Inland Waters and Catchment Ecology

Environmental Water Requirements of native fishes in the Middle River catchment, Kangaroo Island, South Australia

Dale McNeil and Josh Fredberg

SARDI Publication No. F2011/000060-1
SARDI Research Report Series No. 528

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

March 2011

A report to the South Australian Department for Water

Government of South Australia

Environmental Water Requirements of native fishes in the Middle River catchment, Kangaroo Island, South Australia

A report to the South Australian Department for Water

Dale McNeil and Josh Fredberg

SARDI Publication No. F2011/000060-1
SARDI Research Report Series No. 528

March 2011

This Publication may be cited as:
McNeil, D. G. and Fredberg, J (2011). Environmental Water Requirements of native fishes in the Middle River catchment, Kangaroo Island, South Australia. A Report to the SA Department for Water. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000060-1. SARDI Research Report Series No. 528. 50pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

Printed in Adelaide: March 2011

SARDI Publication No. F2011/000060-1
SARDI Research Report Series No. 528

Author(s): Dale McNeil and Josh Fredberg

Reviewer(s): Phillipa Wilson and Mardi van der Wielen

Approved by: Dr Qifeng Ye
Principal Scientist – Inland Waters & Catchment Ecology

Signed:

Date: 22 March 2011

Distribution: SA Department of Water, SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The authors would like to thank Mardi van der Wielen of the Department for Water for conceiving, driving and managing the project and provided support to the field program and assisting with surveys. The entire EWP team, including Tim Doeg, Michelle Cassinova, Mardi van der Wielen, Geoff Vietz, Paul McEvoy, Kumar Savadamutha, Jason van Laarhoven and Luke Esprey contributed to the development of ideas, conceptual models and the sampling hypotheses and strategies pursued in the project and assisted with data collection and the provision of support (sometimes literally) to the fishos in the field. The Pandarna Café provided important technical support with the provision of Galaga machinery that enabled the successful completion of key field work components.

Special thanks is given to the landholders; Peter McGill, Scott Henderson, Bugsy, Geoff Iverson, Colin Wilson and Staff at the Kangaroo Island NRM Board, SA Water, Great Southern Forestry and Flinders Chase National Park Office; who generously allowed and facilitated access to their properties and helped with the selection and access to sampling sites as well as providing important information for the development of the project.

Rod Ward, David Short and Neil Wellman (SARDI) provided excellent assistance in collecting field data and conducting field surveys, processing data, removing otoliths and analyzing gonad development. Qifeng Ye provided management for SARDI Aquatic Sciences and thanks to SARDI reviewers for comments and revisions to the manuscript. The project was funded by the SA Department for Water.

Frontispiece. Adult *Galaxias brevipinnis* from Middle River Kangaroo Island.

EXECUTIVE SUMMARY

During 2009 the South Australian Department of Water Land and Biodiversity Conservation (now the SA Department for Water - DfW) embarked on a process of identifying the environmental water requirements (EWR) of the Middle River Catchment on Kangaroo Island. Field sampling was conducted to explore the specific environmental water requirements of native fishes in the Middle River catchment. Previous expert panel sessions had developed a number of conceptual models outlining the timing, frequency and duration of flows required to support various ecological functions, including key aspects of native fish life history. The field sampling was designed to address identified knowledge gaps and to ground truth specific hypotheses developed in the expert panel forum.

Sampling was conducted during two dedicated field trips in December 2009 and early June 2010, with opportunistic surveys conducted during site visits in November 2009 and March 2010. Overall, sites were sampled across all of the main geomorphic reach types identified for the catchment including upland swamps, valley infill, upper- and mid- channel pool reaches, reservoir, gorge, lowland channel and estuarine reaches. Additional sites were surveyed in adjacent catchments on Kangaroo Island to provide some degree of referential information regarding the distribution, ecology and response to flow for species common to those catchments.

The survey identified four key zones relating to fish community: the estuarine area contained a specific estuarine fish community, a lowland/Gorge section dominated by *Galaxias maculatus*, the reservoir area dominated by introduced Rainbow trout and the mid-upper catchment dominated by *Galaxias brevipinnis*. All species collected were common species previously identified from Kangaroo Island catchments. Strategic sampling provided data to support many of the conceptual models and environmental water targets and flow provisions developed during the Middle River EWR project. In particular data supported the timing of flows targeted for spawning and recruitment, migratory pathways (connectivity) and the maintenance of habitat and water quality values. The survey also raised concerns about the presence of large predatory trout around the reservoir and the possibility of the reservoir wall to act as a barrier to fish migration between the sea and mid- upper- catchment areas. Recommendations are also provided for the provision of flows that protect and enhance native fish sustainability in the Middle Rive catchment.

1. INTRODUCTION

1.1. Background

Establishing accurate environmental requirements for water resources is essential for ensuring that the prescription and allocation of water does not lead to serious environmental impacts. Environmental water requirements (EWR) include any levels of flow, aspects of flow regime or the maintenance of water levels and aquatic habitats that are critical for the natural function of aquatic ecosystems. The South Australian Department for Water (DfW) is currently undertaking a water resources investigation into the Middle River on the north coast of Kangaroo Island, which contains the Island's only public water supply reservoir (van der Wielen *et al*. 2009 a & b). Whilst water requirements are by necessary characterized as periodic volumes of flow, several aspects of the temporal and spatial distribution of water are important for various aquatic organisms to meet critical life history requirements.

Fish are an important indicator of the health of aquatic ecosystems and monitoring fish populations can provide insight into key aspects of aquatic habitat and hydrology that support healthy ecosystem processes. Providing adequate and appropriately timed flows to support key life history requirements of native fish serves as a surrogate for a range of natural flow requirements of freshwater ecosystems because fish are wholly aquatic and rely on the maintenance of aquatic habitats for survival and utilize appropriately timed flows to carry out migrational, spawning and recruitment processes critical for the sustainability of populations (Bunn and Arthington 2002). Fish therefore provide a range of water requirements that also meet the general needs of other freshwater biota, for example, connecting flows that enable fish movement at spawning times may also provide riffle inundation during critical times for insect larval growth and development. Large flows that allow larvae of diadromous fish access to the sea (McDowall *et al.* 1975, McDowall 1976, McDowall and Suren 1995) are also important for the inundation of floodplain areas, for the watering of riparian vegetation (Thomas *et al.* 1999).

As a result, a range of fish related EWRs were developed as part of the assessment of Environmental Flow Requirements for the Middle River catchment (van der Wielen *et al*. 2009a and b). This process utilized an expert panel approach to develop conceptual models and testable hypotheses for specific water requirement of native fish species. The key focus of the current study is to reveal specific EWRs for fish in the Middle River catchment and to inform key hypothesis relating to water requirements, as developed in that process.

1.2. Objectives

This report outlines the results of field surveys to identify the distribution of fish species throughout the Middle River catchment, to assess the movement of fish throughout the catchment including the use of diadromy and requirements for connectivity between freshwater habitats and with marine habitats and to pinpoint the position of key refuge waterholes in which native fish can survive periods of low flow and drought. In particular, the data has been collected so as to maximize knowledge and information regarding each of the EWR models outlined for fish during the EWR process and to inform on the accuracy of expert panel models and address key knowledge gaps and hypotheses developed in the process. Outputs from the survey will be discussed in relation to each of the relevant EWR targets (see section 4).

This paper aims to:

- Outline the survey results
- Present the distribution of fish species across the catchment
- Present key population data for various sites and reach types
- Identify and discuss the use of diadromy in the Middle River catchment
- Summarise and discuss EWR for native fish in relation to survey findings
- Provide recommendations and amendments to EWR models where required.

2. METHODS

2.1. Study site

The Middle River catchment is on the North Coast of Kangaroo Island (Figure 1) and is one of the largest on the Island with an area of ~14,500 Ha. The Middle River reservoir holds approximately 470ML and is the only large water storage on the Island. A large waterfall (Strepera falls is present downstream of the reservoir. Land use is dominated by native tree forestry and sheep grazing. The Middle River catchment has been divided into sub-sections for the purpose of the EWR study. Data will be summarized to identify EWRs specific to upper catchment swamps, intact valley fill zones, pool riffle sections, the reservoir, a reservoir-falls reach, gorge, lowland Channel and Estuarine reaches. A detailed description of habitat characteristics and measured variables from these zones are presented in detail in van der Wielen *et al*. (2010).

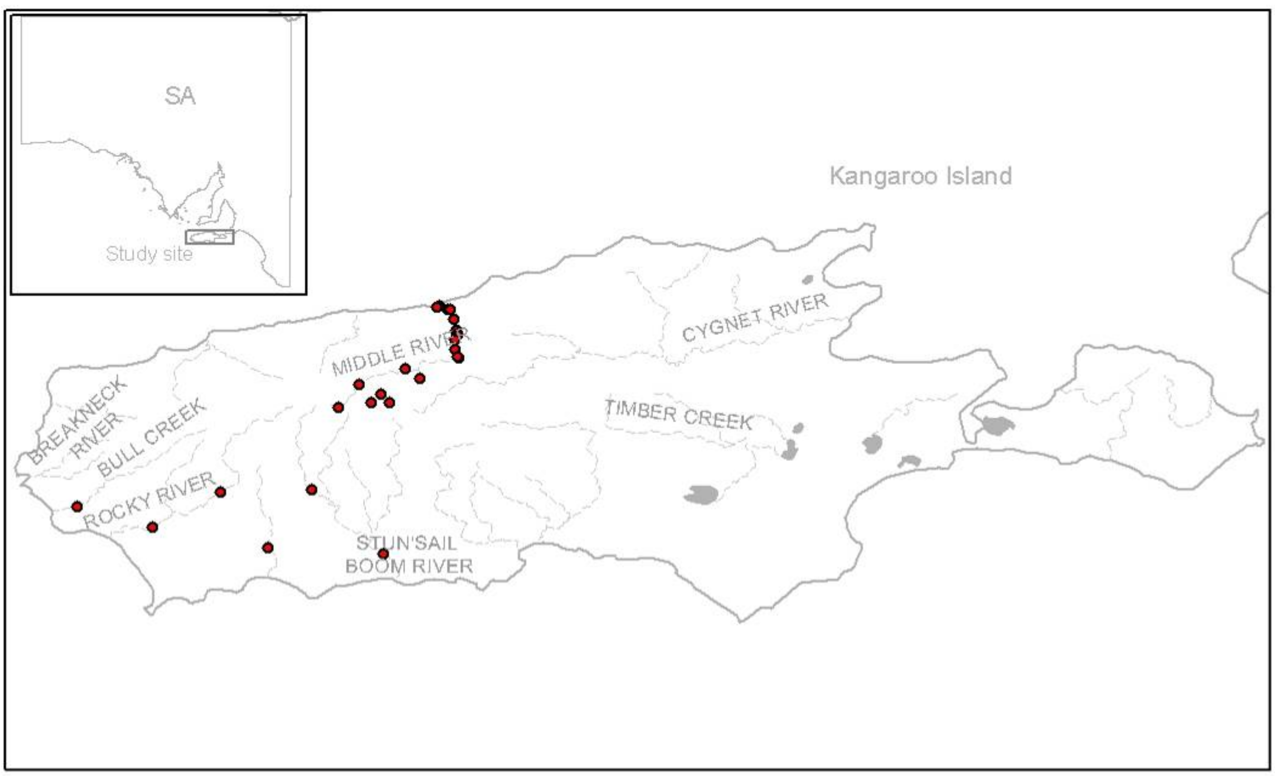

Figure 1. Map of Kangaroo Island showing fish sampling locations (red dots) in the Middle River and other reference catchments

2.2. Data Collection

In December 2009, two field visits were conducted, the first collected observational data from Lower Gorge and Upper Middle River as well as fyke net surveys at Snelling's estuary and ETSA track. A second December survey collected fyke netting data from the Snelling's Beach estuary, Upper Estuary, Iverson's, Strepera Falls, EPA, Upper Middle River (upper), Great Southern and Squashy Creek swamp. A short visit in March provided little opportunity to collect fish but a survey of the predominantly dry Christmas Creek and observational data was collected from the HECRAS modeling sites upstream of the Reservoir and at Iverson's. A final survey in May/June 2010 collected fyke netting data from above Strepera Falls (D/S of reservoir), Middle River reservoir wall, upstream of the Middle River Reservoir, Coopers Road, Christmas Creek, Binnowie and EPA as well as surveying and collecting fish from neighboring catchments in South-west River, Rocky River and North West River as comparison and control sites.

Data was collected somewhat opportunistically during a number of field visits to the Middle River and surrounding catchments between December 2009 and June 2010. Timing constraints required that a variety of survey techniques were utilized for different field visits and therefore highly quantifiable and comparative data was not collected across all sites. The intent of the survey design was therefore to provide maximal information about the distribution of species and assemblages across the catchment and to address specific questions raised in the conceptual models for flow dependency of native fishes. Species were identified using Allen *et al.* (2002) and McDowall (1996).

2.3. Equipment

Fyke netting surveys utilized various numbers of nets and netting durations based on time constraints and habitat size. Where possible fyke nets were set for a 24 hour period and a maximum number of nets were set at each site to adequately sample all available microhabitat types within a reach or site. Small fykes consisted of a 3 m leader and 3 m cod-end with two valves and 3 mm stretch mesh, whilst large fykes consisted of a 5 m leader, 4 m cod end with three valves with 6 mm mesh. Double winged fykes had two 5 m wings, a 3 m cod end with three valves and 3 mm mesh. All fykes were set with a buoyed cod end to enable surface access for air-breathing by-catch and weighted at each end point with chain or attached to stakes (Figure 2 a & b). Multi panel gill nets were used in the Middle River reservoir to sample larger fish that may have been present in the deeper habitats to compliment fyke netting data. Electrofishing surveys were also carried out upstream of the EPA site on the upper middle river using a Smith Root LR24 backpack electrofisher setting ranged between 200-240V, 60-120Hz with a 10% duty cycle using pulsed direct current. All habitat was fished for approximately 50 metres however, difficult terrain and complex habitat structure resulted in only a single observation from electrofishing effort, netting was therefore used preferentially for other sites. Observation data was entirely opportunistic and is presented separately from actual catch data. For effort summaries sampling types will be summarized as follows: SF = small fyke, 2wF = Double winged Fyke, obs. = observational data, EF = electrofishing.

Figure 2. Fyke nets used for field sampling; a) small single winged fyke and b) double winged fyke.

2.4. Reproductive Analysis

All captured fish were stripped to test for reproductive 'ripeness' by squeezing the sides and abdomen of captured fish with sufficient pressure to force sperm or ripe eggs through the anal vent. A sub-sample of fish from 3 sampling sites within the Middle River Catchment was dissected for more detailed assessment of gonad development status.

Macroscopic analysis of gonads was carried out on a number of adult *G. brevipinnis* sub-sampled from the Middle River sites at the ETSA Track, D/S of Reservoir and U/S of Reservoir. Each fish was dissected longitudinally along the ventral axis and the characteristics of colour, size and texture recorded (Table 1). The developmental stage was determined using a staging table devised by SARDI researchers, based on those used for other species of freshwater fish.

Gonado-somatic indices (GSI) were determined for the same fish using the formula: *GSI = 100 * (gonadal weight/ gonad free weight)*. This was performed after gonad staging was completed, whereby the average GSI was determined for both male and females for each of the sites respectively.

Table 1. Macroscopic gonad stages used to classify Climbing galaxias (*Galaxias brevipinnis*).

