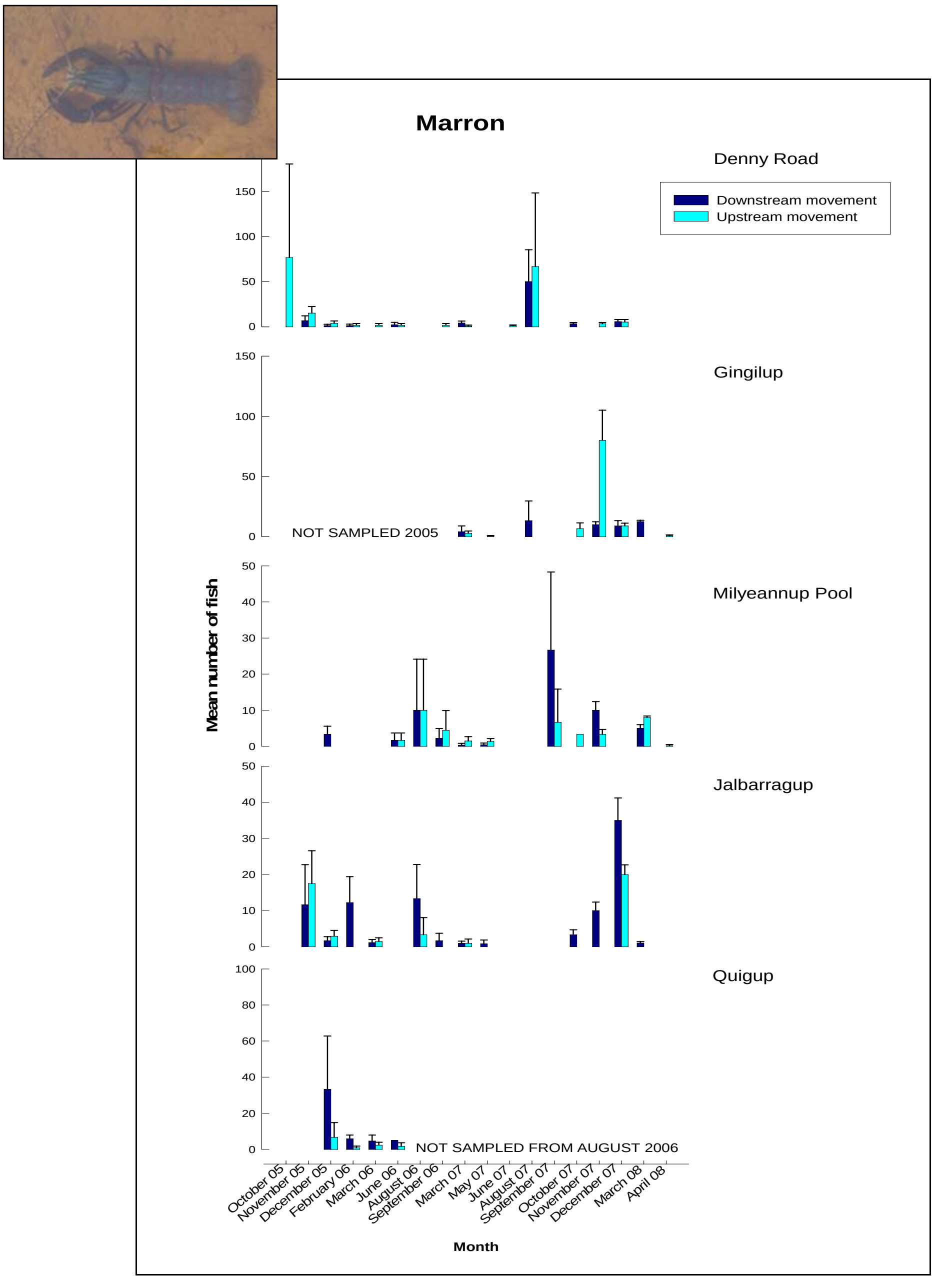


Figure 76 Upstream and downstream movement of Marron in the Blackwood River main channel.

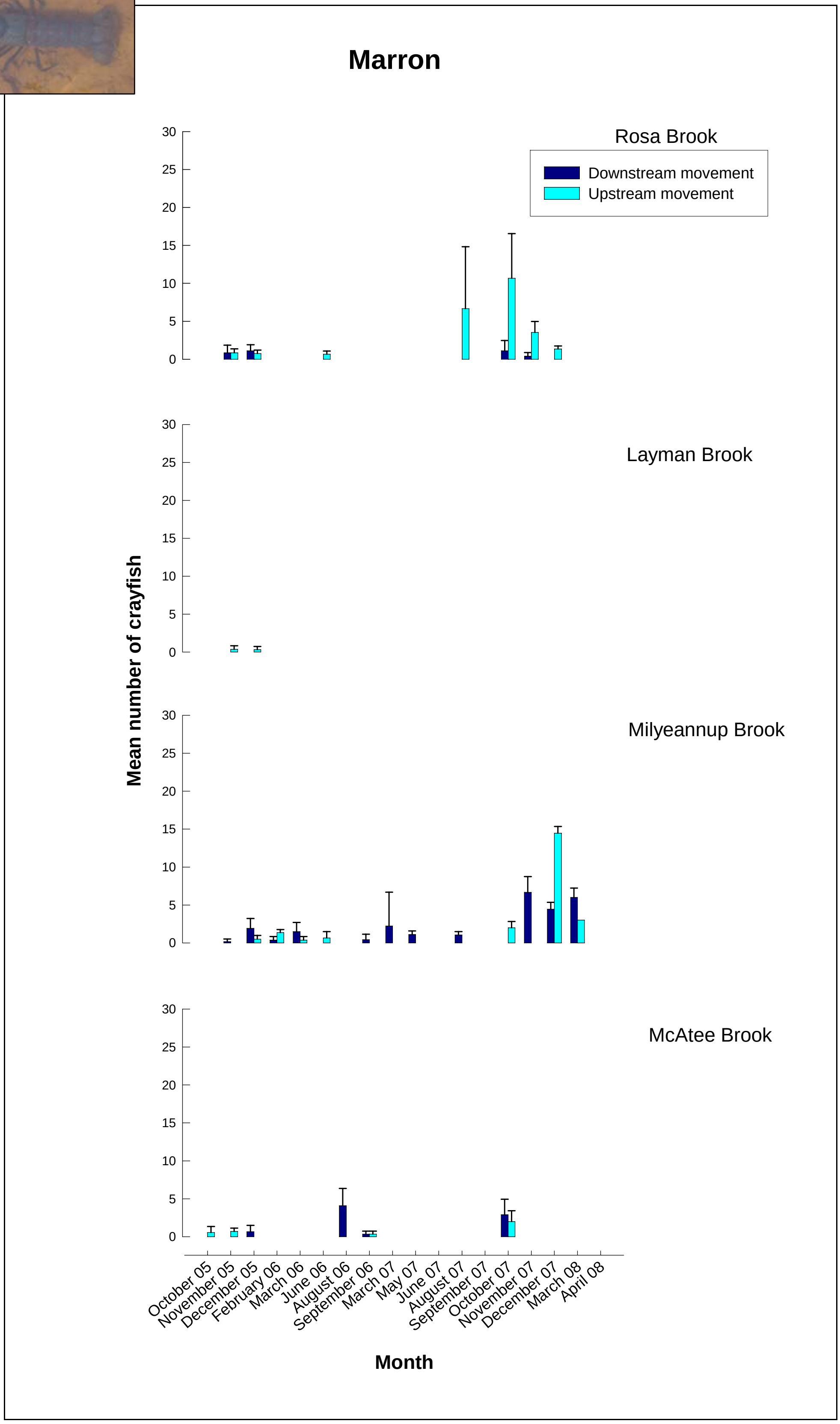


Figure 77 Upstream and downstream movement of Marron in the tributaries.

Gilgie

Habitat associations

Although found in both main channel and tributaries sites, Gilgies were found in higher numbers in the latter habitats (Figures 78 &79). Milyeannup Brook had the most consistent catches. Although this species occupies almost the full range of freshwater systems in south-western W.A., it is often associated with small streams (Austin & Knott 1996). It is also a species able to live in both permanent and temporary systems due to its ability to burrow into the water table to escape drought. It also matures at a small size and is believed to have the ability to breed multiple times over spring and summer (Beatty *et al*. 2005) allowing it to proliferate in seasonally inundated systems.

Migration patterns

Most of the movement in the main channel was recorded during winter in both 2006 and 2007 (Figure 78); possibly as a pre-cursor to breeding within the tributaries. These movements can be traced into the tributaries with substantial upstream migrations occurring in winter and spring (Figure 79). Migrations into the tributaries would provide small juveniles with relatively safe habitats away from large predators such as Freshwater Cobbler and Marron.

