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Fish Community and Flow Ecology in the Western Mount Lofty Ranges Environmental Water Provisions Trial Reaches



Dale McNeil, David Schmarr, Phillipa Wilson and David Reid

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**Final Report to the Adelaide and Mount Lofty Ranges Natural Resources
Management Board and the SA Department for Water.**

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FRONTISPIECE: Surveying Site Access above the South Para River Gorge.





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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>

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Author(s): Dale McNeil, David Schmarr, Phillipa Wilson and David Reid

Reviewer(s): Michael Hammer, Rod Ward, Kathleen Beyer, Katherine Cheshire, Rehanna Halfyard, Steve Gatti and Dean Hartwell

Approved by: Dr. Jason Nicol
A/Principal Scientist – Inland Waters & Catchment Ecology

Signed:

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EXECUTIVE SUMMARY

The coastal reaches of many streams in the Western Mount Lofty Ranges (WMLR) are highly regulated with almost no natural in-flows received from upper catchment areas outside of very large flooding flows that coincide with high water storage volume (reservoirs). With the acknowledgement that these coastal reaches possess ecosystems of high environmental value, a program was initiated in 2005 to develop environmental watering provisions (EWPs) for reaches downstream of major water storages in the Onkaparinga, Torrens and South Para Rivers located in or near Adelaide, South Australia. As part of the EWP process, a project was developed to gain a baseline of knowledge regarding the ecological values of these river reaches, and in particular to assess the sustainability of native fish populations, which comprised key ecological assets and can serve as an effective indicator of overall ecological health. In addition, fish are a primary biotic group utilised in the development of ecological water targets that can inform and support the optimisation of environmental flow planning and design.

The current study collected baseline ecological data over a three year period (sampling twice annually in autumn and spring) from a total of 11 sites downstream of major water storages in the South Para River (3 sites), the Upper Torrens (2 sites), Lower Torrens (3 sites) and Lower Onkaparinga River (3 sites). Each site consisted of three separate pools located within a three kilometre reach, with adjacent riffle and run areas also sampled during periods of hydrological connectivity. Pools were sampled extensively using nets, with shallower areas also sampled using backpack electrofishing. Sites were spread downstream of each designated release point (Weir) so that one site was located within 3km of the release point, another 5-10km downstream of the release point and where appropriate, a coastal or extreme downstream site was also sampled in each of the three River catchments.

The surveys collected a wide range of baseline biological and ecological data that relates directly to the nature of sustainability regarding native fish populations in EWP reaches as well as a range of information regarding the interactions between native and introduced fish and between fish and freshwater flows. As a result, a body of information and knowledge has been created that can contribute to the estimation of native fish values, key threats, and importantly optimise the development of *Environmental Water Targets* that can build the protection of native fishes and the sustainability of coastal stream environments into future plans for the delivery of water resources.

The study collected data through a period of intensifying drought which added additional pressure to EWP ecosystems, providing an exceptional insight into the historical impacts that flow abstraction has had on these coastal freshwater systems during dry climatic periods. The data revealed that without the provision of EWP flows, almost all native fish species suffered extreme contractions during summer zero flow periods into isolated refuge pools, the majority of which dried completely during hot summers leading to the loss of their resident fish populations. Only a small



number of critical refuge pools were maintained without the addition of flows, in which native fish species found protection. This pattern occurred in all EWP reaches demonstrating the importance of flow provisions in maintaining aquatic habitats for aquatic biota.

Associated with this pattern was the gradual reduction in the abundance of key native fish species across all sites and the contraction in range of some species from the entire reach, down to a handful of refuge pools. In the case of the Onkaparinga River, common galaxias, initially widespread through all areas up to Clarendon weir were gradually lost from upstream pools until they were able to persist only in the most downstream pools where local catchment runoff and possibly groundwater inputs were highest. Close linkages were observed between freshwater and estuarine habitats and species in the Onkaparinga River and future studies must take into consideration the broader impacts of water resource use across freshwater and marine habitats. The importance of flow provisions for providing spawning and recruitment cues and providing adequate passage for fish movements were highlighted, particularly under a natural flow regime where late autumn and spring flows need to be re-instated to facilitate critical life history functions of native species.

Baseline data revealed that ecosystems and native fish communities were already significantly impacted to varying degrees by past management, with only a single native species remaining within the South Para River EWP reach between Woodlands Weir and the Barossa Diversion Weir. The high abundance of introduced predators and competitors in redfin perch and gambusia maintain constant pressure on the remaining native fish in both the South Para and Torrens Rivers, with trout adding to the pressure in the mid Torrens. The upper Torrens River also suffered from highly erratic flow changes resulting from inter-basin transfer flows. This highly disturbed flow regime was asynchronous with natural flow regimes and as a result native fish were patchy and in low abundance compared to invasive species that are better adapted to stable and high flow volumes.