Stage	Females	Males
1: Juvenile	Small undeveloped ovaries	Undeveloped testes usually dark in colour
2: Immature	Developing ovaries whereby they are larger and become more orange/yellow/white (varies between species), however eggs cannot be seen with naked eye	Developing testes whereby they are larger and become grey - white in colour but no milt present
3: Maturing	Further developed ovaries that are relatively large and turgid, yellow/orange and eggs can be seen	Developed testes that are large and white in colour and milt is present
4: Ripe	large ovaries with hydrated eggs that can be seen with the naked eye	
5: Spent	Spent ovaries that are similar in size and colour to F2 stage, however they are more flaccid with a granular appearance	Testes flaccid, thin mottled grey in appearance, areas of residual milt, many small blood vessels visible

3. RESULTS

Nine species of fish were caught from the Middle River catchment between November 2009 and June 2010 (Figure 3). Of these, only a single introduced species was captured, rainbow trout, *Oncorhynchus mykiss*, which was introduced to the region for recreational angling purposes. However, this species was contained to the area around the Middle River reservoir only (Figure 4). The other eight species were native, however only two of these were widely distributed within freshwater reaches of the catchment. Climbing galaxias (*Galaxias brevipinnis)* was the most widely distributed species, absent only from the estuary, lowland channel and reservoir sites (Figure 4). Common galaxias (*Galaxias maculatus)* was caught in the highest abundance of all species; however, their distribution was restricted to sites downstream of Strepera falls, which must present a significant natural barrier to the movement of this species.

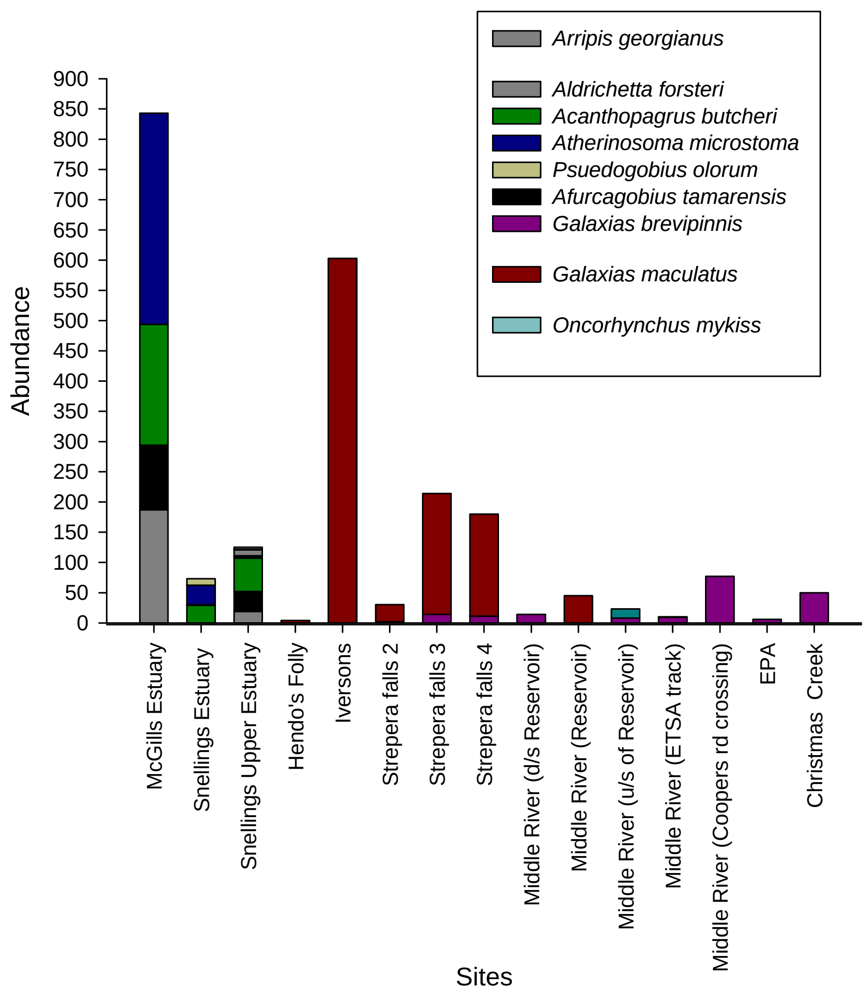

Figure 3. Overall Total Abundance of fish species caught in the Middle River catchment between November 2009 and June 2010.

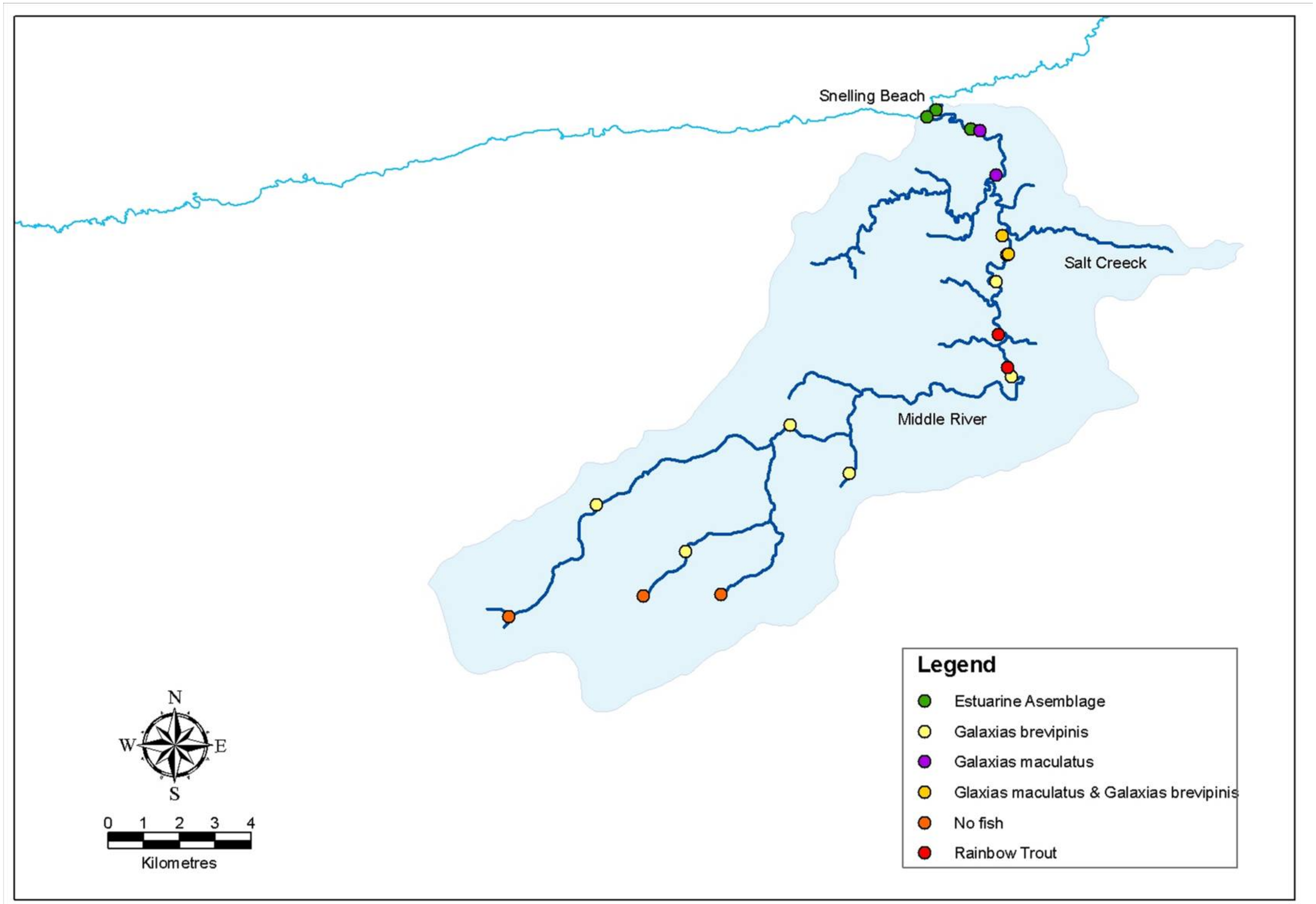

Figure 4. Fish sampling sites in the Middle River indicating the fish community sampled from each site.

All other species were restricted to the estuarine section of the catchment (Figure 5), representing a quite distinct estuarine species cohort, mutually exclusive to freshwater habitats in terms of species composition at the time of sampling. The presence of the two diadromous galaxiids requires that particular life-stages of these species will temporarily utilize the estuary and marine environments for spawning, larval development and growth and as a pathway between freshwater and marine habitats. For all abundance results it must be remembered that variable sampling efforts render comparative abundance data of limited value and should be used as a rough estimate of abundance only. For this reason, observational data will also be included in the site by site analysis to indicate sites where fish catches may be low even though they were observed in abundance. Clear water conditions across freshwater habitats made observational data quite reliable and in some circumstances provided a more accurate estimation of abundance than catch data.

As the collection of data was conducted in such a way as to answer key ecological questions and hypotheses relating to environmental water requirements and conceptual models for water requirements, survey data will be presented separately for each of the reach types used in the EWP process.

3.1. Estuary

Figure 5. The lower Middle River Estuary, and Snelling's Beach, Kangaroo Island.

Figure 6. Lower A) and upper (B) estuary habitats in the Middle River.

3.1.1. Species Abundances

The estuarine sites included three separate sites with the estuary itself closed throughout the survey period (see Figure 5). Estuarine sites were located at the estuary mouth (McGill's Estuary Mouth), in the backwater/lagoon behind the coastal dune system (Snelling's Estuary – Figure 6A, and the upper estuary (Snelling's Upper Estuary - image 6B) which was located at the upstream extent of the estuary. At the time of sampling, no freshwater flows were entering the estuary and therefore the entire system was closed, isolated from both the marine environment and the freshwater habitats upstream. Saline conditions were recorded from all three sites (see Appendix 1) and therefore marine or estuarine species could be expected at all sites, with conditions not favorable for most freshwater fishes at the time of sampling.

All estuarine sites contained common estuarine species in reasonable abundance and were devoid of any freshwater fish populations (Table 2). Small mouth hardyhead (*Atherinosoma microstoma*), Black bream (*Acanthopagrus butcheri*), Tommy rough (*Arripis georgianus*), yelloweye mullet (*Aldrichetta forsteri*) and gobies (*Psuedogobius olorum*, *Afurcagobius tamarensis, Arenigobius bifrenatus*) were the predominant estuarine species caught. Marron were, however present at the upper estuary suggesting that this species has significant salinity tolerance. Blue ringed octopus (*Hapalochlaena maculosa*) was present at the estuary mouth. Of these species, *P. olorum* and *A. butcheri* were observed to utilize samphire wetlands that were inundated at the time of sampling, with small snails (*Nassarius* spp.) also being found in high abundance. Other large fish (<600mm) were observed in the estuary but not captured or successfully identified.

Table 2. Species abundance and composition found at each of the 3 sampling sites, within the estuary reach of the Middle River catchment.

Site ID	Sampling effort	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
McGill's Estuary Mouth	*6 2wF 8 SF*	*Arripis georgianus*		*187*	0
		Aldrichetta forsteri		*107*	0
		Acanthopagrus butcheri		*200*	0
		Atherinosoma microstoma		*349*	0
			*Hapalochlaena maculosa**	*3*	0
		Unidentified post larvae		*0*	300+
Snelling's Upper Estuary	*62wF 8 SF*	*Arripis georgianus*		*19*	0
		Aldrichetta forsteri		*33*	0
		Acanthopagrus butcheri		*55*	0
		Atherinosoma microstoma		*2*	0
		Psuedogobius olorum		*2*	0
		Afurcagobius tamarensis		10	0
		Arenigobius bifrenatus		*1*	0
Snelling's Estuary	*42wF 4SF*	*Acanthopagrus butcheri*		*29*	0
		Atherinosoma microstoma		*32*	0
		Psuedogobius olorum		*11*	0
		Arripis trutta		*1*	0

3.1.2. Length Frequency Distribution

Size distributions were plotted for the three most abundant estuarine species, *A. forsteri, A. butcheri, and A. microstoma*, compiled from the three estuarine sites. Evidence of recent recruitment (<4-6months) was found for all three species, with *A. forsteri* showing the largest proportion of new recruits below ~100mm (Figure 7). *A. butcheri* (Figure 8) had fewer new recruits (<~100mm; Figure 9) and as did *A. microstoma* (<~50mm - Figure 10). In general it appears that recent conditions in the estuary prior to sampling were suitable for both the survival of a range of adult size classes as well as the spawning and recruitment of juveniles in to the estuary population.

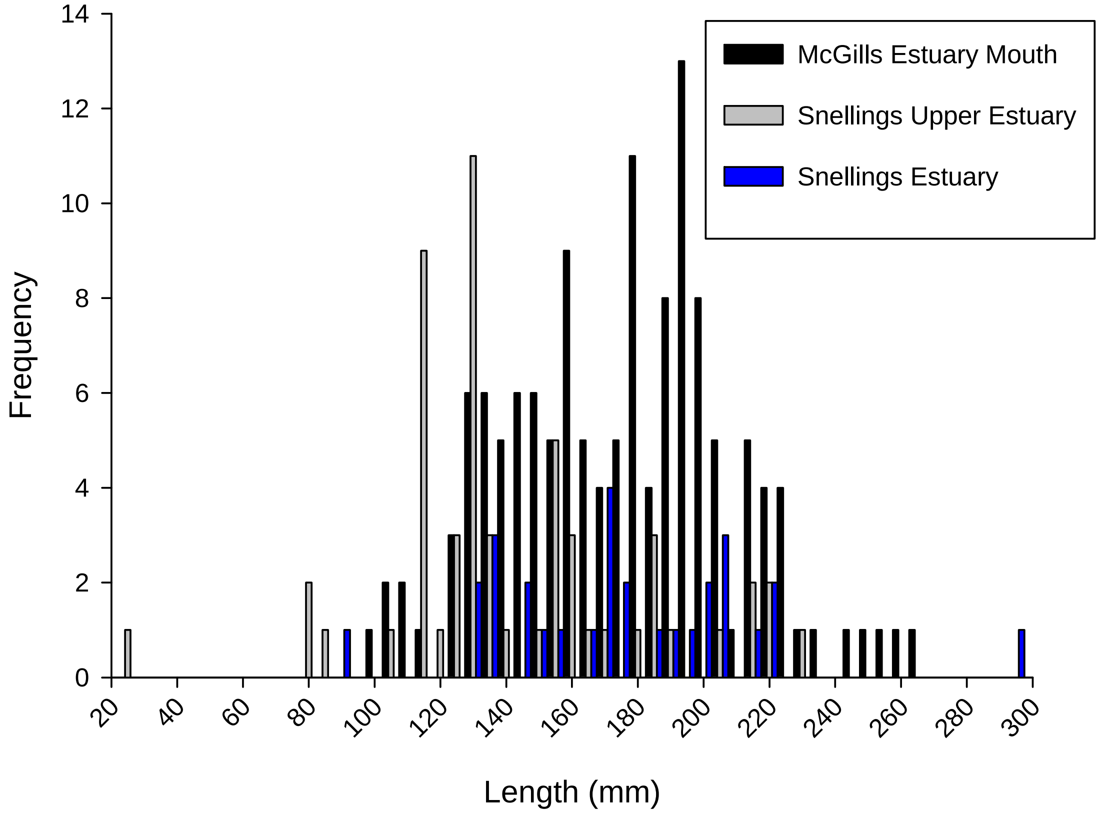

Figure 7. Length frequency of *A. butcheri* for all sites found within the estuary reach of the Middle River catchment area.

Figure 8. Black Bream *A. butcheri* schooling in the Middle River Estuary at Snelling's Beach.