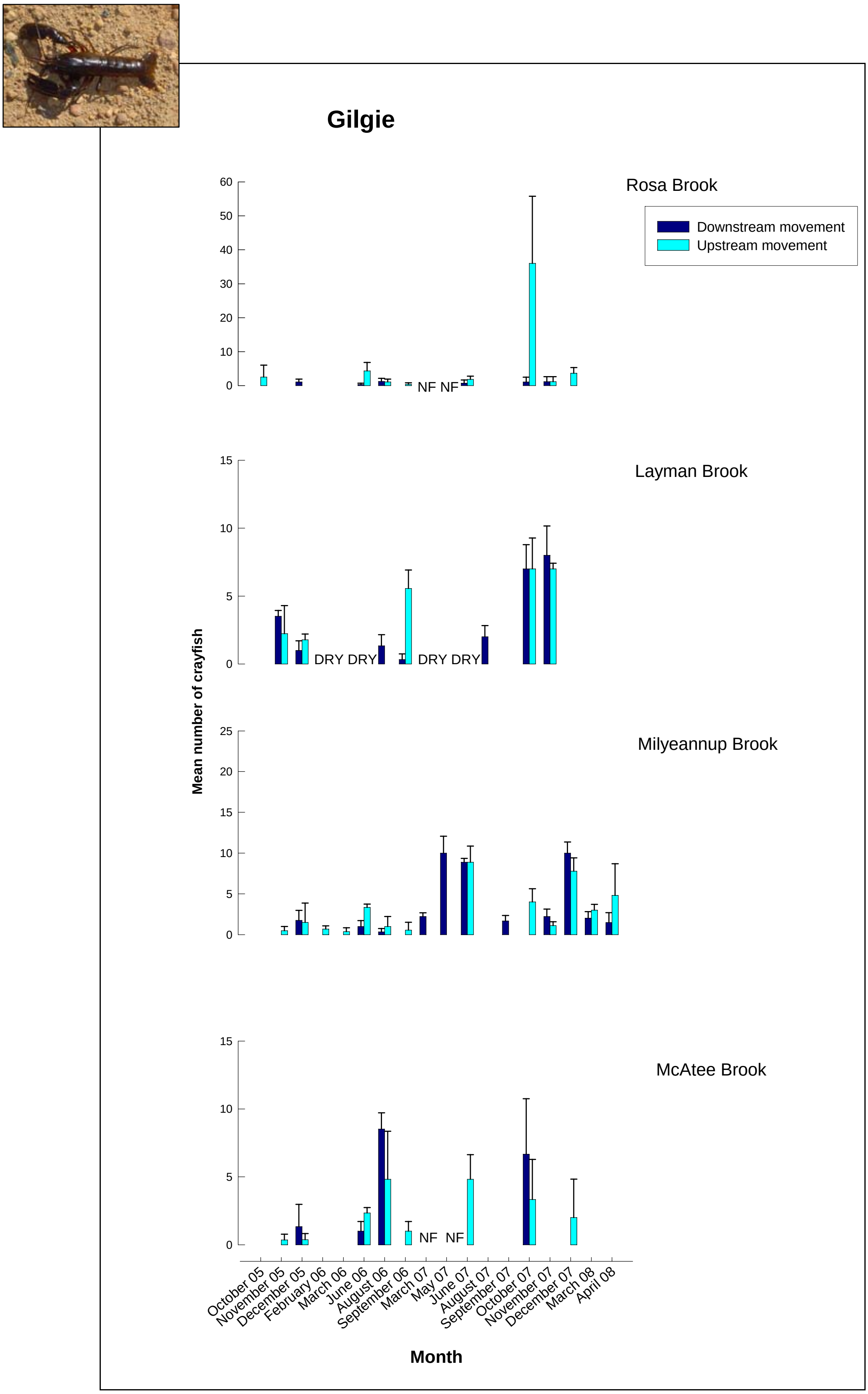


Figure 78 Upstream and downstream movement of Gilgie in tributaries.

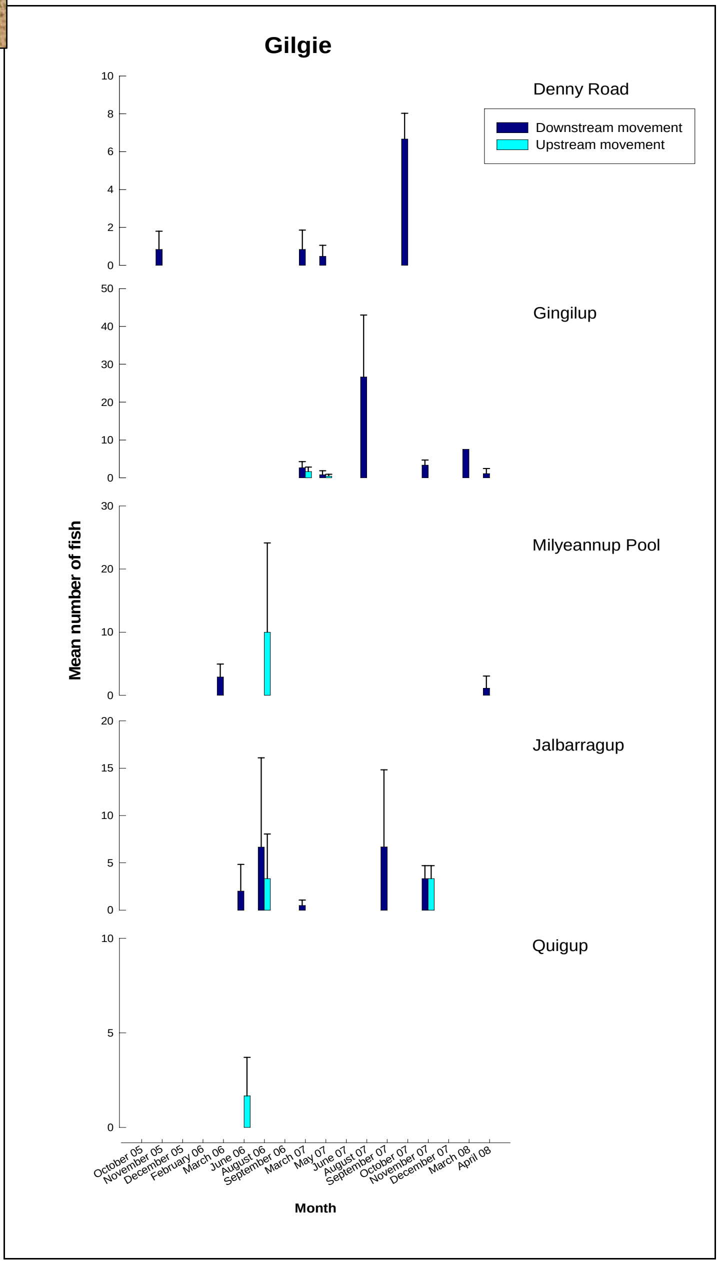


Figure 79 Upstream and downstream movement of Gilgie in the Blackwood River main channel.

Restricted Gilgie

Habitat associations

The Restricted Gilgie was not captured in fyke nets in the main channel sites sampled during this study; however Morgan & Beatty (2005) recorded two individuals of the species in the main channel at the Great North Rd crossing. In this study, we recorded the species during electrofishing and/or seine netting in low numbers at Milyeannup Pool, Jalbarragup and Quigup (Appendix 1). They were also recorded during electrofishing in McAtee Brook, Poison Gully and Milyeannup Brook and Morgan & Beatty (2005) captured the species in Rosa Brook. This species is generally associated with small stream systems and is also able to survive in seasonally inundated systems due to its ability to burrow into the water table (Austin & Knott, 1996).

Migration patterns

Due to the limited movements of the species recorded during the fyke netting (Figure 80) it is not possible to make inferences on migration patterns of the species. Furthermore, apart from genetic studies (Austin & Knott 1996), there has been limited research into the biology and ecology of this restricted species.

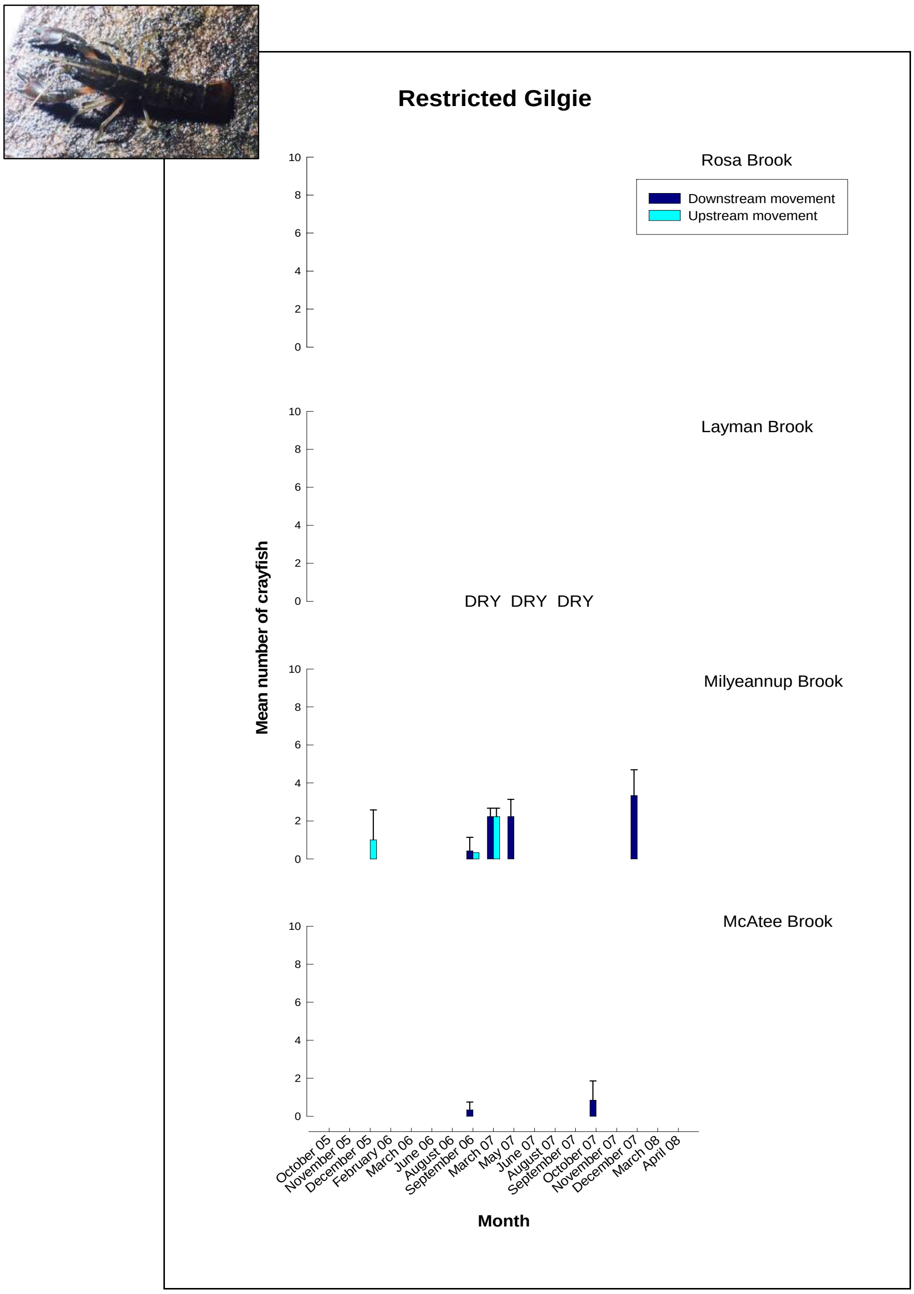


Figure 80 Upstream and downstream movement of Restricted Gilgie in the tributaries.