Despite high degrees of hydrological stress and evidence of other major threats, several native fishes including some threatened taxa persisted in the different EWP reaches, albeit often with localised distributions and/or low abundance. Their presence suggests that restoration of habitat, flow and fish passage linked with the control of introduced species could have a significant positive impact in returning these native fishes to viable and sustainable levels in the future. The removal of fish passage barriers was identified as a strong threat present in all EWP reaches that should be pursued in order to maximise the effectiveness of EWP releases and to optimise the outcomes of environmental water resource allocations. This data provides an excellent 'before' study that can now be compared to similar data collected once EWP releases occur. The subsequent *Before-After-Impact* (BAI) design provides a reasonably strong scientific basis for linking EWPs to ecological responses in lieu of any realistic experimental control options.



Key findings and Recommendations Include:

- The current structure of monitoring with autumn and spring surveys across a number of sites within each EWP reach has provided an excellent level of information for informing the baseline condition and flow requirements of native fish populations.
- Non water resource related threats such as barriers to fish movement, vegetation clearance and encroachment, land use impacts, should be identified throughout EWP reaches to optimise management of flow management outcomes
- Restoration of instream and riparian structural and vegetation habitat should be linked with EWP target reaches to maximise outcomes of flows that promote fish populations, spawning and recruitment.
- Consideration be given to extending the South Para EWP trial reach downstream to the sea to incorporate diadromous fish management issues (following the removal of Gawler weir).
- Transfer flow operations in the Upper Torrens be designed with the aim of minimising ecological impacts of periods of constant high, or low flow volumes.
- Onkaparinga EWPs need to clearly address issues relating to diadromous fish movements as well as maintaining current low levels of exotic species.
- Post EWP monitoring should target the same sites and cover (at a minimum) the duration of pre flow monitoring to assure meaningful comparisons can be drawn.
- The season to season variation in the EWP catchments is such that several years of continuous data are likely to be required for causative flow responses and benefits to the fish community to be confidently identified.
- Flows that boost the volume and duration of autumn and spring flows are likely to provide the largest benefit to native fish and broader aquatic ecosystem health across EWP reaches.



1. INTRODUCTION

1.1. Catchments of the Mount Lofty Ranges

The Mount Lofty Ranges which bound the eastern edge of Adelaide, forms the watershed between the Murray-Darling Basin and The South Australian Gulf Drainage Division. The eastern draining catchments of the MLR drain towards the Murray River and Lower Lakes, with the coastal catchments of the Western Mount Lofty Ranges (WMLR) draining into Gulf St. Vincent. The major catchments in the WMLR are the Gawler River (fed by the North and South Para Rivers), the River Torrens, which runs through the City of Adelaide, and the Onkaparinga which drains a large section of the central MLR and enters the Gulf through the far-southern Adelaide suburbs at Port Noarlunga. Each of these catchments has undergone significant and continuing anthropogenic modification since European settlement in the mid nineteenth century (Kraehnuehl 1996). Largely, modification of waterways revolves around the capture and storage of water resources to support agricultural and urban community uses, and the modification of the physical catchment through land use and urbanisation. As a result, the essential character of these rivers has changed significantly, and subsequently, their role as aquatic ecosystems has also been dramatically changed from pre-European condition (McNeil and Hammer 2007). One of the key mechanisms of anthropogenic change in these systems is the construction of water storage reservoirs and weirs which have in turn, greatly altered the flow regime from natural condition.

1.2. Flow Management and Regime

A number of water storages have been constructed within river valleys to store water for human use, including very large water storages on the South Para River (South Para Reservoir), the River Torrens (Kangaroo Creek Reservoir) and the Onkaparinga (Mount Bold Reservoir). Smaller but significant weirs also exist on all three rivers (Gumeracha Weir, Gorge Weir, City Weir and Breakout Creek Weir (Torrens), Warren Reservoir, Woodlands Weir and Gawler Weir (removed by the time of writing) on the South Para, and Clarendon Weir on the Onkaparinga.

In addition, large volumes of rainfall and catchment run-off are captured in farm dams in upper catchment areas, ensuring that small flows in particular do not flow through natural landscape pathways into creeks and rivers (Teoh 2002). As a result, stream hydrology in the Mount Lofty Ranges has largely shifted from flows resulting from rainfall and catchment runoff toward managed flow transfers between water storages. These transfers utilise some stream reaches but are often moved through an extensive pipeline network that diverts river flows to water storages outside of the catchment such as the Millbrook and Hope Valley Reservoirs. Furthermore, large volumes of



water are piped into MLR catchments from the Murray River, flowing through streams and rivers in the upper catchment into storages.

As a result, stream sections are impacted variously by either highly managed flow releases driven by water usage patterns and human demand, or have been cut off from natural catchment flows which are captured and diverted upstream above water storages. The former scenario has resulted in some river reaches that flow independently to catchment rainfall patterns and a highly altered flow regime. The latter scenario has resulted in river reaches that possess very low flow rates compared to pre-regulation and often have important components of their flow regime missing or greatly reduced; relying entirely on local rainfall and runoff to provide surface flows except during very large events that overtop dams and weirs. In both situations, regulation has lead to changes in the magnitude, frequency, duration and timing of river flows, all of which are critical components of riverine flow regime, and key mechanisms driving riverine ecosystems (Poff *et al.* 1997). These ecosystems and associated aquatic biota are often highly dependent on specific aspects of natural flow regime. Conversely, specific aspects of the altered flow regime are detrimental to these ecosystems.