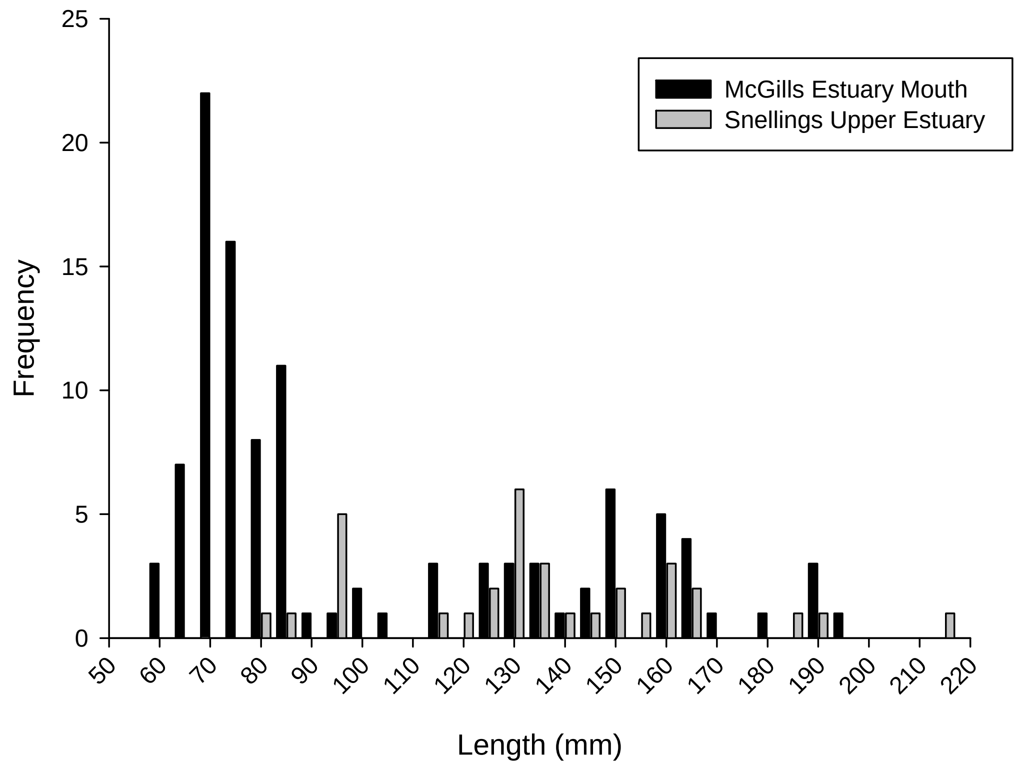

Figure 9. Length frequency of *A. forsteri* for all sites found within the estuary reach of the Middle River catchment area.

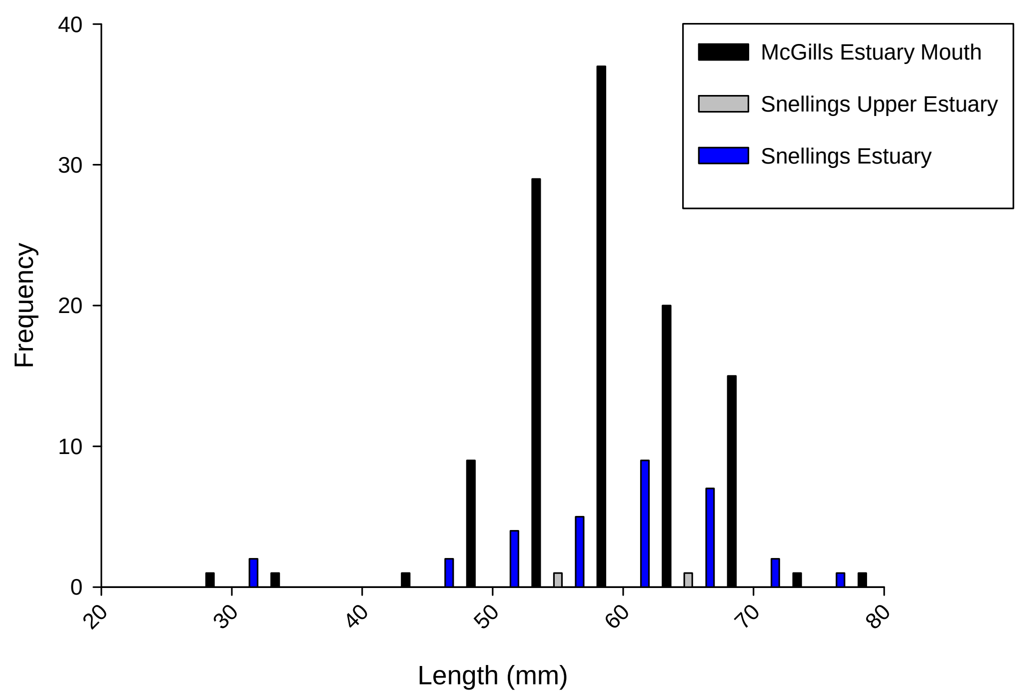

Figure 10. Length frequency of *A. microstoma* for all sites found within the estuary reach of the Middle River catchment area

3.2. Lowland Channel

3.2.1. Species Abundances

Observational and catch data found high numbers of *Galaxias maculatus* throughout the lowland channel reach at both Iverson's and Lower Gorge sites (Table 3). No other fish species were present, although decapod crustaceans (Yabbies and Marron) were caught in the reach. These were predominantly juveniles, which suggest very recent spawning of crustaceans in late spring/early summer.

Table 3. Species abundance and composition found at each of the 2 sampling sites, within the lowland reach of the Middle River catchment. The presence of juvenile life stages is indicated by (Juv) for crustaceans.

Site ID	Sampling Effort	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Iverson's	*4x2wF 4xSF*	*Galaxias maculatus*		603	
			Cherax tenuimanus	50	0
			Cherax destructor	15	0
Lower Gorge	*5x siene*	*Galaxias maculatus*		4	3000+
			Cherax tenuimanus	0	100+ (Juv)
			Cherax destructor	0	100+ (Juv)

3.2.2. Length Frequency Distribution

Length frequency analysis was performed on *G. maculatus* captured from Iverson's in December 2009 (Figure 11). The data shows a very large peak in juvenile abundances (40-70mm) as well as the persistence of good numbers of larger adult fish. This is evidence that recent conditions were amenable to spawning and recruitment and freshwater refugia have been maintained in reasonable condition for the survival of adult life stages during summer.

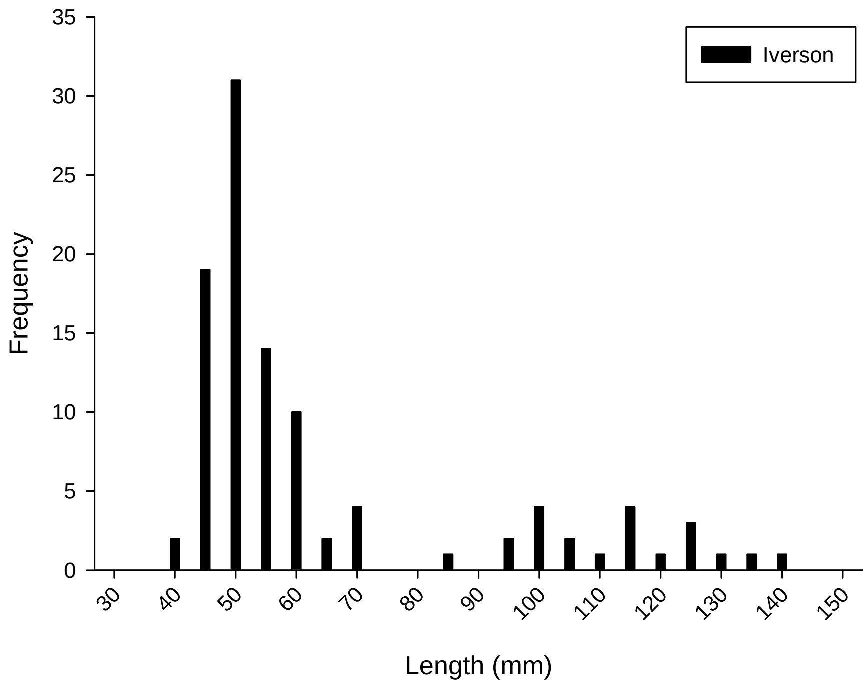

Figure 11. Length frequency of *G. maculatus* for all sites found within the lowland channel reach of the Middle River catchment area

3.3. Middle River Gorge

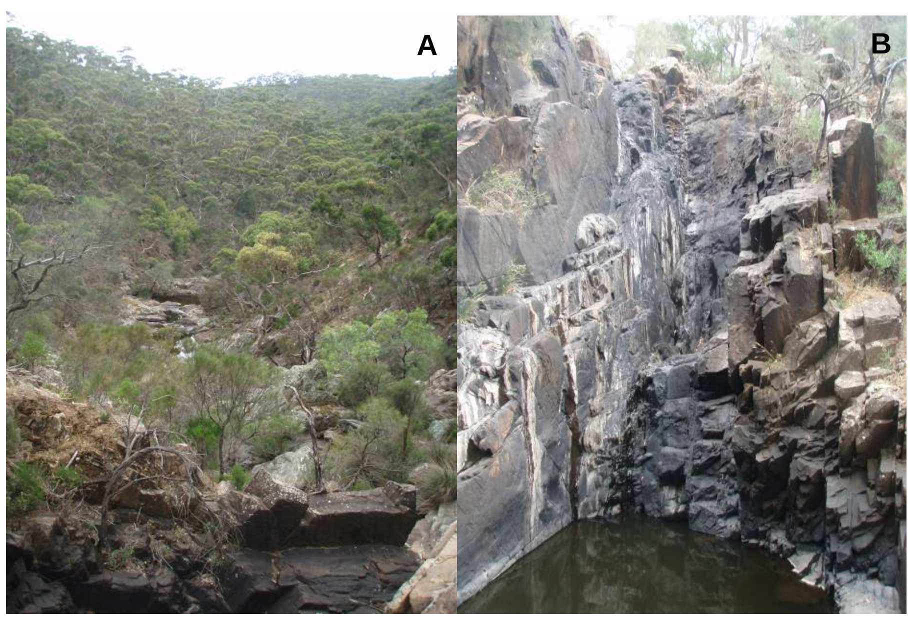

Figure 12. Pools in the Middle River Gorge (A) and a section of Strepera Falls (B) that must be successfully navigated by diadromous fish to access upper catchment habitats.

3.3.1. Species Abundances

The Gorge section (Figure 12 A&B) was dominated by *G. maculatus* with smaller numbers of *G. brevipinnis* also captured (Table 4). These sites also had high abundances of marron and Yabbies and a single large fish was observed at Strepera site 1 which was half way up the falls. No identification was possible but it was probable that this was an adult rainbow trout that may have washed down from the reservoir during high flows. A single specimen of Rosenberg's goanna (*Varanus rosenbergi*) was also caught in fyke nets at Strepera 4. This is not a fish.

Table 4. Species abundance and composition found at each of the 5 sampling sites, within the gorge reach of the Middle River catchment.

Site ID	Sampling Effort	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Strepera falls 1 (DEEP)	*1xSF*	*Large fish unidentified*		0	1
			Cherax tenuimanus	15	20
Strepera falls 1 (SHALLOW)	*1xSF*	*NO FISH*		0	0
Strepera falls 2	*1xSF*	*Galaxias brevipinnis*		*2*	0
		Galaxias maculatus		*28*	0
Strepera falls 3	*2xSF*	*Galaxias brevipinnis*		14	0
		Galaxias maculatus		200	0
Strepera falls 4	*2xSF*	*Galaxias brevipinnis*		11	0
		Galaxias maculatus		169	0
			Cherax tenuimanus	20	20
			Varanus rosenbergi	1	
			Cherax destructor	20	0

3.3.2. Length Frequency Distribution

Length frequency data for both *G. maculatus* (Figure 13) and *G. brevipinnis* (Figure 14) show the presence of recent recruits (<70mm) as well as larger adult size classes. The survival of a large range of adult size classes suggest that resent conditions have been adequate for adult survival and smaller size classes reflect that recent conditions have supported spawning and recruitment to the Gorge reach for both species.

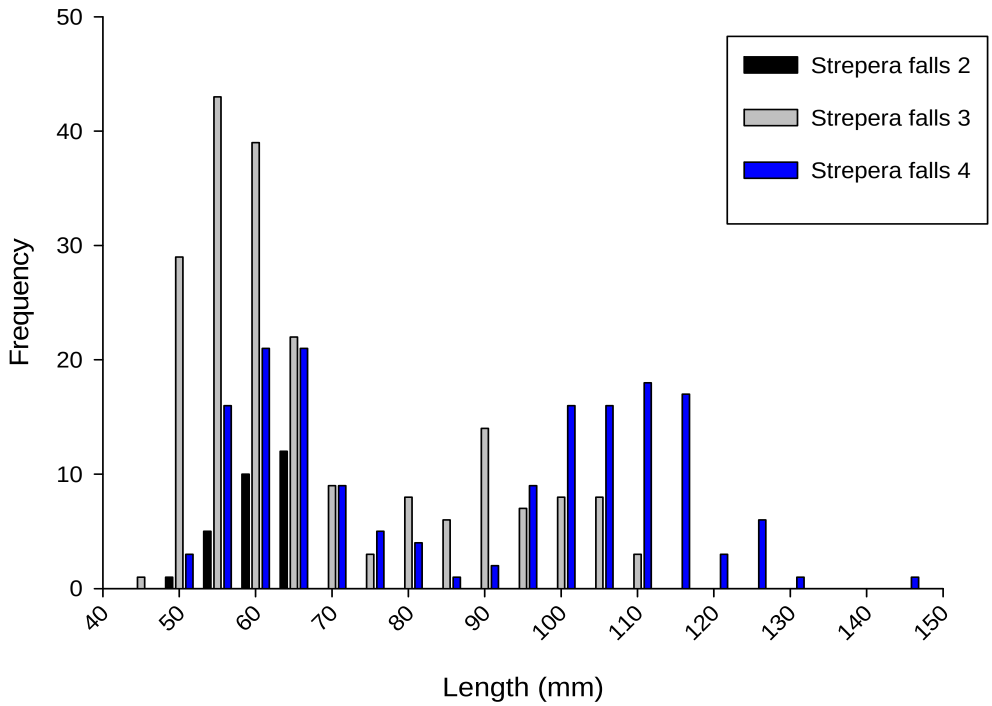

Figure 13. Length frequency of *G. maculatus* for all sites found within the Gorge reach of the Middle River catchment area

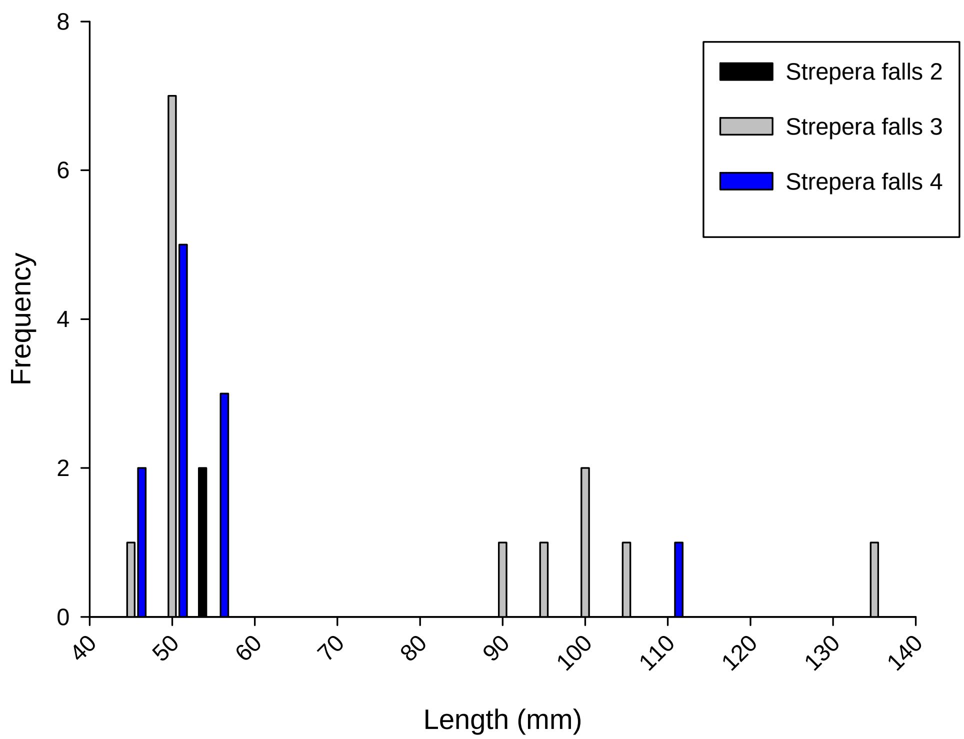

Figure 14. Length frequency of *G. brevipinnis* for all sites found within the Gorge reach of the Middle River catchment area

3.4. Above Strepera falls

Figure 15. Pools above Strepera Falls (A) that contain *G. brevipinnis* and wetted algal pathways on the Falls surface (B) that provide the surface tension required for climbing juveniles to ascend on return from the sea. Drying of these pathways in spring will prevent passage and create a barrier at the falls.