Koonac

Habitat associations

The Koonac was not recorded in fyke nets in the main channel sites sampled during 2005/2006; however they were captured using seines/electrofishing at Jalbarragup (Beatty *et al.* 2006) and three were captured in fyke nets during 2007/2008. Morgan & Beatty (2005) recorded numerous individuals of the species in a number of main channel sites within the Yarragadee Discharge Zone. During 2007/2008 twenty-four Koonacs were captured in fyke nets in the lower section of Milyeannup Brook and by electrofishing in the upper section (Figure 81). It was also recorded on one occasion in fyke nets in Rosa Brook during 2005/2006, on one occasion during 2005/2006 by electrofishing in McAtee Brook and two individuals were captured in Laymans Brook. As with the Gilgie, it is found in a similarly wide range of permanent and temporary aquatic systems throughout the south-west of W.A. as the Gilgie but is most commonly associated with lentic wetlands (Austin & Knott 1996).

Migration patterns

Due to low numbers recording using fyke nets there were no discernable trends evident in migration patterns. There is also no published work on the ecology or reproductive biology for this species; however, it may be similar to that of the Gilgie (Beatty *et al.* 2005) given that it occupies a similarly wide range of permanent and temporary aquatic systems throughout its range.

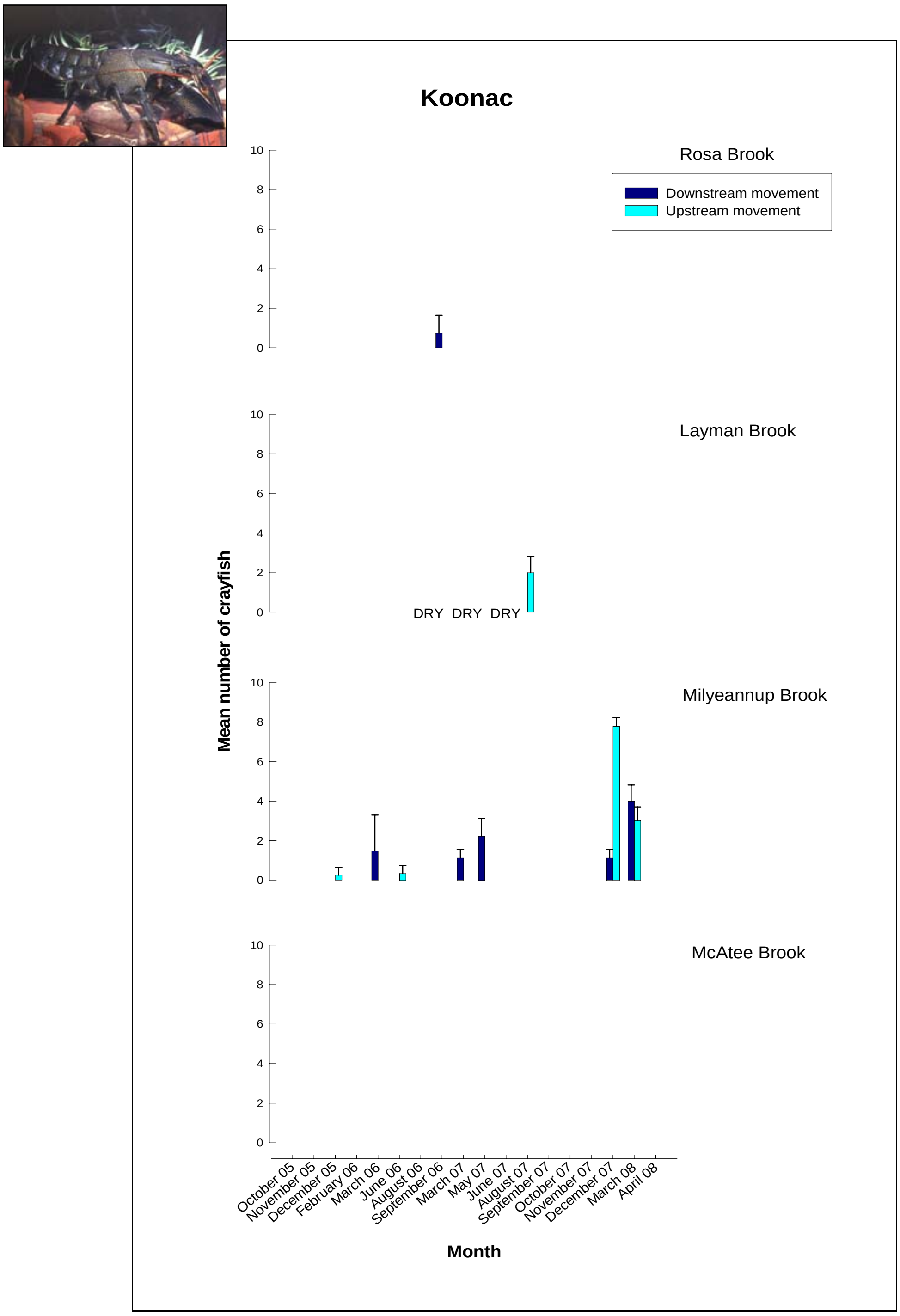


Figure 81 Upstream and downstream movement of Koonac in the tributaries.

St John Brook summary

Sampling at St John Brook was conducted in June and November 2007 and June 2008. Although a summer sample was scheduled for March 2008, the brook had inadequate depth for sampling at that time.

Western Minnow were captured in greatest numbers moving upstream in June 2007, i.e. means of 121 fish over three nights (Figure 82). During November 2007 both upstream and downstream movement was recorded with 42 and 61 fish respectively. In comparison, June 2008 exhibited minimal downstream movement only (Figure 82). Movement of Western Pygmy Perch was considerably smaller than Western Minnow, only 2 and 13 fish moving downstream in June and November 2007. This species was not captured in 2008 (Figure 82). The number of Nightfish captured in November 2007 and June 2008, also moving downstream, was minimal (Figure 82).

Freshwater Cobbler and Lamprey were both captured in St John Brook in 2007 and 2008 (Figure 83). The captures of Freshwater Cobbler were minimal i.e. two cobbler moving downstream in November 2007 and one in each direction in June 2008. Lampreys (ammocoetes) were also captured moving downstream (Figure 83).

Marron were captured in June 2007 and 2008, while Gilgies were captured during each sampling trip (Figure 84). It is interesting to note that in November 2007, when no Marron and only a few Gilgie were captured, that both Redfin Perch and Rainbow Trout were present (Figure 85). Both these feral species, in particular the Redfin Perch, are known to prey heavily on freshwater crayfish. The elevated flows during this month are most likely responsible for these ferals moving downstream from Barrabup Pool, an area known to hold populations of both species.

Summary and recommendations:

- St John Brook clearly provides a spawning habitat for both Western Minnow and the Pouched Lamprey.
- Sampling has thus far also recorded Western Pygmy Perch, Freshwater Cobbler and Nightfish as well as Marron and Gilgies utilising the system.
- The presence of Redfin Perch and Rainbow Trout, below Barrabup Pool is cause for concern as both species are known to impact on native fish and crayfish.

- It is recommended that St John Brook be sampled more regularly between 2008-2010 (i.e. as part of the scheduled sampling regime) in order to describe the fish migration patterns in the system.