3.4.1. Species Abundances

The site is best classified as a Gorge habitat but is treated separately because of its extreme importance to informing on the nature of diadromy in the catchment and the importance and impact of barriers to fish migration being above the natural barrier of Strepera falls (Figure 15 A) but below the man-made barrier of the Reservoir wall. The only fish species present in this reach was *G. brevipinnis* (Table 5), which were observed in pools at the top of the falls (Figure 15B) and caught using the backpack electrofisher closer to the reservoir.

Table 5. Species abundance and composition found between the reservoir wall and Strepera Falls.

Site ID	Sampling Effort	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Middle River (d/s Reservoir)	*2xSF*	*Galaxias brevipinnis*		*14*	3

3.4.2. Length Frequency Distribution

The vast majority of *G. brevipinnis* caught between the falls and reservoir in June 2010 were juvenile recruits approaching adult size and therefore are likely to have been spawned the previous year and recruited as small juveniles in spring 2009 (Figure 16). Only a single large adult was caught in the reach, however, observations from above the falls in December 2009 were of large adults (100mm+)

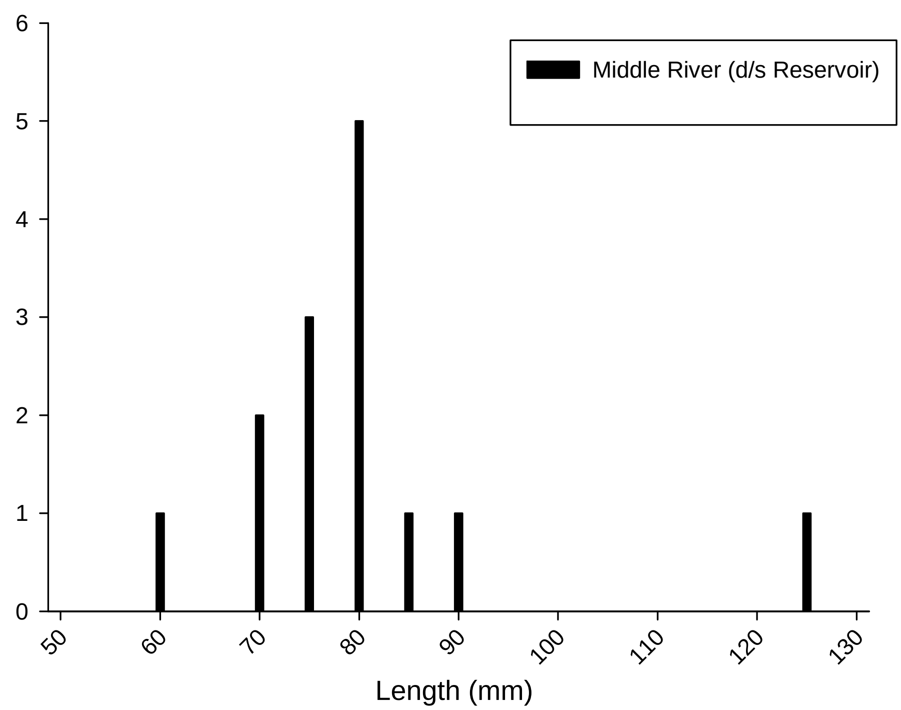

Figure 16. Length frequency of *G. brevipinnis* for the above Strepera Falls reach of the Middle River catchment area.

3.5. Middle River Reservoir

Figure 17. Middle River Reservoir Looking Upstream: Note fyke nets set on bank (left) and setting gill nets from the dingy (right).

3.5.1. Species Abundances

The reservoir site (Figure 17.) contained only introduced rainbow trout (*O. mykiss*) (Table 6). All fish were captured using multi-panel gill nets near the reservoir wall.

Table 6. Species abundance and composition found at the reservoir sampling site, within the Middle River catchment.

Site ID	Sampling Effort	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Middle River (Reservoir)	*1x Gill net*	*Oncorhynchus mykiss*		*45*	0

3.5.2. Length Frequency Distribution

The size range of trout captured within the Middle river reservoir encompassed a broad range of adult and juvenile classes (Figure 18). Two general size ranges were caught with smaller bodied trout 140mm-250mm and very large older size classes 300-400mm suggesting that recruitment to this population is continuous and successful over the past several years.

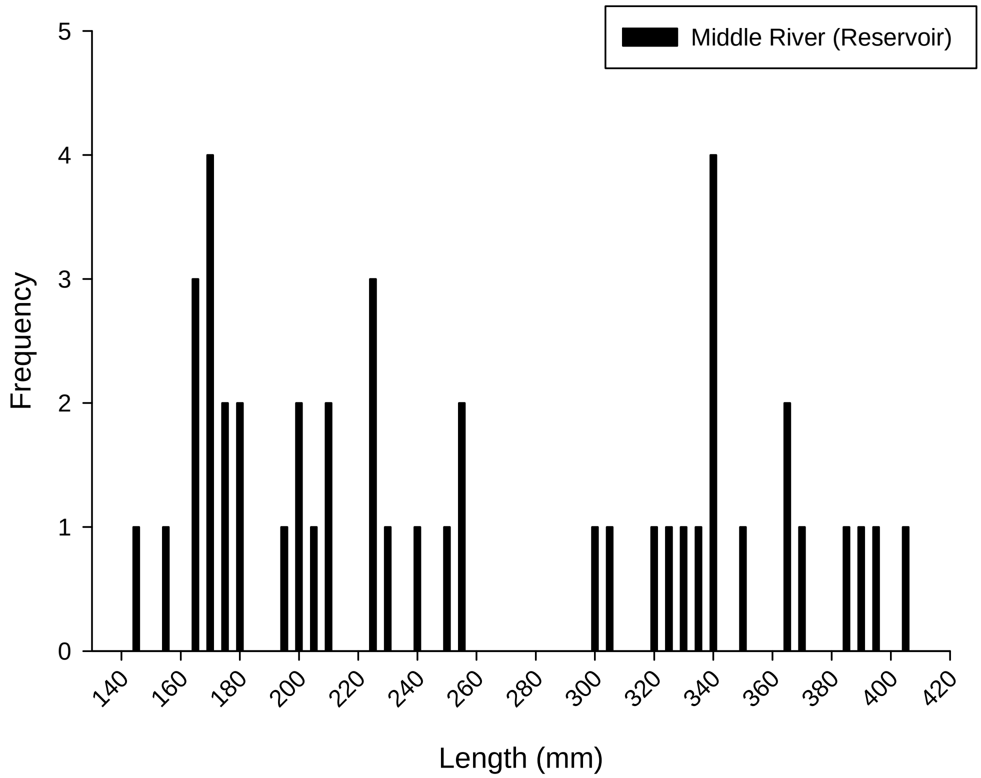

Figure 18. Length frequency of *O. mykiss* found within the Reservoir reach of the Middle River catchment area.

3.6. Mid Pool-Riffle

Figure19. Fyke nets set in Mid Pool-Riffle reach upstream of the ETSA Track (above reservoir).

3.6.1. Species Abundances

Mid Pool-riffle type habitats (Figure 19) cover a large area of the Middle river catchment and a number of sites sampled reflect this reach category. This reach type was dominated by two species of fish *G. brevipinnis* and the introduced predator, rainbow trout (*Oncorhynchus mykiss*). *O. mykiss* were predominantly caught near the reservoir where low numbers of G. brevipinnis were also caught in relatively consistent numbers (n=6-9 per site) (Table 7). *G. brevipinnis,* however, were widely distributed across the catchment and were caught from all Pool-riffle sites. The Coopers road site however contained very large numbers (n=77) of *G. brevipinnis* when sampled in June 2010.

Table 7. Species abundance and composition found at each of the 4 sampling sites, within the mid-pool riffle reach of the Middle River catchment.

Site ID	Sampling effort	Fish Species Composition	Total abundance (capture)	Total abundance (observed)
EPA	*2xSF (4 nets stolen)*	*Galaxias brevipinnis*	6	1
Middle River (Coopers rd crossing)	*4x2wF* *4x SF*	*Galaxias brevipinnis*	*77*	0
Middle River (ETSA track)	*1xSF (2 hour set)*	*Galaxias brevipinnis*	*9*	0
		Oncorhynchus mykiss	1	0
Middle River (u/s of Reservoir)	*4x SF*	*Galaxias brevipinnis*	*8*	0
		Oncorhynchus mykiss	*15*	0

3.6.2. Length Frequency Distribution

The length frequency data for *G. brevipinnis* is somewhat different than other reach types in that a single site, Coopers Road had a very high proportion of small size classes, with peaks at 70mm and 90mm suggesting there were possibly two waves of spawning and recruitment to this population over the preceding winter and spring (Figure 20). All sites however, had reasonable populations of adult *G. brevipinnis* 100mm+. The size distribution of *O. mykiss* also revealed reasonable numbers of juvenile size classes (~140-220mm) which are likely to represent fish 1+ and 2+ years old (Figure 21). In addition, some very large trout 340-400mm were caught from the pool-riffle site upstream of the reservoir.

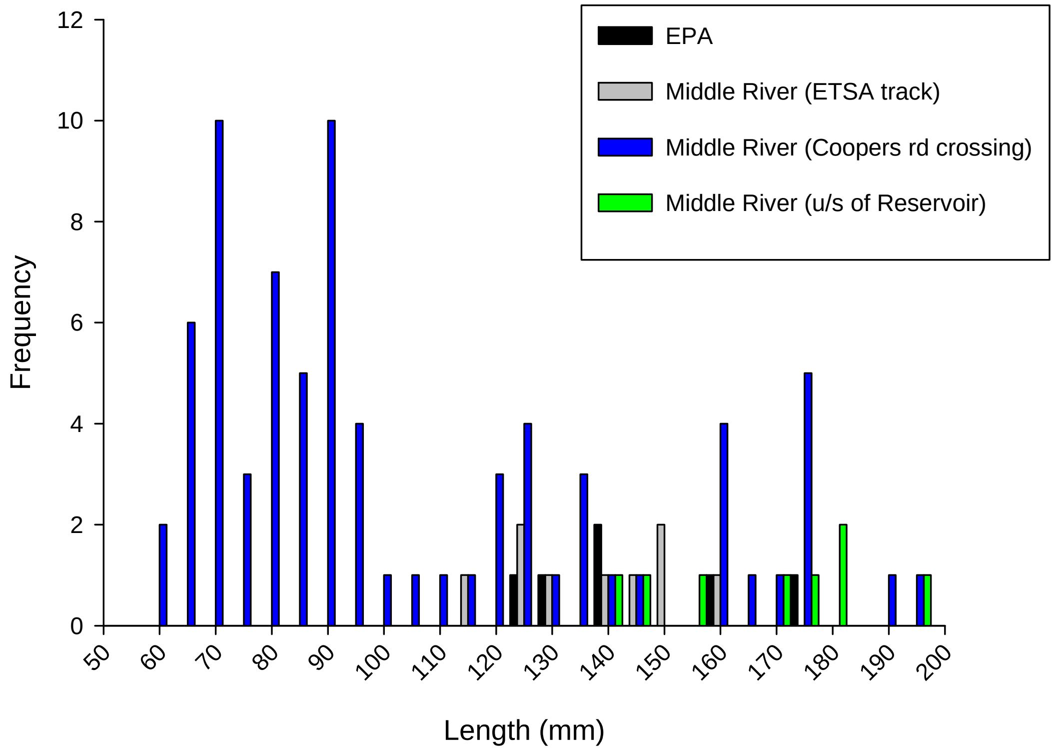

Figure 20. Length frequency of *G. brevipinnis* for all sites found within the Pools & Riffles reach of the Middle River catchment area.

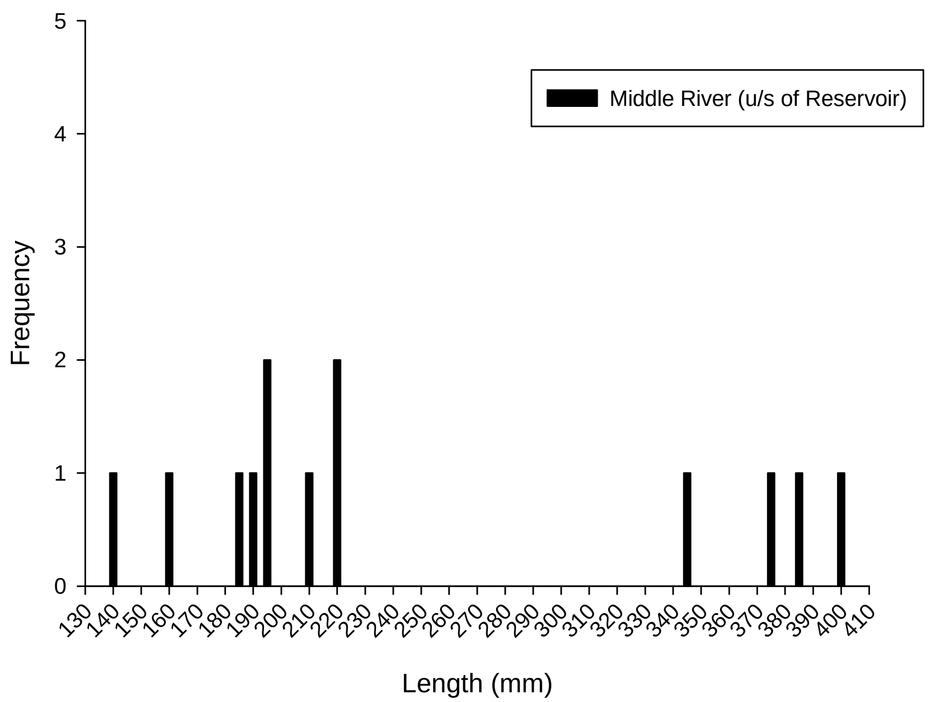

Figure 21. Length frequency of *O. mykiss* for all sites found within the Pools & Riffles reach of the Middle River catchment area.

3.7. Upper Pool-Riffle

3.7.1. Species Abundances

Christmas creek is an ephemeral tributary of the Middle river. It was almost totally dry in November and December 2009, with no fish present, but had recently filled (~3days) prior to sampling in June 2010. At this time large numbers of *G. brevipinnis* (n=50) were caught at the site (Table 8). Upper Middle River possesses permanent waterholes and very low flows throughout some sections in summer, with two *G. brevipinnis* being observed in a small pool predominantly filled with a bacterial iron floc which were believed to be a risk to oxygen levels in the waterbody. These fish were observed to perform aquatic surface respiration, maintaining a position at the water surface and breathing the well oxygenated water surface layer (McNeil and Closs 2007). The level of dissolved oxygen in the pool was measured at below 1mg/l, which is considered hypoxic and insufficient to support long term fish respiration.

Table 8. Species abundance and composition found at Christmas and Upper Middle River

Site ID	Sampling Effort	Fish Species Composition	Total abundance (capture)	Total abundance (observed)
Christmas Creek	*4xSF*	*Galaxias brevipinnis*	*50*	0
Upper Middle River	*Obs. only*	*Galaxias brevipinnis*	*0*	2

3.7.2. Length Frequency Distribution

The *G. brevipinnis* population at Christmas creek was dominated by larger adult size classes between 100mm and 170mm (Figure 22). A smaller number of recent recruits 60-80mm in length were also caught from the site. Both *G. brevipinnis* observed in November swimming at the surface in Upper Middle River were approximately 80-90mm in length and under assumed sub-optimal conditions were assessed as being small adults of at least 1year +.