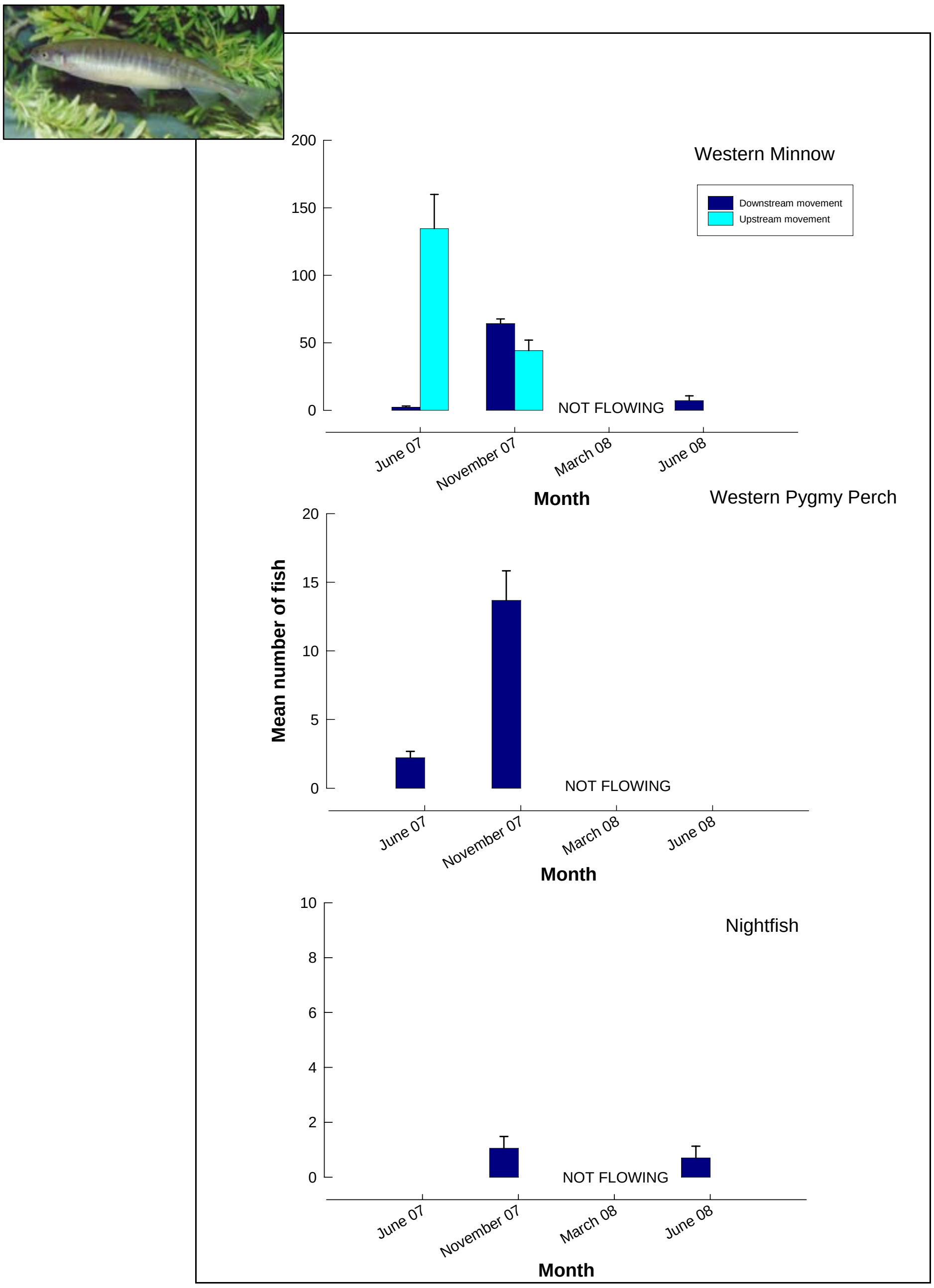


Figure 82 Upstream and downstream migration of Western Minnow, Western Pygmy Perch and Nightfish in St John Brook.

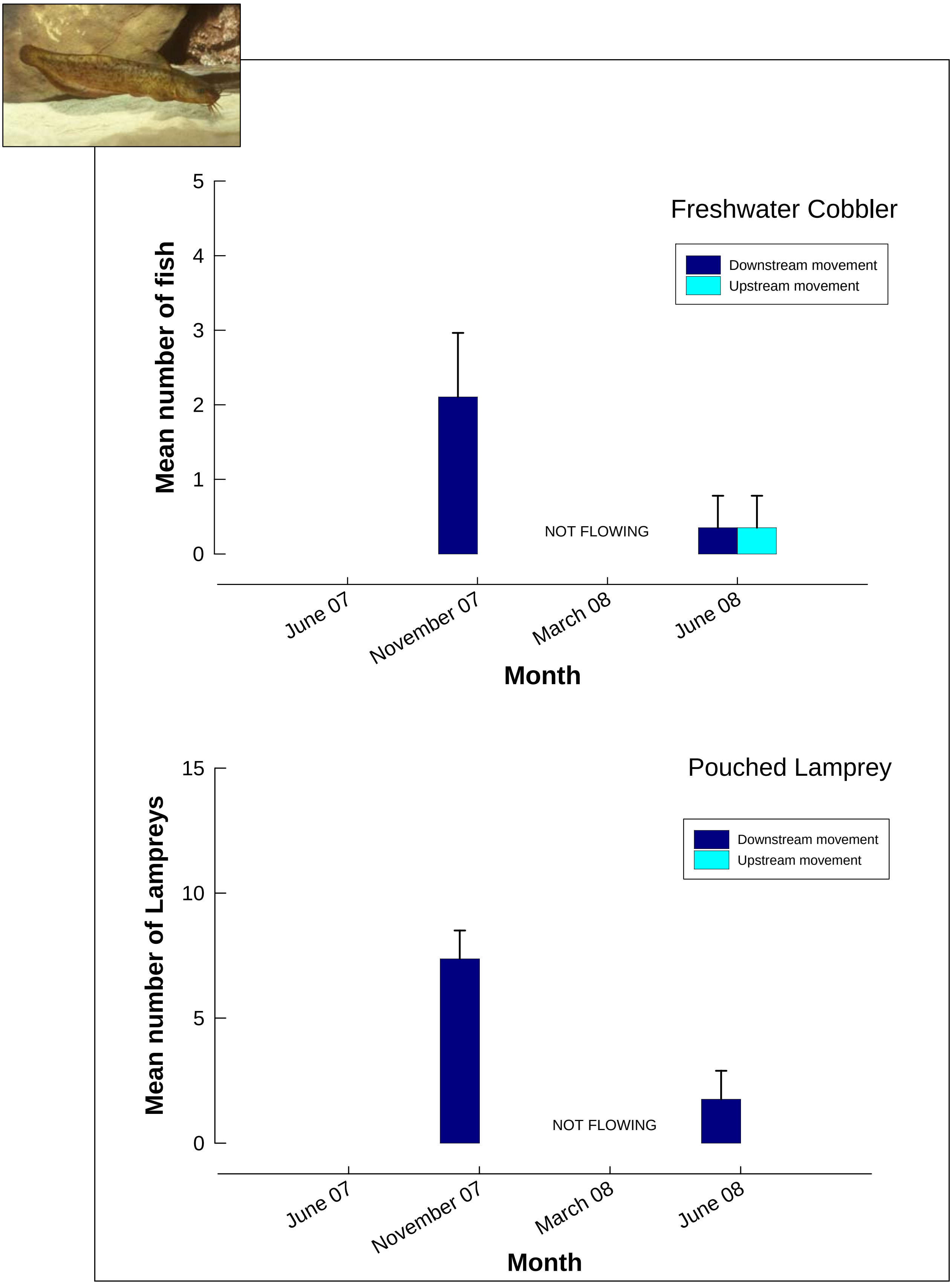


Figure 83 Upstream and downstream movement of Freshwater Cobbler and Pouched Lamprey in St John Brook.

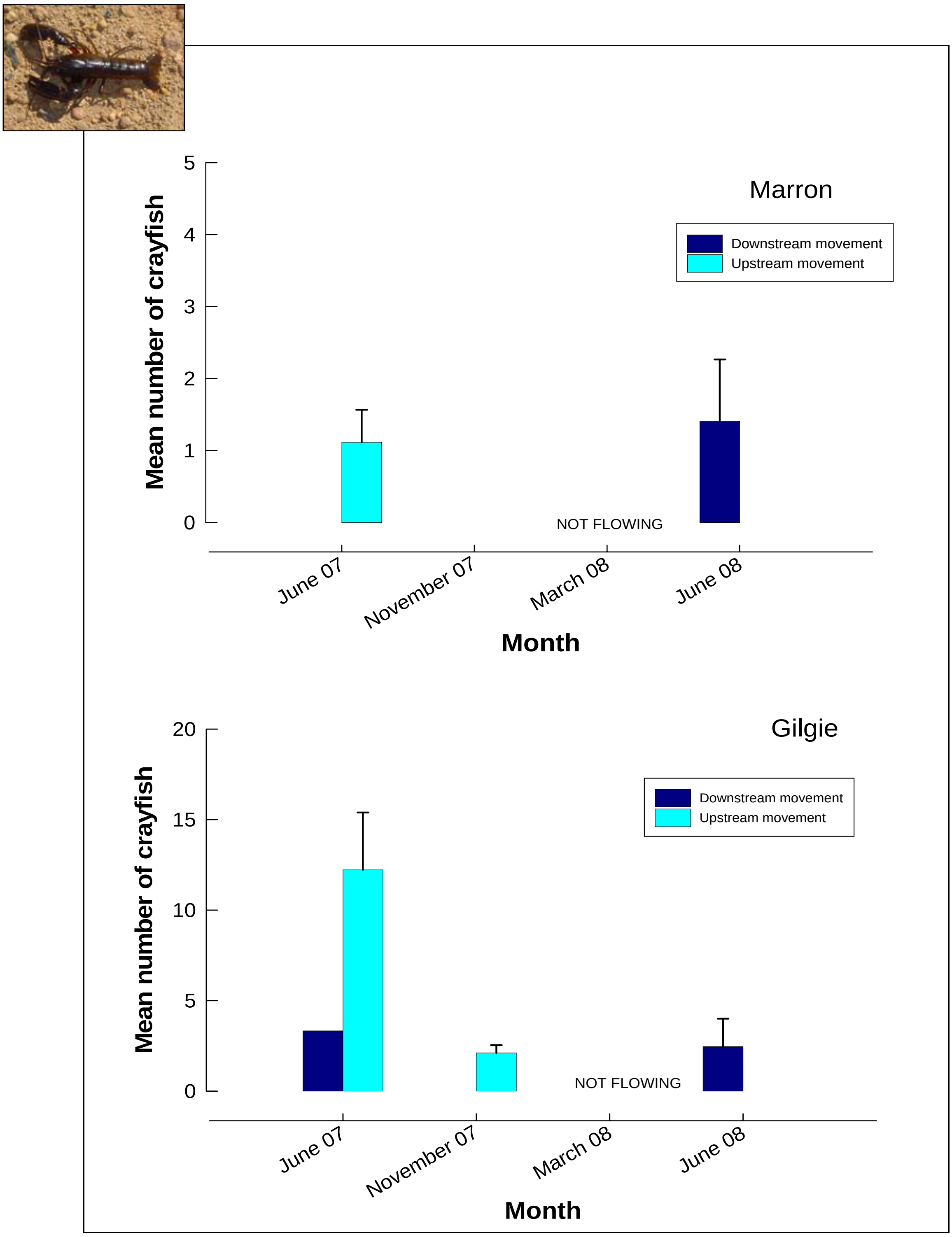


Figure 84 Upstream and downstream movement of Marron and Gilgie in St John Brook.

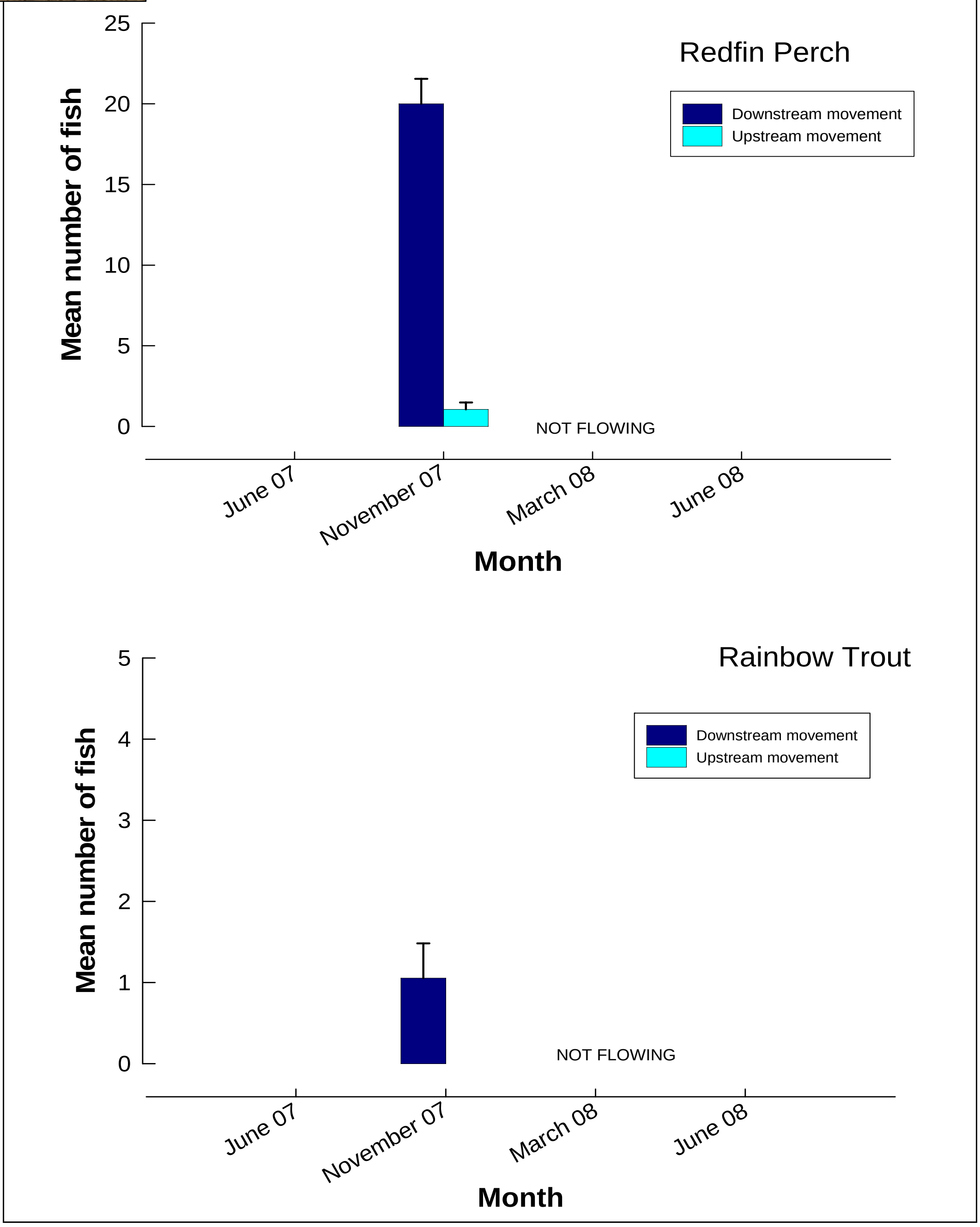


Figure 85 Upstream and downstream movement of Redfin Perch and Rainbow Trout in St John Brook.

Milyeannup Brook baseflow fish habitat associations

Permanent flow in Milyeannup Brook was found to decrease from a distance of ~2500m from the Blackwood River in March 2006 (i.e. between Mil 6 and Mil 7) to between 1600m-1800 in 2007 and 2008. Site Mil 6 contained segmented, shallow pool habitats in March 2007 and 2008 and those sites upstream of that site were dry on both occasions (Table 8). Based on discharge estimates at Mil 3 in March 2007 and 2008, baseflow discharge was greater in 2007 (3.6 l/sec) compared to 2008 (2.0 l/sec). Negligible flow was observed at Mil 5 in both March 2007 and 2008 however; clearly deeper pool habitats existed in the former year presumably as a result of higher groundwater level that increased level of baseflow discharge downstream at Mil 3 (Table 8, Figure 86).

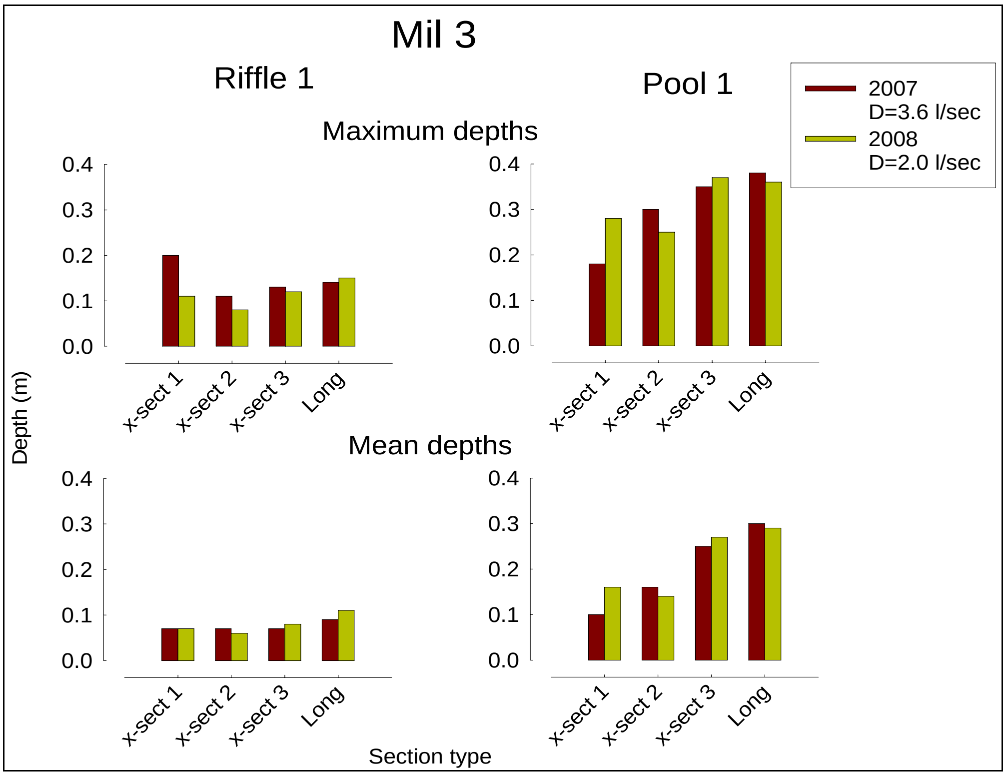
Densities of fishes in the habitats at the various sites are presented in Table 9. Balston's Pygmy Perch were consistently recorded at sites Mil 3 (2007, 2008) and Mil 4 (in 2007: not sampled in 2006, 2008). This species was not recorded at Mil 5 suggesting its upstream distribution (despite inter-annual variations in discharge) to be consistently between Mil 4 and Mil 5 (i.e. <1600m from the Blackwood River). However, as with other species it appears that it may have a preference for deeper pool habitats as suggested by the fact that the species was only recorded in pools and an (albeit relatively weak at this stage i.e., $r^2 = 0.35$) positive relationship existed between habitat depth and density of the species in Mil 3 and Mil 4 (Figures 87, 88 and 90). Balston's Pygmy Perch were found in pool habitats with an average depth of >~19cm. The scheduled replicate monitoring that is will occur in March 2009 and March 2010 will allow substantiation of these relationships.

Other native fishes were consistently recorded as far upstream as Mil 5; further than the Balston's Pygmy Perch (Figure 87, 88 and 89). Although the Western Minnow, Western Pygmy Perch and Nightfish were generally more prevalent and concentrated in pool habitats, each was recorded in riffle zones on at least one occasion during the sampling in the three sites in March 2007 and 2008. This suggests that these species may occupy a wider range of aquatic habitats in Milyeannup Brook during baseflow conditions than Balston's Pygmy Perch. However, this apparent wider habitat usage by these species requires further verification during the replicate sampling scheduled in subsequent years. Re-analysis of all these relationships, with the inclusion of data from subsequent sampling events that are scheduled for March 2009 and 2010, will be undertaken that will enable more specific aquatic habitat requirements of these native fishes.

Freshwater crayfishes were shown to occupy both pool and riffle habitats with no clear preference being evident (Figures 87, 88 and 89). The Gilgie, Restricted Gilgie and Koonac are known to occupy a wide range of permanent and temporary aquatic systems in the south-west region (Austin & Knott, 1996) and therefore the occupation of both riffle and pool habitats within Milyeannup Brook is not unexpected. Furthermore, their ability to tolerate drought by burrowing into the water table also allows them to permanently inhabit the upstream, seasonally inundated, sections of Milyeannup Brook (and other tributaries of the Blackwood River).