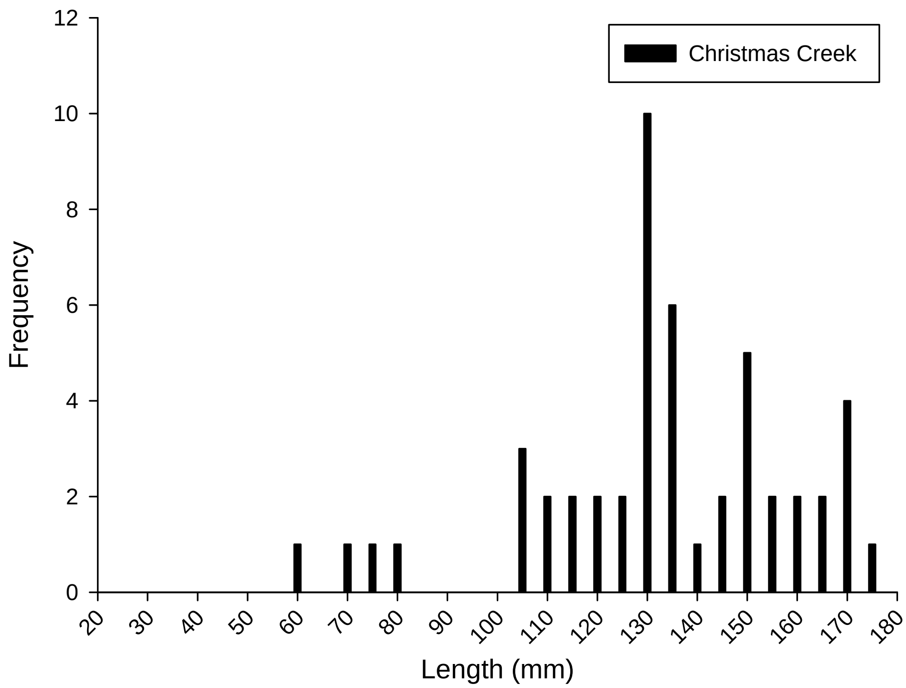

Figure 22. Length frequency of *G. brevipinnis* for the Christmas Creek sampling site, within the Pool-Riffle reaches of the Middle River catchment area.

3.8. Valley Fill Intact

3.8.1. Species Abundances

No fish were observed in Valley fill sections of the catchment where very little surface water was encountered, although *G. brevipinnis* may exist where permanent water of appropriate environmental quality is maintained.

3.9. Swamps/Wetlands

3.9.1. Species Abundances

No fish were observed in upper catchment swamps and wetlands (Table 9) although *G. brevipinnis* may exist where permanent water of appropriate environmental quality is maintained or during surface flows in ephemeral reaches. Other aquatic fauna were present in very high abundance in Squashy Swamp in November and December, including a variety of tadpoles and frogs as well as abundant invertebrate fauna including yabbies and marron. By March 2010, however, Squashy swamp had dried completely and no fauna was observed at the site at all. Starvation Creek dam had abundant decapod crustacean fauna but no tadpoles or frogs whilst the small wetland at Great Southern Swamp had abundant tadpoles as well as crustaceans.

Table 9. Species abundance and composition found at each of the wetland/swamp sampling sites, within the Middle River catchment.

Site ID	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Great Southern Swamp	*NO FISH*	*Cherax tenuimanus*	6	0
		Cherax destructor	6	0
		Tadpoles	25	0
Squashy Swamp	*NO FISH*	*Cherax destructor*	3	0
		Tadpoles	325	0
		Limnodynastes dumerili	2	0
Starvation Creek dam (Binnowie)	*NO FISH*	*Cherax tenuimanus*	23	0
		Cherax destructor	15	0

3.10. Neighboring Catchment Data

3.10.1. Species Abundances

Neighboring catchments possessed similar hydrological and physical characteristics to many of the sites in the Middle River (Figure 23). The fish fauna was also similar to the Middle River, with *G. brevipinnis* dominating upper catchment areas (Rocky River, North West River) and *G. maculatus* also present in the mid and lower reaches (Table 10). Blue spot goby, (*P. olorum*) was also present in low numbers in downstream reaches at Stun'sail boom and South West Rivers. A single platypus (*Ornithorhynchus anatinus)* was also captured at Rocky River.

Figure 23. Sampling sites in neighboring catchments Stun'sail Boom (left) and Rocky River (right).

Table 10. Species abundance and composition found at each of the 6 sampling sites, within the surrounding catchments of Middle River.

Site ID	Reach Type	Fish Species Composition	Other Species Composition	Total abundance (capture)	Total abundance (observed)
Rocky River	*Gorge*	*Galaxias brevipinnis*		*14*	0
			Ornithorhynchus anatinus	*1*	0
North-West River	*Gorge*	*Galaxias brevipinnis*		*99*	0
Lower Rocky River (Flinders chase)	*Mid Pool - Riffle*	*Galaxias brevipinnis*		*37*	0
Breakneck River (Flinders chase)	*Mid Pool - Riffle*	*Galaxias brevipinnis*		*39*	0
		Galaxias maculatus		*74*	0
Stun'sail boom River	*Lower Pool - Riffle*	*Galaxias maculatus*		*100*	0
		Psuedogobius olorum		*1*	0
Southwest River	*Lower Pool - Riffle*	*Galaxias brevipinnis*		*2*	0
		Galaxias maculatus		*248*	0
		Psuedogobius olorum		*7*	0

3.10.2. Length Frequency Distribution

The length frequency data for Gorge (Figure 24) and mid pool-riffle (Figure 25) sections of catchments adjacent to the Middle river did not show the clear peaks in smaller sized juvenile *G. brevipinnis* that were apparent in the Middle River data. Instead, peaks in juvenile size classes are smaller, and occur at around 90-100mm in length, with the exception of North West River where smaller *G. brevipinnis* ~70-90mm were caught (Figure 24). Small individuals (~55mm) were also caught at both Rocky River sites. Catches in the South West River were very small with only a few adult fish captured (Figure 25). Adult size classes were also well represented across sites showing that reasonable adult survival has been maintained over past seasons.

Size frequency data for *G. maculatus* in mid pool riffle reaches displayed a clear peak in juvenile size classes below ~80mm, particularly in the South West River (Figure 26). A wide range of adult size classes were also evident from the *G. maculatus* data, showing that adult survival is strong across all catchments. A very large peak in adult size classes around 110-120mm (1 year+ fish) reveals a very strong recruitment event in the North West River over a year ago.

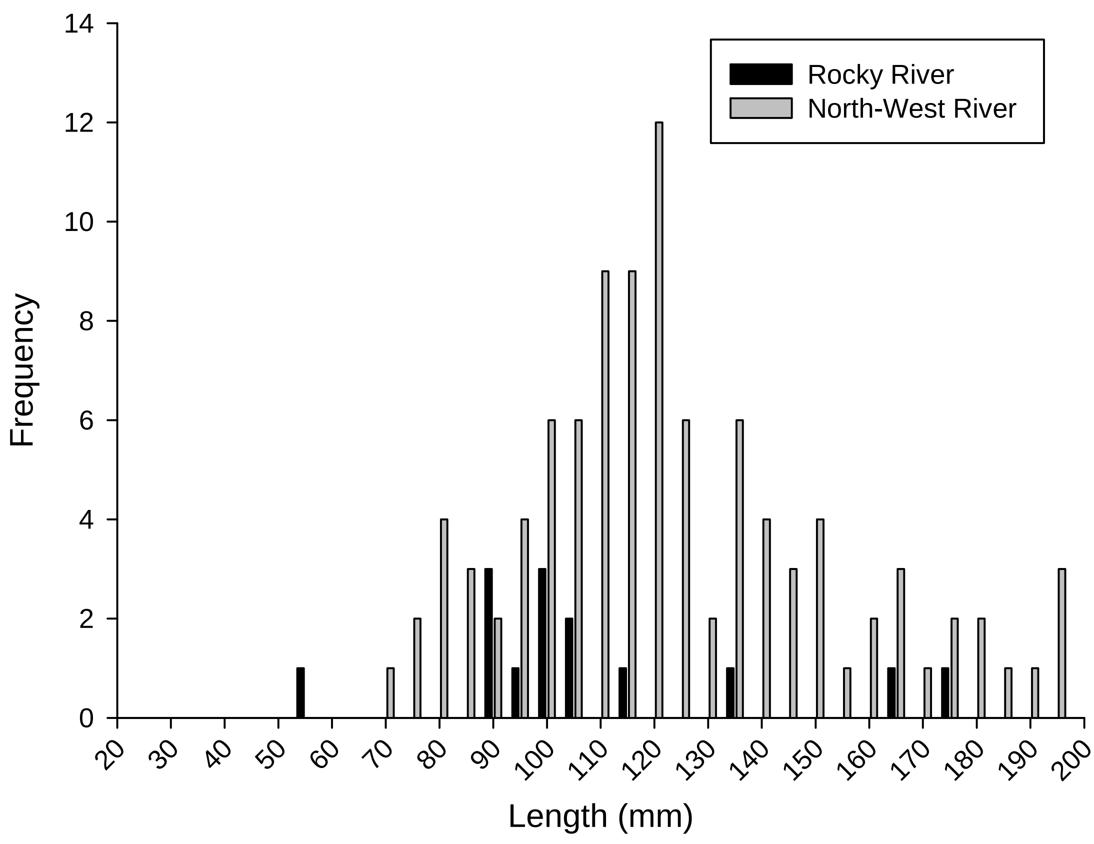

Figure 24. Length frequency of *G. brevipinnis* for all sites found within the *Gorge* reaches of adjacent catchments.

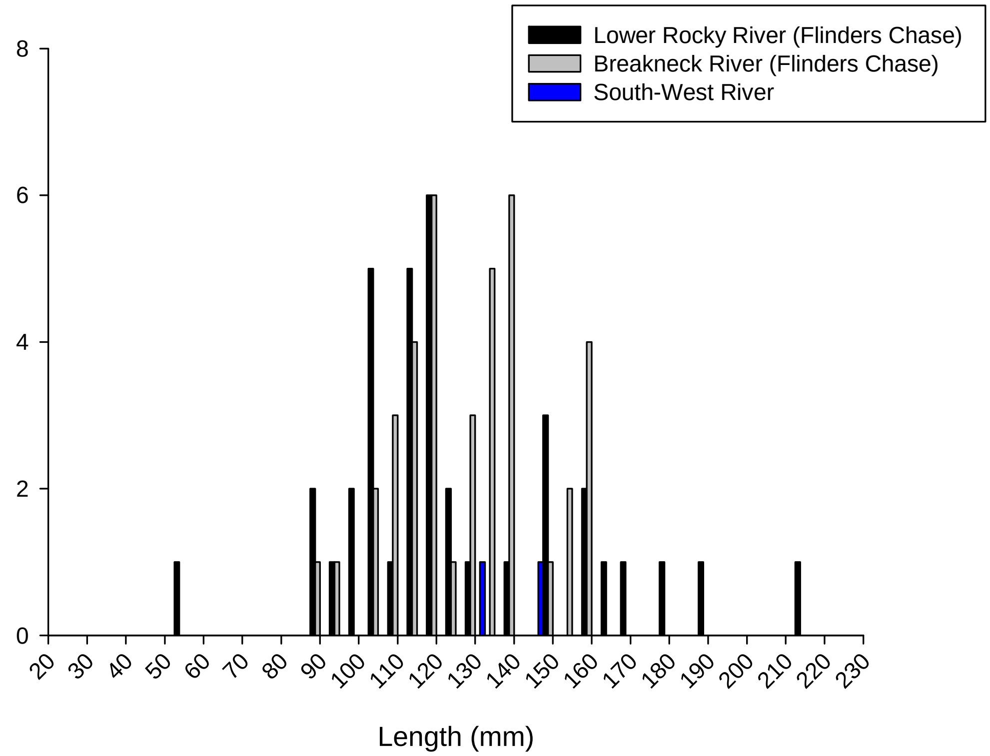

Figure 25. Length frequency of *G. brevipinnis* for all sites found within *Mid Pool-Riffle* reaches of adjacent catchments.

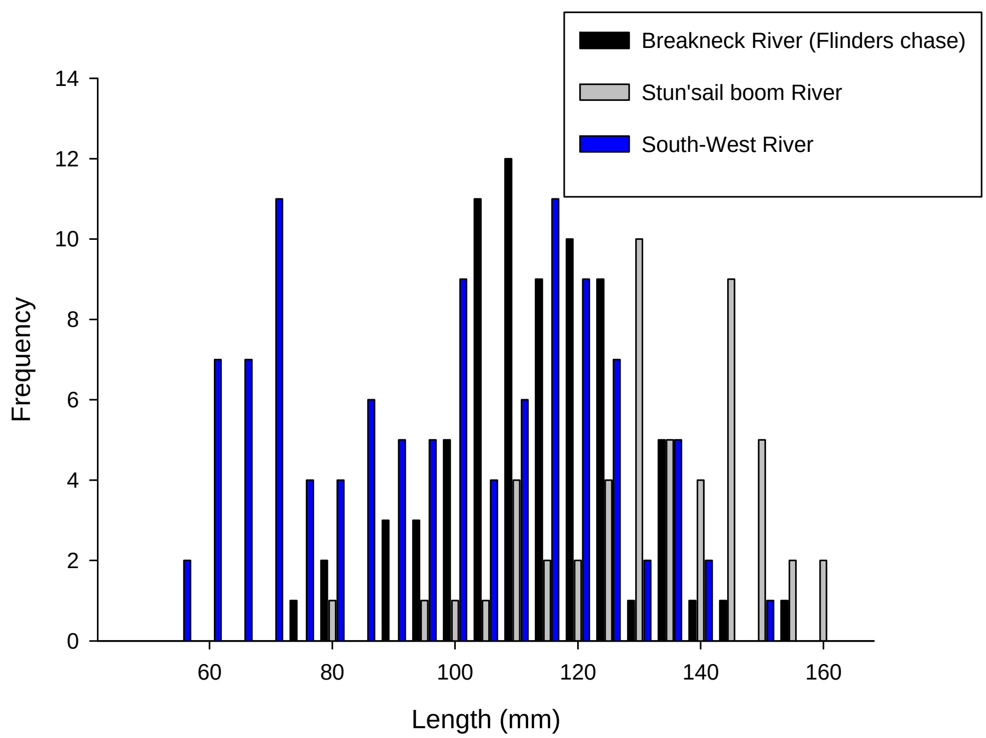

Figure 26. Length frequency of *G. maculatus* for all sites found within *Mid Pools-Riffle* reaches of adjacent catchments.

3.11. Spawning Patterns

Sampling identified ripe male and female fish of both Galaxiid species across a range of sites and catchments in early June 2010 (Table 11). Ripe *G. brevipinnis* were predominantly male with the exception of the Coopers Rd site, which was also the site with the highest overall abundance of this species in the Middle River catchment. Both male and female *G. maculatus* were captured in spawning condition during early June and although no sites were sampled in the lower Middle River at that time, it is likely that this species would also be in spawning condition below Strepera falls. Relatively similar numbers of males and females were found in spawning condition from neighboring catchments, but at Breakneck and South West Rivers, ripe fish were predominantly male as in the Middle River.

Table 11. Presence of ripe male and female *G. maculatus* & *G. brevipinnis* at each survey site showing percent of total catch that was ripe (n=total catch in parentheses).