Summary and Recommendations

- Inter-annual variation in baseflow in Milyeannup Brook is considerable as evidenced by a length of flow decrease from a distance of ~2500m from the Blackwood River in March 2006 down to between 1600-1800m in 2007 and 2008.
- The upstream extent of the baseflow distribution of Balston's Pygmy Perch in Milyeannup Brook is upstream distribution was consistently between Mil 4 and Mil 5 (i.e. <~1600m from the Blackwood River).
- Balston's Pygmy Perch was not recorded in riffle zones on any occasion and were only found in habitats with an average depth of >~19cm suggesting that it may have a preference for pool habitats.
- Western Minnow, Western Pygmy Perch and Nightfish were generally more prevalent and concentrated in pool habitats; however, each species was recorded in riffle zones suggesting they may have the ability to occupy a wider range of aquatic habitats in Milyeannup Brook during baseflow conditions than Balston's Pygmy Perch.
- Freshwater crayfishes were shown to occupy both pool and riffle habitats with no clear preference being evident.
- It is recommended that these relationships be further validated by again replicating the sampling during baseflow conditions in March 2009 and 2010 in order to recommend specific aquatic habitat requirements of these native fishes.



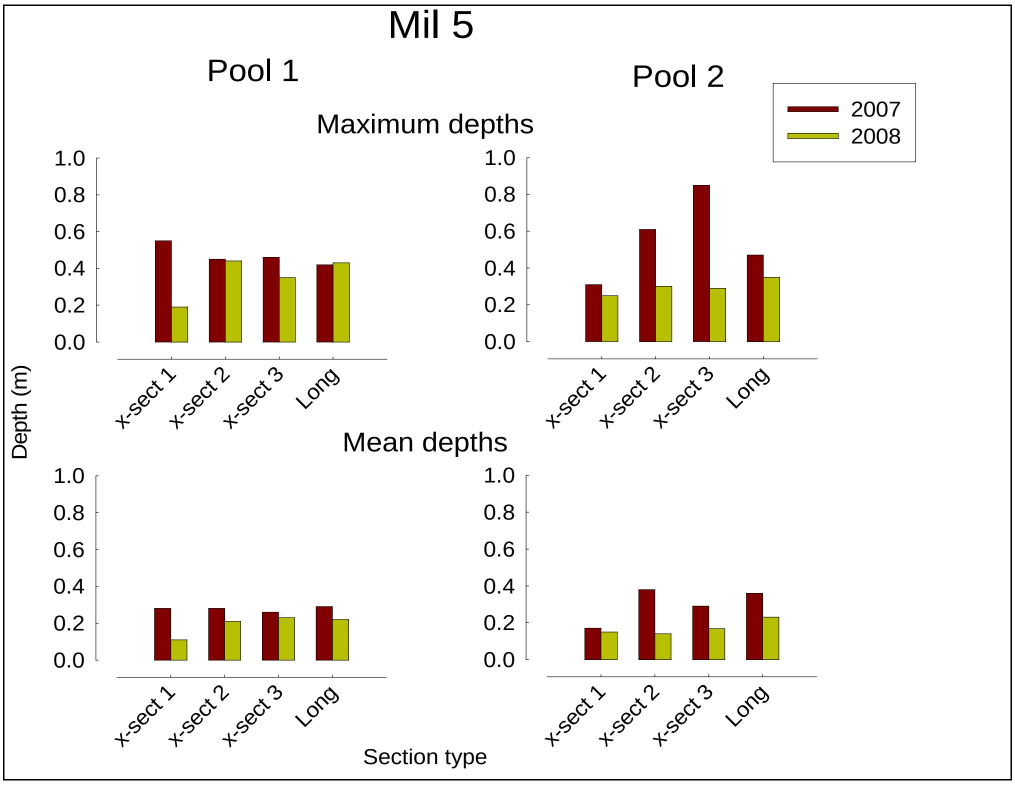


Figure 86 Maximum and mean depths of the cross (x-sect) and longitudinal (long) sections of dominant habitat types (either pool or riffle zones) at Mil 3 and 5. N.B. the greater depths in the pools in Mil 5 in the 2007 during greater discharge (measured at Mil 3) compared with 2008. Note also the lack of clear depth difference between those times in Mil 3 despite the increased discharge measured at that site.

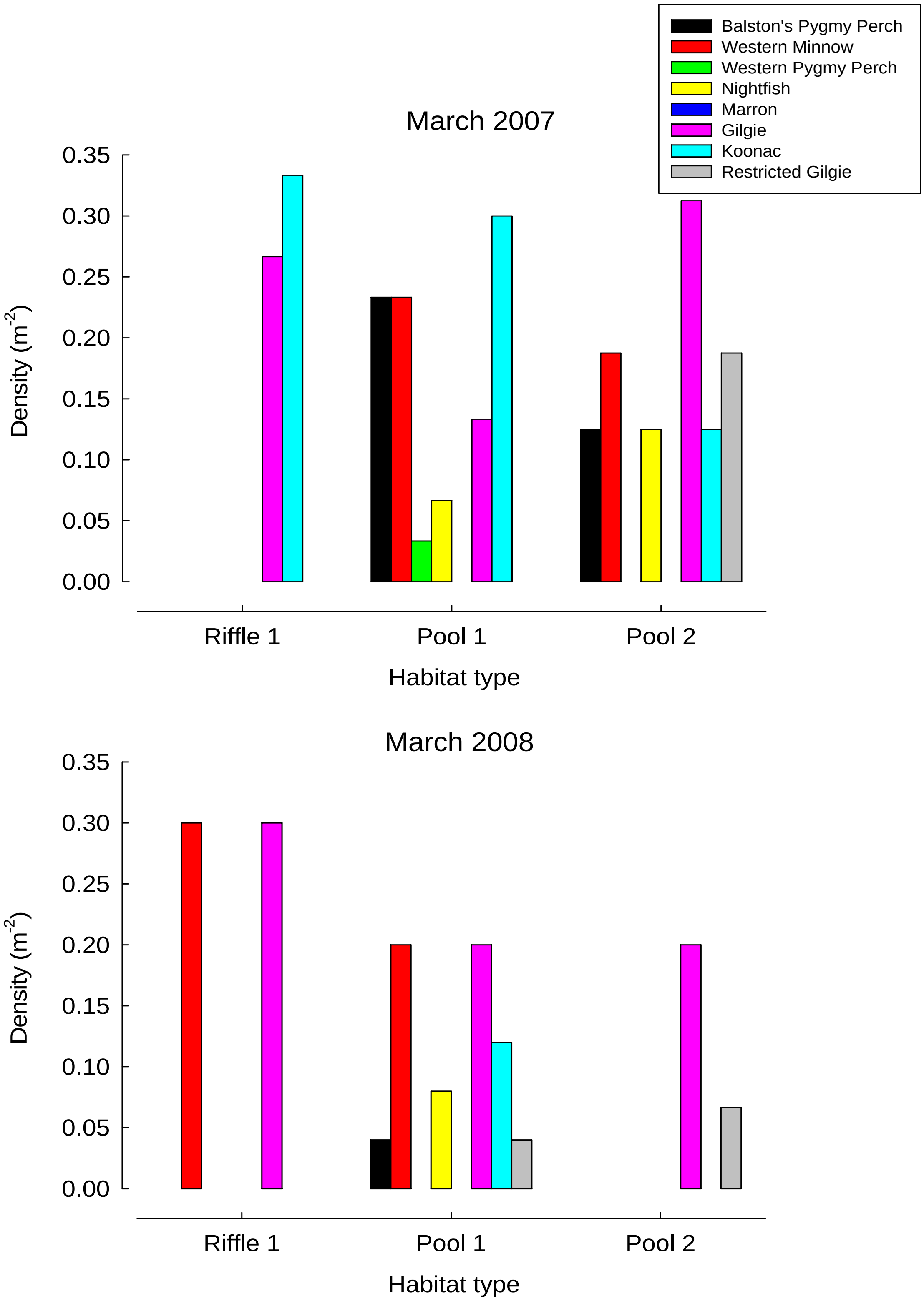


Figure 87 Densities of fish and freshwater crayfish in the three habitat types at Mil 3 during baseflow in 2007 and 2008. N.B. the lower diversity of fish in the riffle habitat compared with the pool habitats.

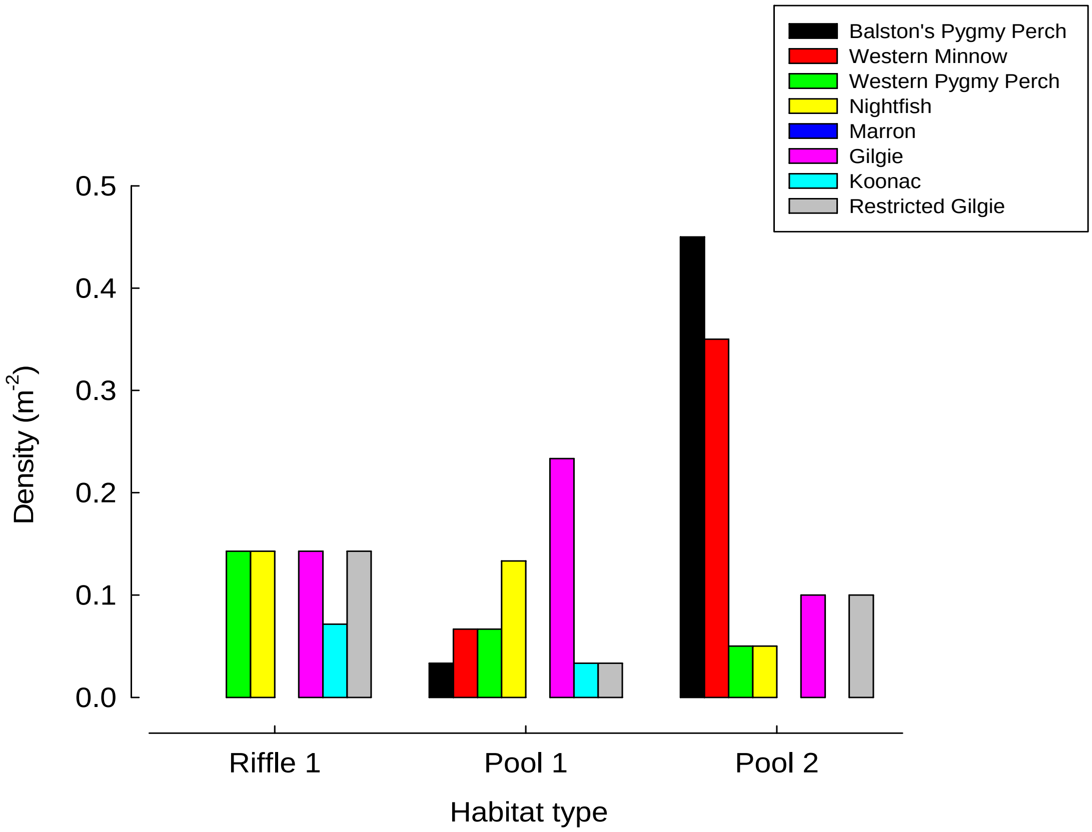


Figure 88 Densities of fish and freshwater crayfish in the three habitat types at Mil 4 during baseflow in 2007. N.B. the relatively high abundance of the Balston's Pygmy Perch in Pool 2.

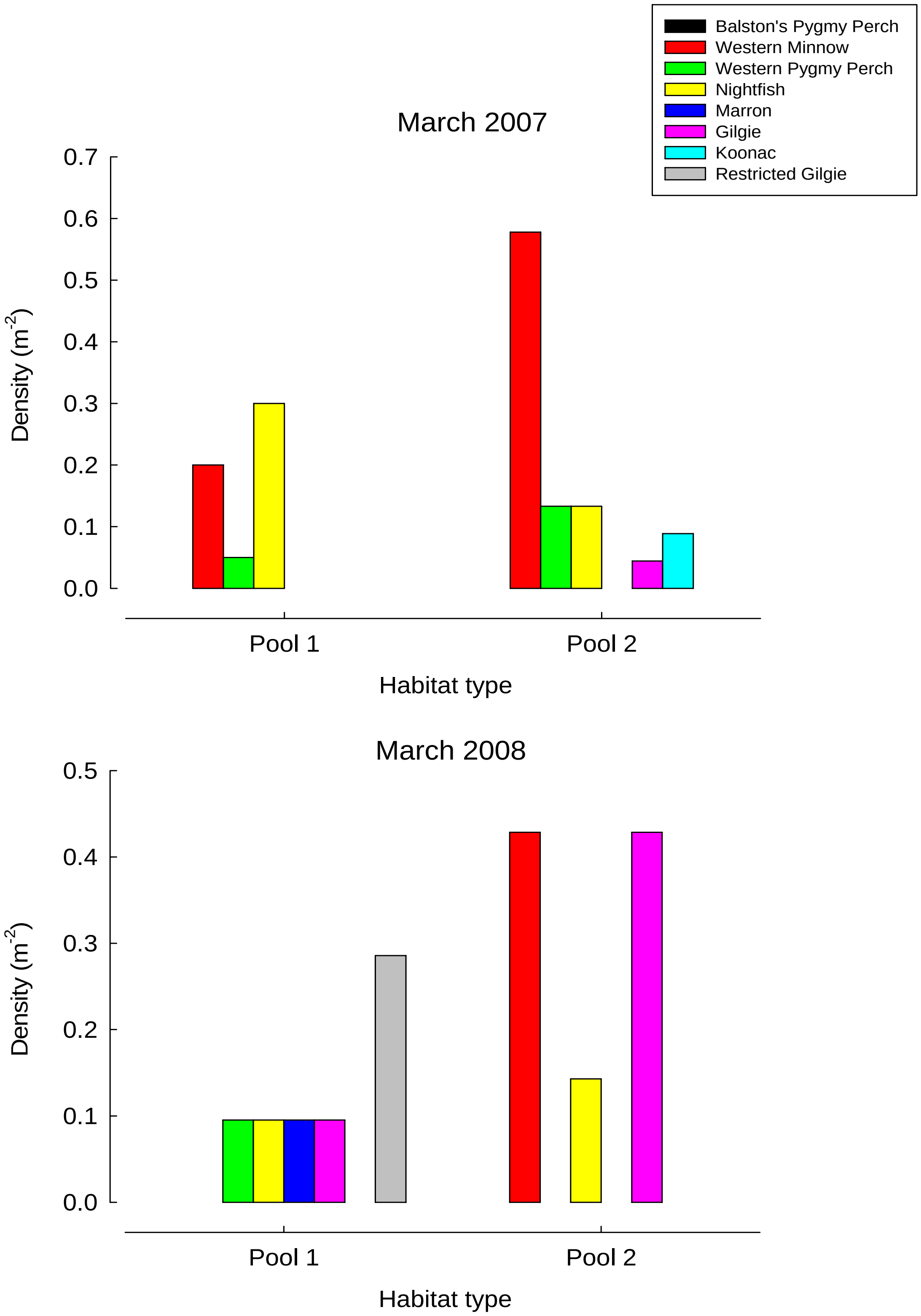


Figure 89 Densities of fish and freshwater crayfish in the three habitat types at Mil 5 during baseflow in 2007 and 2008. N.B. the lack of Riffle habitat in this section and it approximated the upstream point of permanent aquatic habitat with negligible flow being recorded in both years.

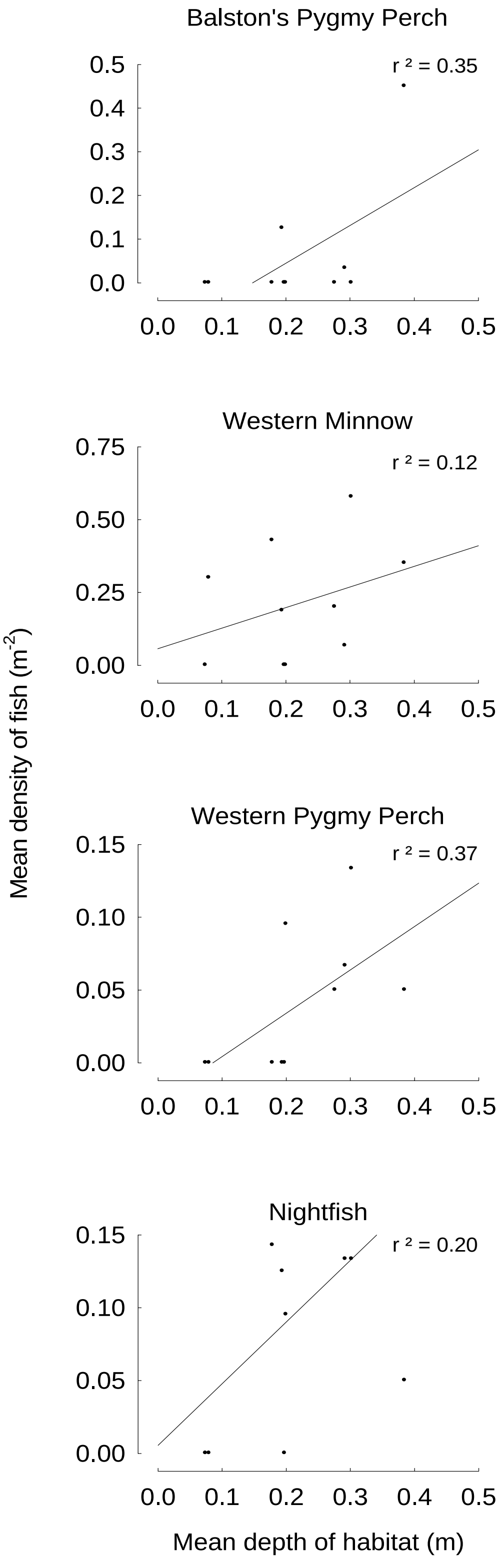


Figure 90 Preliminary relationships between the mean depths of habitats sampled within Mil 3, 4 and 5 and the mean density of fish within each of those habitats. N.B. the weak positive relationship between the depth and fish density of Balston's Pygmy Perch and Western Pygmy Perch.

Table 8 Depths of pool and riffle habitats at sites sampled during baseflow period (March) in 2007 and 2008 in Milyeannup Brook. N.B. Included is the mean temperature, conductivity, pH and dissolved oxygen at each site. Note the reduced flow velocity and discharge during 2008 relative to 2007 and the greater depths at pools at Mil 5 in 2007 relative to 2008 whereas no clear differences existed at Mil 3 between those years. *disconnected pool habitats at Mil 6 in March 2007 and 2008.