Site I.D.	Date	Species	Male	Female	% of spawning fish
Iverson's	22/12/2009	*G. maculatus*	N/A	N/A	**0** (n=603)
Strepera falls 2	23/12/2009	*G. brevipinnis*	N/A	N/A	**0** (n=2)
		G. maculatus	N/A	N/A	**0** (n=28)
Strepera falls 3	23/12/2009	*G. brevipinnis*	N/A	N/A	**0** (n=14)
		G. maculatus	N/A	N/A	**0** (n=200)
Strepera falls 4	23/12/2009	*G. brevipinnis*	N/A	N/A	**0** (n=11)
		G. maculatus	N/A	N/A	**0** (n=169)
Middle River (d/s Reservoir)	31/05/2010	*G. brevipinnis*	N/A	N/A	**GSI, Staging** (n=14)
Middle River (u/s of Reservoir)	1/06/2010	*G. brevipinnis*	N/A	N/A	**GSI, Staging** (n=8)
Middle River (ETSA track)	1/06/2010	*G. brevipinnis*	N/A	N/A	**GSI, Staging** (n=9)
Middle River (Coopers rd)	3/06/2010	*G. brevipinnis*	**9**	**14**	**29.9** (n=77)
Middle River (EPA)	22/12/2009	*G. brevipinnis*	N/A	N/A	**0** (n=6)
Christmas Creek	2/06/2010	*G. brevipinnis*	**17**	**2**	**38** (50)
Northwest River	3/06/2010	*G. brevipinnis*	**24**	**2**	**26.3** (n=99)
Rocky River	4/06/2010	*G. brevipinnis*	**1**	**0**	**7.1** (n=14)
Breakneck River	8/06/2010	*G. brevipinnis*	**22**	**1**	**59** (n=39)
		G. maculatus	**14**	**10**	**32.4** (n=74)
Southwest River	9/06/2010	*G. brevipinnis*	**1**	**1**	**100** (n=2)
		G. maculatus	**55**	**24**	**31.9** (n=248)
Stun'sail boom River	9/06/2010	*G. maculatus*	**26**	**10**	**36** (n=100)
Lower Rocky River (Flinders Chase)	9/06/2010	*G. brevipinnis*	**7**	**6**	**35.1** (n=37)

3.11.1. Gonado-Somatic Index (GSI) and gonad staging

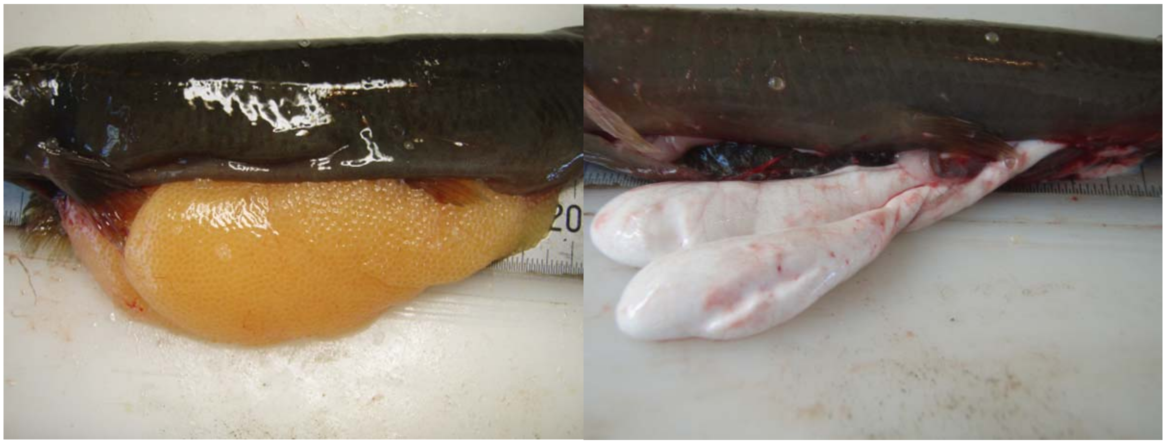

Figure 27. Gonads from reproductively advanced female (left) and male (right) *G. brevipinnis*.

Gonads from male and female *G. brevipinnis* were removed and staged (Figure 27). Downstream of the reservoir, results indicated that only one male seemed to be in spawning condition, with a GSI of 9.56% and gonad stage of 3 (Figure 28A). The average GSI for female *G. brevipinnis* was 0.97% with a gonad staging of 2 (Figure 28B), suggesting that both were in sub-optimum spawning condition. This was much the same for the remaining males caught at this site, with the GSI remaining at a low 1.32% and gonad staging of 2 (Figure 28A).

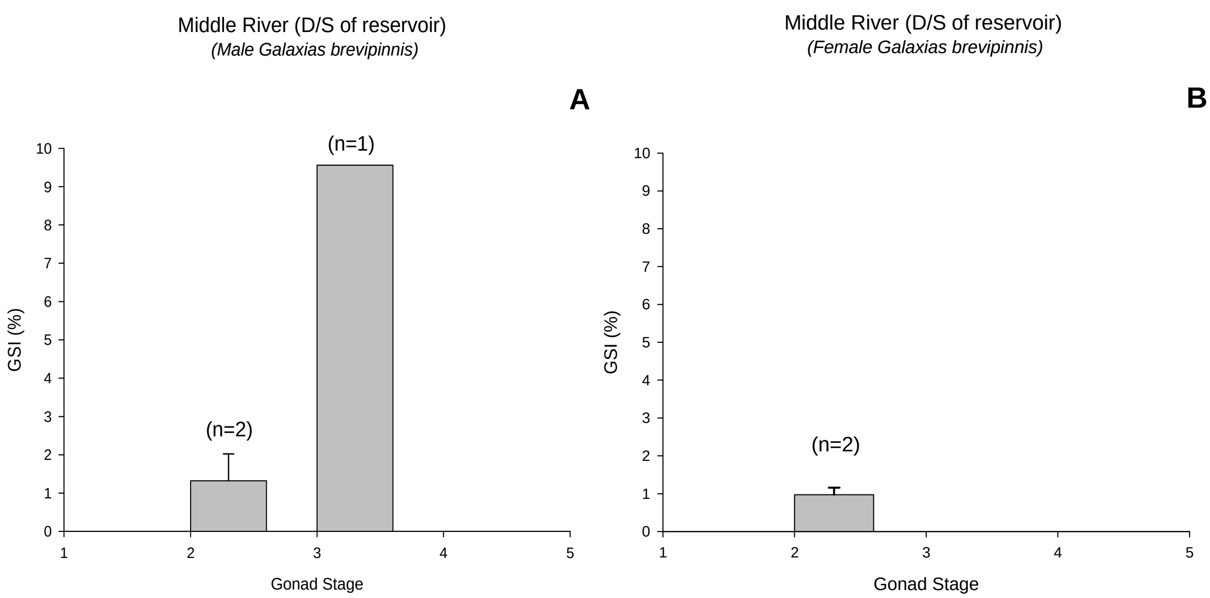

Figure 28. Average Gonado-Somatic Index (GSI) and gonad staging of Galaxias brevipinnis males (A) and females (B) sampled downstream of the Middle River reservoir (mean ± S.E.).

Results upstream of the reservoir indicate that both male and female *G. brevipinnis* were nearing optimum spawning condition (Figure 29). All males were in stage 3/4 of gonad development with an average GSI of 17.01% Figure 29A). Females were also advanced in their reproductive development, with all individuals being at stage 4 with an average GSI of 32.29% (Figure 29B).

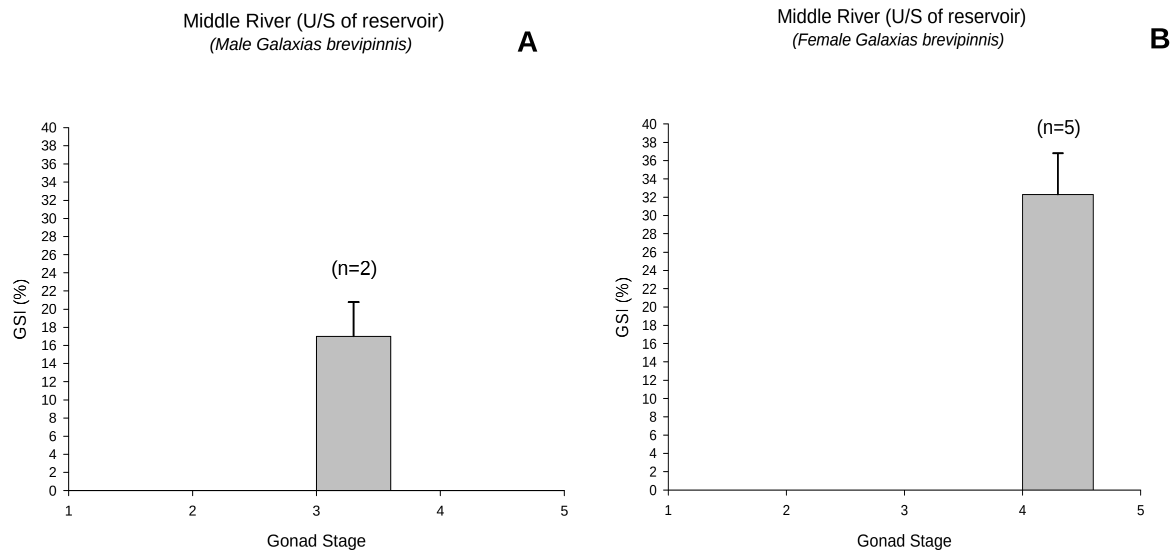

Figure 29. Average Gonado-Somatic Index (GSI) and gonad staging of Galaxias brevipinnis sampled upstream of the reservoir, in the Middle River Catchment (mean ± S.E.).

The average GSI and gonad staging of *G. brevipinnis* found at the ETSA track were similar to that found at the site downstream of the reservoir, with male *G. brevipinnis* being in either stage 2 or 3 of gonad development with an average GSI of 4.82% and 12.78% respectively (Figure 30). This suggests that male G*. brevipinnis* at the ETSA track site were approaching reproductive maturity (Figure 30A). Female gonads, however, were less mature being at stage 2, with an average GSI of 1.44% (Figure 30B).

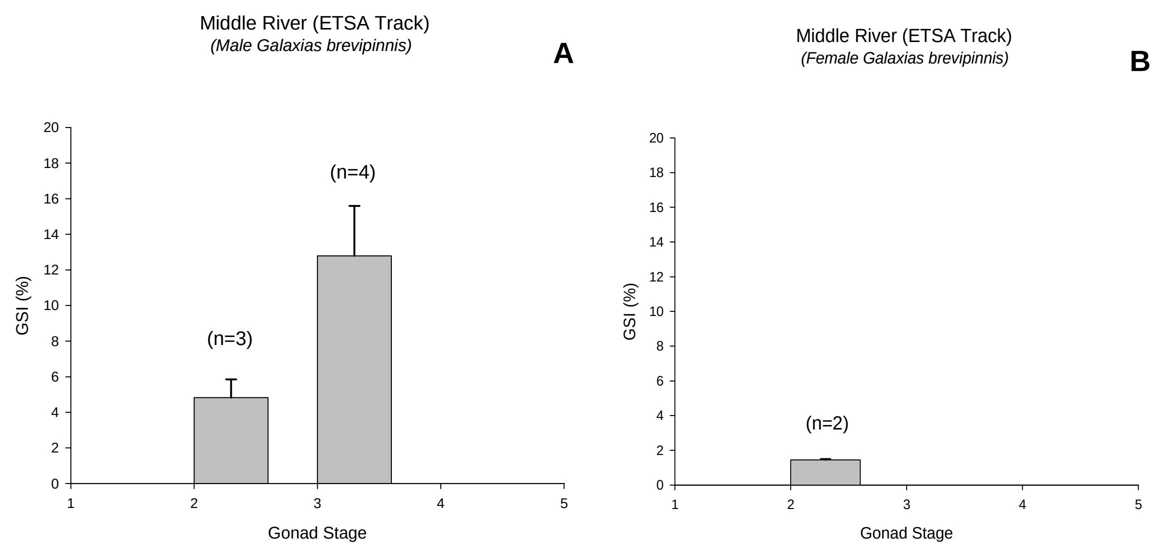

Figure 30. Average Gonado-Somatic Index (GSI) and gonad staging of Galaxias brevipinnis sampled at the ETSA Track site, in the Middle River Catchment (mean ± S.E.).

4. DISCUSSION

4.1. Fish of the Middle River Catchment:

Implications for management

The fish species caught during the current survey included all of the species recently sampled from the Middle River (Nilson 2006, EBS 2007) with the exception of the river blackfish (*Gadopsis marmoratus*) for which only a single record exists in the SA Museum collected from a pool at Strepera falls (Hammer 2004). It is likely that if this record is indeed accurately labeled, that the blackfish have since disappeared or become extremely rare in the Middle River catchment as several pools around this site were sampled. The observation of a single unidentified large fish, similar in size to adult blackfish (or trout) raises the possibility, but provides no evidence that this species is extant in the region. Rarer diadromous species, such as short headed lamprey (*Mordacia mordax*) and eels (*Anguilla australis*) whilst previously recorded on Kangaroo Island were not collected in the survey. Two freshwater species *Galaxias olidus* and *Philypnodon gr*andiceps have been suggested as resident to Kangaroo Island but require verification (Nilson 2006), with these species not caught during the current survey.

There are broadly three zones in the Middle river catchment as defined by fish assemblage, the estuarine zone, which has a distinct marine based fish assemblage characterized by *Arripis georgianus, Aldrichetta forsteri, Acanthopagrus butcheri, Atherinosoma microstoma, Psuedogobius olorum, Afurcagobius tamarensis* and *Arenigobius bifrenatus,* all of which will utilize freshwater habitats to some degree, but are primarily salt water species (McDowall 1996, Allen *et al*. 2002). This zone also provides a critical pathway for diadromous fish species to move between marine and freshwater habitats. The need to move through the estuary between the sea and freshwater habitats applies to both Galaxiid species present in the catchment as well as some not caught in this survey, but potentially present, such as lamprey (*M. mordax, Geotria australis*) and eel (*A. australis*).

The second zone extends from the freshwater estuarine boundary at the North Coast Road Bridge, upstream through the lowland channel section and Gorge to Strepera falls. This zone is dominated by *G. maculatus* which schools in large numbers throughout the zone, inhabiting all sampled pools. *G. brevipinnis* are also distributed throughout the gorge reach within this zone with populations at around 5-10% of those of *G. maculatus*. Both of these species are diadromous and this zone provides open access to the estuary and marine environments during higher flows allowing larval fish to move out to sea and recruit back into the reach as juveniles.

The final upland zone is dominated by *G. brevipinnis*, with the reservoir area dominated by introduced trout. This zone encompasses the majority of the catchment area including the mid and upper pool riffle sections in the Middle river and tributary systems with some likely to extend up into valley fill and swamp/wetland areas during wet periods. Most of this zone is dominated by relatively low numbers of large adult *G. brevipinnis* but there are clear signs of recruitment and aggregation activity around the Coopers Road site.

It is not known whether the galaxiids in this zone represent a landlocked population that spawn and recruit entirely within freshwater habitats, or whether they may be carrying out a diadromous lifestyle typical of this species. Diadromy would require that juveniles returning from the sea are able to effectively navigate the falls at Strepera, as well as the weir wall at the Middle River Reservoir. This question is being addressed within this study through the assessment of microchemical signatures laid down within the otoliths (ear stones) of fish. The use of saline habitats is often associated with a peak in the strontium to calcium ration in the structure of the otolith, which is laid down in ever expanding layers similar to an onion. Diadromy is linked to a peak in strontium calcium ratio during the larval period and this can be analyzed using laser ablation (Closs *et al.* 2003, Gillanders 2005, Crook *et al.* 2006, Crook *et al.* 2008). Fish otoliths from various reaches in the catchment and other catchments will be analyzed to determine what, if any populations of galaxiids are utilizing diadromous or land locked life history strategies. The results of this study will be presented separately in an accompanying paper. However, if any sites are likely to rely on land locked life history strategies, the upper zone above the falls and/or the reservoir is the most likely zone for this to occur due to the potential for those barriers to prevent upstream movement of fishes.