Site	Habitat type	Section taken	2007 Max depth (m)	Av depth (m)	Av vel (m/sec) and disch (l/sec)	Temp (°C)	Cond (µS/cm)	pH	DO (ppm)	2008 Max depth (m)	Av depth (m)	Av vel (m/sec) and disch (l/sec)	Temp (°C)	Cond (µS/cm)	pH	DO (ppm)	Turb (NTU)
Mil 3	Riffle 1	x sect 1	0.2	0.07						0.11	0.07						
		x sect 2	0.11	0.07						0.08	0.06						
		x sect 3	0.13	0.07						0.12	0.08						
		Longitudinal	0.14	0.09	V = 0.06 D = 3.6	16.5 (0)	483 (11.1)	5.69 (0.01)	5.30 (0.06)	0.15	0.11	V = 0.04 D = 2.0	15.1 (0.11)	481 (0.71)	5.26 (0.01)	5.36 (0.01)	1.52 (0.13)
	Pool 2	x sect 1	0.18	0.10						0.28	0.16						
		x sect 2	0.30	0.16						0.25	0.14						
		x sect 3	0.35	0.25						0.37	0.27						
		Longitudinal	0.38	0.30						0.36	0.29						
Mil 4	Pool 1	x sect 1	0.45	0.28													
		x sect 2	0.45	0.29													
		x sect 3	0.35	0.24													
		Longitudinal	0.48	0.41		15.4 (0.04)	514 (7.79)	5.37 (0.04)	4.44 (0.02)								
	Pool 2	x sect 1	0.5	0.28													
		x sect 2	0.75	0.53													
		x sect 3	0.32	0.21													
		Longitudinal	0.89	0.57													
Mil 5	Pool 1	x sect 1	0.55	0.28	V = ~0 D = ~0	17.6 (0.19)	556 (10.82)	5.38 (0.05)	2.68 (0.04)	0.19	0.11	V = ~0 D = ~0	15.1 (0.14)	591 (4.30)	4.98 (0.03)	4.45 (0.11)	1.51 (0.24)
		x sect 2	0.45	0.28						0.44	0.21						
		x sect 3	0.46	0.26						0.35	0.23						
		Longitudinal	0.42	0.29						0.43	0.22						
	Pool 2	x sect 1	0.31	0.17						0.25	0.15						
		x sect 2	0.61	0.38						0.3	0.14						
		x sect 3	0.85	0.29						0.29	0.168						

		Longitudinal	0.47	0.36	0.35	0.23
Mil 6	Pool 1*	Length (m)	6		4	
		Width (m)	1		1.2	
		Max depth (m)	0.08		0.06	
	Pool 2*	Length (m)	4		1	
		Width (m)	0.8		1.2	
		Max depth (m)	0.1		0.05	
	Pool 3*	Length (m)	5		4	
		Width (m)	1		1	
		Max depth (m)	0.1		0.08	
Mil 7A			DRY		DRY	
Mil 7B			DRY		DRY	
Mil 7			DRY		DRY	
Mil 8			DRY		DRY	
Mil 9			DRY		DRY	
Mil 10			DRY		DRY	
Mil 11			DRY		DRY	

Table 9 Mean densities of fish and freshwater crayfish during baseflow sampling in sites in Milyeannup Brook in 2006, 2007, 2008.

Season Site	**Lat**	**Long**	**Total area sampled (m^2)**	**Mean Species Density m^2 (total number captured 2006, S.E. 2007, 2008) in Milyeannup Brook using Seine and/or Electrofishing.**									
				Native Fishes					**Feral Fishes**	**Freshwater Crayfishes**			
				Nannatherina balstoni	*Galaxias occidentalis*	*Edelia vittata*	*Bostockia porosa*	*Galaxiella munda*	*Oncorhynchus mykiss*	*Cherax cainii*	*Cherax quinquecarinatus*	*Cherax preissii*	*Cherax crassimanus*
Mil 3	**34.09882**	**115.5699**											
Autumn 2006			NS										
Autumn 2007			51	0.12 (0.08)	0.14 (0.09)	0.01 (0.01)	0.06 (0.04)				0.24 (0.07)	0.25 (0.08)	0.06 (0.08)
Autumn 2008			65	0.01 (0.02)	0.17 (0.11)		0.03 (0.03)				0.23 (0.04)	0.04 (0.05)	0.04 (0.02)
Mil 4	**34.10128**	**115.5700**											
Summer 2006			20		1.25 (20)	0.20 (4)	0.10 (2)	0.10 (2)			0.70 (14)		0.15 (3)
Winter 2006			125	0.07 (9)	0.40 (50)	0.10 (13)	0.064 (8)	0.024 (3)			0.06 (7)		0.01 (1)
Autumn 2007			64	0.17 (0.14)	0.14 (0.13)	0.09 (0.04)	0.11 (0.04)				0.16 (0.05)	0.03 (0.03)	0.09 (0.04)
Autumn 2008													
Mil 5	**34.10403**	**115.57085**											
Summer 2006			30		0.83 (25)	0.03 (1)	0.03 (1)	0.03 (1)		0.03 (1)	0.30 (9)		
Autumn 2007			44.5		0.39 (0.27)	0.09 (0.06)	0.22 (0.12)				0.02 (0.03)	0.04 (0.06)	
Autumn 2008			37.5										
Mil 6	**34.10682**	**115.56996**											
Summer 2006			20				0.600 (12)	0.300 (6)			0.100 (2)		
Autumn 2007	**Disconected pools**		14										
Autumn 2008	**Disconected pools**		10										

REFERENCES

Austin, C. M. and Knott, B. (1996). Systematics of the freshwater crayfish genus *Cherax* Erichson (Decapoda: Parastacidae) in south-western Australia: Electrophoretic, Morphological and Habitat Variation. *Australian Journal of Zoology* 44: 223-58.

Beatty, S.J., Morgan, D.L. and Gill, H.S. (2003). Reproductive biology of the large freshwater crayfish *Cherax cainii* in south-western Australia. *Marine & Freshwater Research* 54: 597-608.

Beatty, S.J., Morgan, D.L. and Gill, H.S. (2004). Biology of a translocated population of the large freshwater crayfish, *Cherax cainii* (Austin & Ryan, 2002) in a Western Australian river. *Crustaceana* 77(11): 1329-1351.

Beatty, S.J., Morgan, D.L. and Gill, H.S. (2005). Life history and reproductive biology of the gilgie *Cherax quinquecarinatus*, a freshwater crayfish endemic to south-western Australia. *Journal of Crustacean Biology* 25(2): 251-262.

Beatty, S., Rashnavidi, M., Morgan, D. and Lymbery, A. (2008). Salinity tolerances of native freshwater fishes of the Blackwood River. Centre for Fish & Fisheries Research, Murdoch University research report to South West Catchments Council.

Beatty S., Morgan D., McAleer F., Koenders A. and Horwitz P. (2006). Fish and freshwater crayfish communities of the Blackwood River: migrations, ecology and the influence of surface and groundwater. Research Report Murdoch University and Edith Cowan University to South-west Catchments Council and Department of Water, Western Australia.

Boulton, A.J. and Hancock, P.J. (2006). Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications. *Australian Journal of Botany* 54: 133-144.

Centre of Excellence in Natural Resource Management (2005). *Ecological water requirements of the Blackwood River and tributaries – Nannup to Hut Pool*. Report for the Water Corporation of Western Australia, February 2005., pg 11

Gill, H.S., Renaud, C.B., Chapleau, F., Mayden, R.L., and Potter, I.C. (2003). Phylogeny of Living Parasitic Lampreys (Petromyzontiformes) Based on Morphological Data. *Copeia*, 2003(4): 687-703.

Gill, H.S., Wise, B.S., Potter, I.C. and Chaplin, J.A. (1996). Biannual spawning periods and resultant divergent patterns of growth in the estuarine goby *Pseudogobius olorum*: temperature-induced? *Marine Biology* 125: 453-466.

Laevastu, T. (1965). *Manual of Methods in Fisheries Biology.* Food and Agriculture Organisation: Rome, Italy.

Morgan, D. and Beatty, S. (2004). *Monitoring the Lion's Weir Fishway Hotham River, Western Australia*. Centre for Fish & Fisheries Research Murdoch University. Report to the Department of Environment, Government of Western Australia.

Morgan, D.L., and Beatty, S.J. (2005). Baseline study on the fish and freshwater crayfish fauna in the Blackwood River and its tributaries receiving discharge from the Yarragadee Aquifer. Centre for Fish & Fisheries Research Murdoch University.

Morgan, D.L. and Gill, H.S. (2000). Fish associations within the different inland habitats of lower south-western Australia. *Records of the Western Australian Museum* 20: 31-37.

Morgan, D.L., Gill, H.S. and Potter, I.C. (1995). Life cycle, growth and diet of Balston's pygmy perch in its natural habitat of acidic pools. *Journal of Fish Biology* 47: 808-825.

Morgan, D. L., Gill, H. S., and Potter, I. C. (1998). Distribution, identification and biology of freshwater fishes in south-western Australia. *Records of the Western Australian Museum* Supplement No. 56. 97 pp.

Morgan, D.L., Thorburn. D.C. and Gill, H.S. (2003). Salinization of south-western Western Australian rivers and the implications for the inland fish fauna – the Blackwood River, a case study. *Pacific Conservation Biology* 9: 161-171.

Morgan, D., Beatty, S., Gill, H., Thorburn, D. and Rowland, A. (2004). *Assessment of groundwater discharge from the Yarragadee Aquifer on the fish and decapod fauna of Rosa Brook*. Centre for Fish & Fisheries Research Murdoch University. Report to the Water Corporation of Western Australia.

Pen, L.J., Potter, I.C. and Hilliard, R.W. (1991). Biology of *Galaxiella munda* McDowall (Teleostei: Galaxiidae), including a comparison of the reproductive strategies of this and three other local species. *Journal of Fish Biology* 39: 717-731.

Petts, G.E., Bickerton, M.A., Crawford, C., Lerner, D.N. and Evans, D. (1999). Flow management to sustain groundwater-dominated stream ecosystems. *Hydrological Processes* 13: 497-513.

Phillips, N., Chaplin, J., Morgan, D. & Beatty, S. (2007). *The evolutionary significance of Balston's Pygmy Perch and Mud Minnow populations in the Blackwood River*. Centre for Fish & Fisheries Research Murdoch University report to Department of Water, Western Australia.

Potter, I.C. (1980). The Petromyzoniformes with particular reference to paired species. Canadian Journal of Fisheries and Aquatic Science, 37(11): 1595-1615.

Potter, I.C. and Hilliard, R.W. (1987). A proposal for the functional and phylogenetic significance of differences in the dentition of lampreys (Agnatha: Petromyzontiformes). *Journal of Zoology*. 212(4): 713-737.

Potter, I.C. Hilliard, R.W. and Neira, F.J. (1986). The biology of Australian lampreys. Deckker, Pde; Williams, WD (eds).