4.2. Environmental Water Requirements:

Implications for Conceptual & Hydrological Models

The process utilized for identifying the Environmental Water Requirements (EWRs) for the Middle River has involved the classification of the catchment into a number of reach types. These were largely based on geomorphic typologies but also considered biotic and ecological factors such vegetation and habitat structure, water quality and substrate types. In the following section, the results of the 2009/10 fish surveys will be discussed in relation to each of the reach types identified for the catchment, with specific reference to the targets and conceptual models developed using expert opinion.

4.2.1. Estuary

EWR targets developed for the estuarine reach are based largely around four key principles:

1 Provide cues for fish spawning and recruitment at appropriate times.

2 Provide adequate flushing to maintain water quality levels conducive to ecosystem function

3 Inundate benches to maintain samphire wetlands and shallow habitats for gobies and juvenile fishes (as well as food resources such as snails and other invertebrates).

4 Provide connectivity for estuarine and diadromous fish movements

The current survey revealed that all species caught in estuarine sites are present in reasonable abundances and are represented by an appropriate range of size classes to support ongoing recruitment of juvenile fish as well as the survival of larger, more fecund adults. This suggests that recent hydrological conditions have been sufficient for the maintenance of reasonable populations of estuarine fish, although the data is extremely limited for addressing this hypothesis. The species present are, however, characteristic of other estuarine systems around the Gulf of St. Vincent drainage (McNeil *et al*. 2009). Samphire benches remained inundated throughout summer and autumn and supported populations of gobies and bream, with abundant snails and other invertebrates. Important wetlands are present in Snelling's estuary, near the estuary mouth and it is believed that under high flow conditions, wetland areas at the upstream extent of the estuary would become significant. Water quality characteristics were relatively benign and saline. Temperature and oxygen levels were adequate for the survival of fish species at the time of sampling.

The data suggests that recent flow conditions have been sufficient to meet targets 1, 2 and 3 above, in that adequate water quality and cues for spawning and recruitment of estuarine species have been met under recent conditions. Target 4 is more difficult to investigate without sampling during periods of hydrological connectivity, or in lieu of otolith microchemistry data, which may provide evidence of recent connectivity and the successful passage of diadromous fish moving between freshwater and the sea. However, the successful recruitment of small size classes in to the Galaxiid populations in the lower channel and Gorge reaches clearly supports the hypothesis that recent flow and connectivity conditions have been adequate for the passage of larvae out to sea as well as the movement of juveniles back into freshwater habitats. The spawning periodicity identified under the current study reveals that this connectivity is required during early winter in order to provide appropriate cues for spawning and to provide appropriate passage for larvae to sea. This data also reveals that connectivity for upstream passage of juveniles is likely to be required in early spring and therefore flow targets should attempt to provide connectivity at both of these timeframes to facilitate the persistence of diadromous fish.

Possible EWR targets:

- Moderate connecting flows linking lowland channel habitats to the estuary and estuary to the sea in June and the following October/November at least once in every two years.
- Flushing flows one in two seasons to maintain water quality.
- Freshes to maintain estuarine bench inundation following any short periods of bench emergence.

4.2.2. Lowland Channel

EWR targets for lowland channel reaches included

1 Cease to flow periods sufficiently brief to provide permanent refuge pool habitats and maintain water quality.

2 Freshes occur regularly to flush out sediments and litter from remnant pools and freshen waterbodies, resetting water quality.

3 Freshes to allow the dispersal of fish between habitats and re-establishment of populations within previously dry reaches, accessing food/habitat resources.

4 High flows to support the connection of lowland channels to the estuary (and on to the sea)

5 High flows to discourage settlement of potential pests such as *Gambusia holbrooki*

6 High flows to inundate floodplain areas to assist in spawning and food resource inputs.

7 Appropriately timed pulses of flow to inundate Galaxiid spawning habitat in particular gravel benches and bank vegetation.

The abundance of *G. maculatus* throughout aquatic habitats in this reach and the evidence of recent large scale juvenile recruitment as well as older size classes suggest that recent flow conditions have been sufficient for meeting the EWR targets set out for this reach type. No evidence was collected that suggest water quality decline was significant during the survey period and sufficient refuge habitats were maintained to sustain adult populations. As described for estuarine targets, connecting flows in 2009 appear to have been sufficient in timing and volume to allow spawning, larval access in winter as well as juvenile upstream migration in early spring (McDowall 1975, & 1976, McDowall and Suren 1995, McNeil and Hammer 2007). Reconnecting flows in June 2010 appear to have been sufficient to link up and refresh lowland channel habitats

No evidence of overbank flows was recorded and the activation and utilization of food resources provided by floodplain inundation could not be ground truthed as flows were insufficient to flow out of the channelized reach onto floodplain habitats during the survey period. Furthermore, the floodplain is likely to receive far less inundation than historically due to the deeply incised channel form. The loss of inundation at this floodplain site may have greatly reduced the spawning area available for Galaxias and other species in the past (Closs et al 2006) and restoration of floodplain inundation may significantly improve native fish sustainability in the Middle River.

There is only a single pest fish species (*O. mykiss*) recorded from Middle River and this has not been found in lowland channel habitats. Widespread pests including redfin perch (*Perca fluviatilis*) and mosquitofish (*Gambusia holbrooki*) are not found on Kangaroo Island (Nilsen 2006). As a result, targeted flow regimes should be as close to natural as possible to deter the settlement and establishment of pest fishes if they are introduced rather than to manage extant populations. Subsequently, targets 1-4 appear to have been met under recent (2009) flow conditions, but insufficient evidence is available regarding flows required for meeting targets 5 & 6.

It is suggested that target 2 could be better informed by the measurement of constituents following flushing flows to determine the amount of organic and sedimentary material mobilized by high flows and whether the volumes required to serve this function can be met by high flows timed to support targets 3 and/or 4. Target seven involves the inundation of Galaxiid spawning habitats (O'Connor and Koehn 1998), which appear to have been met by recent flows, however, actual spawning sites have not been identified for the Middle River. Identification of these sites will allow more accurate hydrological regimes to be set to maintain spawning habitat inundation and re-inundation patterns.

4.2.3. Gorge

The Gorge section remains moist permanently, but smaller pools dry annually and larger pools shrink with increasing climatic pressure and increasing cease to flow duration. The upstream reservoir severely reduces baseflow to this reach and inputs from tributaries such as salt creek are sufficient to maintain refuge pools during dry summer conditions, but not to provide connectivity. During winter, tributary flows may provide significant connectivity through the Gorge section without flow overtopping the reservoir. Fish based EWR targets for the gorge reach are:

1. The maintenance of pool habitats of adequate depth during low flow and cease to flow periods
2. The maintenance of acceptable water quality in those pools
3. Flushing flows to provide connectivity between late autumn and late spring, maintaining pathways for fish movement to and from spawning and settlement habitats.
4. Sufficient duration of connectivity under flushing flows to allow the migration of fishes through this reach (*G. brevipinnis* may need longer duration than *G. maculatus* because they may require durations that allow them to ascend Strepera Falls and continue into the upper catchment).
5. Appropriately timed pulses of flow to inundate Galaxiid spawning habitat in particular gravel benches and bank vegetation.
6. Maintenance of damp pathways allowing *G. brevipinnis* to ascend Strepera Falls.

The Gorge section is dominated by *G. maculatus*, which in this reach have access to the sea and are likely to be entirely diadromous. As with other reaches, the nature of diadromy will be explored using otolith microchemistry in a separate paper. *G. maculatus* are found in high densities throughout the gorge, more so than *G. brevipinnis* which appear to be more solitary or gathered in smaller sized schools. All pools in the reach contain large numbers of galaxiids and in shrinking habitats; there will be an increasing risk of predation from marron, birds, other terrestrial fauna and invertebrate predators.

The survey has shown that pools are currently maintained throughout summer and that pool maintenance and water quality have been adequately maintained for fish survival meeting Targets 1 and 2. It must be noted however, that this does not mean that flows have been optimal and the maintenance of deeper and more permanent pools in this reach is likely to benefit galaxiid populations in the gorge.

The distribution of size classes however, and in particular the absence of juveniles from pools closer to the falls reveals that the flow duration and/or hydraulic conditions may have been insufficient to allow returning juveniles a sufficient pathway through the gorge reach up to the falls. If this hypothesis is correct then *G. brevipinnis* returning from the sea may also have insufficient flow duration to undertake migration upstream of the falls (assuming this does not provide a barrier for this species). As a result, Target 4 may not be being met under current or recent flow conditions and environmental flow provisions from the reservoir may be required to ensure flow duration targets are met.

As with the other reach types, the inundation of galaxiid spawning habitats appears to be being met by recent flow conditions, however the spawning sites were not identified in the survey and therefore assessment of Target 5 can not be accurately completed. It is possible that fish in the gorge are spawned elsewhere, however the presence of recent recruitment suggests spawning habitats are being adequately inundated somewhere in the catchment, if not within each reach type.

Damp pathways were maintained during the summer at Strepera falls due to very low levels of baseflow and moisture holding epiphytes in the rock face. It should be cautioned that reductions in seepage baseflow could threaten Target 6 and this would almost certainly impact on the ability for *G. brevipinnis* to ascend the falls, if this occurs at all.

4.2.4. Above Strepera Falls

This site is extremely significant due to its position between the two principal barriers to fish movement in the catchment. The survey revealed the reach contains low numbers of adult fish but also reasonable numbers of juveniles. The source of this recruitment is not determined but is a key aspect of fish ecology in the catchment and can be revealed using modern otolith microchemistry techniques outlined earlier. A number of scenarios exist:

1. If these fish show no signals for diadromy then Strepera falls is most likely a significant barrier to upstream migration and all fish above Strepera are likely to be obligate freshwater spawners, relying on localized freshwater habitats for spawning development of larvae and recruitment.

2 If these fish are recruiting from a diadromous population then Strepera falls is not providing a significant barrier to upstream migration and flows must be maintained to allow the passage of these fish from the sea.

3 If the fish in this reach are diadromous and those of the mid-upper catchment are not, then the reservoir wall is likely to be acting as a barrier to migration and management efforts will be required to re-instate fish passage past this barrier.

4 If fish passage can be re-instated for the catchment then flow regimes must be maintained to allow passage of diadromous fish from the sea into the very upper reaches of the Middle River catchment.

5 If fish from the upper catchment show signs of diadromy then neither the falls nor the reservoir are presenting a barrier to diadromous movement.

4.2.5. Reservoir

The reservoir itself was dominated by introduced trout (*O. mykiss*) which are a veracious predator of native fish (McDowall 2006) and were largely restricted to the reservoir and the reaches directly upstream. It is likely that unregulated flow conditions in the mid-upper catchment, combined with harsh summer conditions are sufficient to control cold-adapted European predators such as trout (Wilson *et al.* 2008). Alternatively, stable, good and well oxygenated water conditions, such as those that dominate the reservoir, are likely to enhance the establishment and maintenance of trout populations.

The presence of large numbers of spawning *G. brevipinnis* upstream of the reservoir suggests that the site may be an extremely important larval rearing site if the mid-upper catchment population is indeed landlocked. Although the data does not prove that larvae utilize this reservoir, to do so would require the adequate abundance of food resources such as zooplankton and insect larvae on which developing larvae and juveniles feed (Lewis *et al.* 2002).

Perhaps the maintenance of cryptic habitat such as rocky bank and beds may improve the survival of developing galaxiids and provide refuge form trout predation. At very low reservoir levels, these complex habitats may disappear, forcing Galaxiids out into trout dominated open waters; however, severely reduced water levels are likely to lead to a decrease in trout survival and may provide a benefit to native fish in the reservoir. Management of trout may require physical removal programs, but may also include the manipulation of reservoir levels to

a) improve the effectiveness of removal during low water levels,

b) to create summer low reservoir levels that may impact preferentially on trout (Closs and Lake 1996)

c) to inundate and maintain shallow, complex edge habitats, vegetation beds and upstream reaches of the reservoir where *G. brevipinnis* may be able to escape predators in complex littoral habitats (Chapman *et al.* 1996).

d) Protect inflows into the reservoir to maintain shallow refugia for *G. brevipinnis* as well as maintaining inflows during autumn for spawning and migration of adults and in spring for juveniles.

4.2.6. Mid-Pool Riffle

This reach type covers a large area of the catchment upstream of the reservoir and due to lowered levels a small area at the upstream extent of the reservoir. The survey has revealed that these reaches are almost exclusively dominated by *G. brevipinnis* with low numbers of trout present near to the reservoir. Fish based EWR targets for mid-pool riffle sites are very similar to those for the gorge and lowland channel.

1 Cease to flow periods sufficiently brief to provide permanent refuge pool habitats and maintain water quality.

2 Low flow freshes to increase habitat distribution throughout the mid catchment and facilitate the movement of fish between habitats and access additional food resources.

3 Dual flow pulses in early winter to inundate spawning habitat and facilitate hatching on re-emergence.

4 High flows of adequate duration in early winter:

   a. To enable adult *G. brevipinnis* to access spawning sites and to return to adult refugia

   b. To allow larvae to colonize appropriate larval habitats and resources

   c. To allow the migration of recruits back to adult habitats in the spring.

5 If diadromous populations are present above the reservoirs, high flow durations must be sufficient to allow long distance migration between the sea and upper catchment area.

Large numbers of adult fish in spawning condition as well as the presence of large numbers of juveniles at Coopers Rd, suggest that these populations may in fact be land locked and rely on local spawning and recruitment processes to maintain the population. This emphasizes the potential importance of targets 1-3 in maintaining adult and spawning habitats within this reach type. It is also possible that the reservoir is serving as a sink habitat for larval fish that are unable to reach the sea and is therefore a key recruitment source for the upper catchment. The survey revealed a number of refuge reaches and pools where adult fish persisted, although the humic nature of many of these pools suggest high dissolved oxygen demand could be an issue under some conditions and that water quality declines could pose a threat to the survival of adults in refuge habitats (McNeil and Closs 2007) if baseflow is reduced or flushing flows are inappropriate for refreshing these habitats regularly.

These movement patterns and the land-locked nature of populations were not assessed in the current survey and it is difficult to quantify the duration and volume of flow required for fish movement addressing targets 4 and 5 as a result. Otolith microchemistry, the identification of spawning sites and sampling for larval and juvenile fish movement are required to address these questions accurately. Data collected from Christmas Creek reveals that *G. brevipinnis* movement can be rapid and that adults and juveniles may move reasonable distances of several kilometers within a few days of flow initiation. More research is required, however, to determine the relative swimming abilities over long distances. This knowledge is required to estimate the duration of flow required for migrations and can be assessed using recently developed technologies for tracking fish movements (SARDI unpublished data).

The survey also revealed that these sections may have a previously unacknowledged pressure relating to the recreational by-catch of *G. brevipinnis* using marron fishery techniques such as bait trapping. Observations made during the survey also indicate that predation by marron on fish does occur and may be a significant issue within refuge pools, particularly under advanced states of drying when water levels are too low to allow fish to escape such benthic predators. This stresses the need to maintain adequate depth in refuge pools.

4.2.7. Upper Pool-Riffle

Upper pools rifle sites are predominantly in tributary catchments of the Middle River and may be either permanent, such as Upper Middle River, or ephemeral such as Christmas Creek. These habitats are likely to be sub-optimal for long term fish habitation and Upper Middle River sites had very low numbers of *G. brevipinnis* and observations of Aquatic Surface Respiration behaviour lead to analysis of oxygen levels which were indeed hypoxic. Conditions in Christmas

Creek had deteriorated to a greater extent and the very few remaining shallow pools had no fish at all during the March 2010 site visit. The abundant *G. brevipinnis* caught at that site after resumption of flows in June 2010, however, reveals that native fish will move very rapidly upstream to inhabit newly inundated and connected upper pool riffle reaches. Most of these were adults and therefore have moved out of refuge habitats in the main channel in response to the commencement of flow.

Migration into these habitats allow the utilization of new food and habitat resources and flow duration therefore will need to be sufficient for fish to move into these habitat and escape back to permanent refugia. Alternatively, connecting flows will need to occur frequently enough for fish to move into and out of these reaches prior to drying. This demands that refugia within upper pool-riffle reaches must be maintained for multiple years to allow the effective utilization of resources as well as the return to safer refuge habitats in the main channel.

4.2.8. Swamp/Wetland

The survey revealed no fish were present in these habitats but they are likely to provide important nutrient and food resources that drive native fish sustainability in downstream reaches. The regular connectivity between wetlands and creeks as well as the maintenance of abundant frog, tadpole and invertebrate populations are likely to be important for native fish in the Middle River catchment.

4.3. Spawning Observations

The results of field spawning assessment, GSI and gonad staging indicated that both Galaxiid species were in spawning condition during early June 2010 following late-autumn flows, but were not ripe at other sampling times (spring, summer and early autumn). This fits with observations for these species in other catchments (McNeil and Hammer 2007). The pattern has direct implications for the development of EWP targets relating to flow bands that support spawning migrations and inundation of spawning habitats.

In particular, models developed that require flushing and connecting flows in late autumn and early winter are supported strongly by the present data, and spawning flows should be targeted to this season to facilitate spawning requirements of native fish, particularly Galaxiids. Whilst *G. maculatus* is only found below Strepera falls and would easily obtain access to spawning and marine habitats during periods of moderate connecting flow lasting several days, *G. brevipinnis* is potentially landlocked above either Strepera falls or the reservoir.

Conceptual models (van der Wielen *et al.* 2009a and b) hypothesized that landlocked populations are likely to utilize the reservoir area as a surrogate for marine systems, with larvae potentially washing into and developing within pelagic lake habitats. This hypothesis proposed that a likely spawning site under this scenario would be the area where the river flowed into the reservoir, replacing the lowland coastal spawning habitats utilsed by diadromous *G. brevipinnis* populations (O'Connor and Koehn 1998).

Whilst male *G. brevipinnis* were approaching or in spawning condition over much of the catchment, the survey revealed that females in spawning condition were largely confined to the hypothesized spawning area at the u/s reservoir site (Figure 31) and further upstream at Coopers Rd and the recently inundated Christmas Creek. It should be noted that the upstream reservoir site would be inundated to a depth of <2m under high reservoir levels and under this scenario, spawning habitat is likely to contract upstream somewhat.

Figure 31. *G. brevipinnis* spawning site at upstream extent of reservoir under early winter low-flows and low reservoir levels. Under higher reservoir levels spawning habitats may contract upstream from the upper reservoir into the river.

The absence of data from below the falls makes it difficult to determine, but it is likely that *G. brevipinnis* below the falls would similarly time spawning in response to these early winter flow cues as demonstrated by both Galaxiid species in unobstructed lower reaches of neighboring catchments such as the lower Rocky River. The exact location of spawning habitats is very difficult without comprehensive spatial surveys, but the data clearly shows that Galaxiid spawning is occurring across catchments following early winter flows although the exact timing of spawning and the level of reproductive maturity differs somewhat from site to site.

It follows that spawning activity during early winter will also be linked to the upstream migration of juvenile 'whitebait' into the Middle River from the sea. Data from the survey revealing large numbers of juvenile recruits in the lower catchment indicate that upstream migration was successful during the September 2009 flows prior to the field surveys, consistent with previous data for these species (McNeil and Hammer 2007). Similarly, the winter spawning observed will require that connecting flows of appropriate duration to allow migration to between the sea and the mid- and upper-catchment will be required in spring 2010 to allow successful recruitment of juveniles from this spawning event. As a result, the data supports models for the inundation of spawning habitat in winter and connecting flows for spawning and recruitment migrations in winter and spring.

4.4. Water Quality Impacts and Flows

The majority of habitats possessed a reasonable level of water quality that would be unlikely to impact negatively on native fishes. However, a number of sites had particularly harsh water quality parameters. The upper catchment swamps in particular had extremely low levels of dissolved oxygen, well below those tolerable for native fish for extended periods (McNeil and Closs 2007). In Upper Middle River, hypoxic conditions resulting from bacterial productivity were linked to the observation of two small *G. brevipinnis* performing Aquatic Surface Respiration (ASR) to survive these otherwise intolerable conditions.

Clearly water quality declines under low or no flow conditions are likely to be impacting on refuge habitats within the Middle River catchment. Conceptual flow targets set to protect water quality declines are therefore likely to be important for protecting native fish within refuge pools and the survey supports the provision of adequately timed flows to alleviate the build up of organic material and to flush stagnant habitats and maximize water quality conditions for fish sustainability during low and no flow periods.

Particularly high risk areas for water quality are refuge pools throughout the catchment, with isolated reaches possessing low but tolerable water quality. For example, dissolved oxygen levels at the EPA site and at Iverson's were approaching levels that will impact on fish in the long term and indicate that these habitats could be very close to becoming hypoxic to intolerable levels for most aquatic life. As indicated at Upper Middle River, the energetic demands for fish to survive even brief hypoxic episodes, such as maintaining constant swimming at the surface, increased predation risk from birds etc, make even mild conditions a serious threat to fish survival.

Finally, the lowland channel habitat is at risk of increasing levels of saline upstream intrusion under the rising sea levels predicted with climate change scenarios (Murphy and Timbal 2007). Similar habitats in the Onkaparinga River have recently been shown to become highly saline under high tidal and storm surge conditions leading to large fish kills and the localized depletion of freshwater fish communities including *G. maculatus* (McNeil *et al*.2009. Such storm surge conditions were historically met with large river flows prior to regulation which captures large flow volumes in the mid-catchment. This suggests that high flows should be provided or maintained to counter tidal intrusion during storms to protect freshwater habitat and biota in the lowland channel, especially given the prevalence of marine conditions all the way through the estuary and the sharp transition between marine and freshwater conditions at the North Coast Road Crossing, a situation identical to that in the Onkaparinga River on the mainland.

4.5. Conclusions

The surveys presented above have provided field data for the testing and development of conceptual models and EWP targets for the Middle River catchment. Whilst some of these are quite specific, a number of over-arching objectives can be recommended for the ongoing provision of water in the catchment to support key aspects of the sustainability of native fishes. These flow objectives are somewhat different for various reach types and include:

- Estuary: Maintain self sustaining populations of the estuarine fish community. Maintain suitable connectivity between marine and freshwater environments to support diadromous fish populations.
- Lowland Channel: Maintain self-sustaining populations of *G. maculatus* and *G. brevipinnis*. Maintain suitable connectivity for the movement of diadromous fish species.
- Gorge: Maintain self-sustaining populations of *G. maculatus* and *G. brevipinnis*. Maintain suitable connectivity for the movement of diadromous fish species.
- Mid Pool Riffle: Maintain self-sustaining populations of *G. brevipinnis*.
- Upper Pools Riffle: Maintain ephemeral habitat, resources and connectivity for utilization of *G. brevipinn*is.
- Swamp Wetland: Maintain viable swamp ecosystems and connectivity with permanent streams to provide essential resources for fish sustainability.
- All Reaches: Maintain appropriate water quality in permanent refuge pools to maintain native fish populations through low flow periods.

5. REFERENCES

Allen, G.R, Midgley, S.H. and Allen, M. (2002) ‘Field guide to the freshwater fishes of Australia’. Western Australian Museum, Perth. 394pp.

Bunn, S.E and Arthington, A.H. (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management* 30, 492-507.

Chapman, L. J. Chapman, C. A. Ogutu-Ohwayo, R. Chandler, M., Kaufman, L. and Keiter, A.E (1996). Refugia for Endangered Fishes from an Introduced Predator in Lake Nabugabo, Uganda *Conservation Biology*, 10, 554-561.

Closs, G. P. and Lake, P. S. (1996) Drought, differential mortality and the co-existence of a native and an introduced fish species in a south east Australian intermittent stream. Environmental Biology of fishes. 47, 17-26.

Closs GP, Balcombe SR, Driver P, McNeil DG & Shirley MJ (2006) The importance of floodplain wetlands to Murray-Darling fish: What’s there? What do we know? What do we need to know? Report for the Native Fish and Wetlands in the Murray-Darling Basin. Murray Darling Basin Commission: Canberra.

Closs, G. P., Smith, M., Barry, B., and Markwitz, A. (2003). Non-diadromous recruitment in coastal populations of common bully (*Gobiomorphus cotidianus*). *New Zealand Journal of Marine and Freshwater Research* 37, 301–313.

Crook, D. A., Macdonald, J. I., O’Connor, J. P., and Barry, B. (2006). Use of otolith chemistry to examine patterns of diadromy in the threatened Australian grayling *Prototroctes maraena. Journal of Fish Biology* 69, 1330–1344. doi:10.1111/J.1095-8649.2006.01191.X

Crook, D. A., Macdonald, J. I., and Raadik, T. A. (2008). Evidence of diadromous movements in a coastal population of southern smelts (*Retropinninae: Retropinna*) from Victoria, Australia. *Marine and Freshwater Research* 59, 638–646. doi:10.1071/MF07238.

Gillanders, B. M. (2005). Otolith chemistry to determine movements of diadromous and freshwater fish. *Aquatic Living Resources* 18, 291–300.doi:10.1051/ALR:2005033

Hammer, M. (2004) kangaroo Island Fish Inventory; Interim Report. Native Fish Australia, South Australia. 3pp.

EBS (2007) Kangaroo Island – Middle River Reservoir reserve, Flora and Fauna Assessment. Consultants report for SA Water. Environmental and Biodiversity Services. 64pp.

Lewis, D. M., J. A. Elliott, et al. (2002). "The simulation of an Australian reservoir using a phytoplankton community model: PROTECH." *Ecological Modelling* 150: 107-116.

McDowall, R.M.E. (1996) 'Freshwater fishes of South-Eastern Australia.' (Reed: Sydney).

McDowall, R.M., Robertson, D. A. And Saito, R. (1975) Occurrence of galaxiid larvae and juveniles in the sea. *New Zealand Journal of Marine and Freshwater Research*. 9 (1): 1-9.

McDowall, R.M. (1976) The role of estuaries in the life cycles of fishes in New Zealand. *Proceedings of the New Zealand Royal Society*. 23: 27-32.

McDowall, R. M., Suren, A. M. (1995) Emigrating larvae of Koaro (Galaxias brevipinnis Günther (Teleostei: Galaxiidae), from the Otira River, New Zealand. *New Zealand Journal of Marine and Freshwater* Research. 29: 271-275.

McDowall, R, M. (2006) Crying wolf, crying fowl, or crying shame. Alien salmonids and a biodiversity crisis in the southern cool-temperate galaxioid fishes? *Reviews in Fish Biology and Fisheries*. 16 233-422.

McNeil, D.G., Hammer, M. (2007) 'Biological review of the freshwater fishes of the Mount Lofty Ranges.' South Australian Research and Development Institute (Aquatic Sciences), Publication number: F2006/000335, Adelaide

McNeil D. G. and, Closs, G.P. (2007) Behavioural responses of a south-east Australian floodplain fish community to gradual hypoxia. Freshwater Biology 52, 412–420.

McNeil, D.G., Fredberg, J. and Wilson, P.J. (2009). Coastal Fishes and Flows in the Onkaparinga and Myponga Rivers. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board. South Australian Research and Development Institute, Aquatic Sciences. SARDI Report Series No 400. 76pp.

Murphy BF, Timbal B (2007) A review of recent climate variability and climate change in southeastern Australia. International Journal of Climatology 7, 859-879.

Nilsen, T. (2006) Technical background to water management planning on Kangaroo Island, South Australia. Kangaroo Island Natural Resources Management Board. 205pp.

O'Connor W.G and Koehn, J.D. (1998) Spawning of the broad-finned Galaxias *Galaxias brevipinnis* Günther (Pisces: Galaxiidae) in coastal stream of southeastern Australia. *Ecology of Freshwater Fish*. 7: 95-100.

Thomas, D, Kotz, S, Rixon, S (1999). 'Watercourse survey and management recommendations for the Myponga River catchment, EPA, The Riparian Zone Management Project, SA DEH: Chapter 2, pg 12.

Van der Wielen, M, Casanova, M., Doeg, T., Esprey, L., McEvoy, P, McNeil, D., Savadamutha, K., and Vietz, G. (2009a). Environmental flow requirements for middle river, Kangaroo Island. Draft report on stage 1. Middle River Environmental Flow Technical Panel.

Van der Wielen, M, Casanova, M., Doeg, T., Esprey, L., McEvoy, P, McNeil, D., Savadamutha, K., and Vietz, G. (2009b). Environmental flow requirements for middle river, Kangaroo Island. Report on stage 2: Draft environmental flow requirements. Middle River Environmental Flow Technical Panel.

Wilson, P., J., McNeil, D. G. and Gillanders B. M. (2008) Impacts of introduced redfin perch on native flathead gudgeons in the South Para River. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication Number: F2007/000882-1. 47 pp.

6. APPENDIX 1. WATER QUALITY PARAMETERS MEASURED AT SAMPLING SITES

SITE I.D	Sampling Date	DO (ppm)	Conductivity (mS)	pH	Temperature (°C)	SECCHI depth (mm)	Flow	Connectivity
Great South Swamp	22/12/2009	1.20	0.34	5.70	17.9	200	n/a	isolated
Squashy swamp	22/12/2009	0.50	0.72	6.12	17.2	120	still	isolated
Upper Middle River	30/11/2009	0.20				1000+	low	connected
Middle River (Electro-fishing)	10/06/2010	5.43	1.05	5.96	9.1	800	low	connected
EPA	22/12/2009	3.13	0.64	6.17	18.9	300	still	isolated
Christmas Creek	2/06/2010	4.50	3.30	4.77	9.2	600	low	connected
Middle River (Coopers rd crossing)	3/06/2010	6.50	1.40	6.88	9.3	600	low	connected
Middle River (ETSA track)	1/06/2010	7.41	1.27	6.72	12.8	300	low	connected
Middle River (u/s of Reservoir)	1/06/2010	9.50	4.30	6.58	14.7	300	low	connected
Middle River (Reservoir)	31/05/2010	9.51	0.95	6.55	14	n/a	still	isolated
Middle River (d/s Reservoir)	31/05/2010	9.60	4.00	6.35	13.5	1000+	low	connected
Strep 3	23/12/2009	9.10	2.33	7.20	23.1	650	still	isolated
Strep 2	23/12/2009	8.80	2.08	8.20	21.3	1000+	still	connected
Strep 1(DEEP)	23/12/2009	3.15	2.11	6.77	20.0	1000+	still	isolated
Strep 1(SHALLOW)	23/12/2009	6.09	2.02	7.20	21.6	1000+	still	isolated
Strep 4	23/12/2009	5.96	5.13	6.80	22.1	1000+	still	isolated
Iverson’s	22/12/2009	3.90	7.17	7.60	19.4	500	still	isolated
Snelling’s Upper Estuary	21/12/2009	4.60	54.00	7.30	24.1	500	still	isolated
Snelling's Estuary	11/12/2009	6.87	57.50	n/a	n/a	800	n/a	isolated
McGill’s Estuary Mouth	21/12/2009	5.80	58.50	7.81	24.9	200	still	isolated
Rocky River	4/06/2010	11.11	4.67	6.38	10.4	650	n/a	isolated
Lower Rocky River (Flinders chase)	9/06/2010	13.00	5.01	7.19	9.9	1000+	moderate	connected
Breakneck River (Flinders chase)	8/06/2010	11.22	5.42	7.12	11.5	500	moderate	connected
Stun'sail boom River	9/06/2010	9.81	2.42	7.27	10.5	550	moderate	connected
Southwest River	9/06/2010	9.39	3.24	7.11	11.2	600	moderate	connected
North-West River	3/06/2010	10.48	5.42	6.65	9.9	500	moderate	connected