1.3. Flow Ecology and fish in the WMLR

Flow regime determines the physical structure of riverine habitats and provides connectivity between catchment components both longitudinally, connecting upstream and downstream reaches, tributaries, estuarine and marine systems, and laterally, connecting to floodplains and off channel wetlands and lakes. Critically, many aquatic organisms have evolved life history strategies that rely directly on specific components of the natural flow regime and on patterns of longitudinal and lateral connectivity (Bunn and Arthington 2002; Lloyd *et al.* 2003). In particular, native fish species are dependent on a wide range of flow regime components having evolved to survive within the highly variable and often harsh conditions within Australia's waterways (Puckridge *et al.* 2000; Lloyd *et al.* 2003; Lintermans and Cottingham 2007).

Flow magnitude controls inundation of floodplains and connection across aquatic habitats, and native fish have evolved to utilise high magnitude flows for migrating long distances along rivers, for moving into and out of floodplain and wetland habitats and for migrating to and from the sea both as adults and as larvae or juveniles. The duration of these flows is also critical to provide connectivity across these habitats for long enough so that these life history functions can be completed, to generate appropriate ecological processes such as macrophyte growth and the production of abundant food resources during wetland inundation (Zeug and Winemiller 2008), for diadromous migrants to move long distances from the sea to upper catchment habitats (McDowall 1988; Mackay 2008; McNeil *et al.* 2009), or for freshwater species to move to spawning grounds and return to adult habitats without being stranded. Timing and seasonality of flow is often critical



for native fishes which have evolved very specific seasonal spawning, migrational and recruitment traits linked to the peculiarities of the Australian climate and flow regime (McNeil and Hammer 2007).

Diadromous fish are often highly dependent on autumn and/or spring flows to allow larvae and adults to move out to sea and return to freshwater habitats later in the year. Pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) live in the sea as adults but return to freshwater habitats where they spawn and where larval and juvenile life stages develop and grow before returning to the sea as adults (Potter 1970). Galaxiid species such as common galaxias (*Galaxias maculatus*) and climbing galaxias (*G. brevipinnis*) rely on autumn flows for newly spawned larvae to move out to sea and on spring flows for those fish to move back into freshwater catchments (McDowall 1988).

At even finer scales, climbing galaxias also rely on multiple pulses of flow during autumn for spawning, development and hatching of eggs which are spawned during a high flow event but require subsequent inundation a couple of weeks later to hatch and migrate to sea; Mountain galaxias require flows that maintain cool, well oxygenated water, minimising stagnation during dry periods (O'Connor and Koehn 1998). Therefore, multiple aspects of flow regime such as magnitude, timing, duration and frequency, all combine to support critical life history functions in Australia's freshwater fish. These relationships demonstrate the intricate linkages between very specific flow components and the long term survival and viability of native fish populations in coastal waterways.

Rivers with a greatly changed flow regime often possess depauperate and less diverse native fish communities and are susceptible to becoming dominated by species – mostly introduced – which are better adapted to the changed regime (Marchetti *et al.* 2004). A number of introduced fish species have become well established within the WMLR, including voracious predators such as brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and redfin perch (*Perca fluviatilis*) as well as tench (*Tinca tinca*), goldfish (*Carassius auratus*), common carp (*Cyprinus carpio*) and gambusia (*Gambusia holbrooki*) (McNeil and Hammer 2007).

Recent research into redfin perch in the WMLR has suggested that this species is a predator of native fishes but that harsh summer conditions and diverse macro-invertebrate assemblages may ease predation pressure on native fish as long as flow regime and native riparian and in-stream habitat condition is in fairly natural condition (Wilson *et al.* 2008). Victorian research also suggests that brown trout predation can similarly be restricted under natural flow regime where summer temperatures become high (Closs and Lake 1996). Carp appear to prosper under both regulated and variable flow conditions especially when linked to large floods, however, numbers have decreased significantly in relation to the current low flow conditions associated with drought (McNeil *et al.* 2011a). Gambusia may be disadvantaged under natural flow regimes that support



increased native fish biodiversity (McNeil 2004), and as a still water specialist they may also be flushed downstream under high flows (Meffe 1984). The ecology of other introduced species regarding flow regime is poorly understood.

Given that all freshwater fish species present in the WMLR are unable to survive periods of desiccation i.e. they have no special adaptations to survive drying of their pool habitat (Bunn and Arthington 2002; McNeil *et al.* 2011b), flows provide habitat and prevent declines in water quality that can reach lethal levels within isolated waterholes under inadequate flow regimes (McNeil and Closs 2007). In this way, the duration of very low or zero flow periods is critical for the survival of native fish, particularly during harsh climatic conditions such as during drought, or under extreme levels of river regulation, such as exist in most river reaches in the MLR (McNeil and Hammer 2007; McNeil *et al.* 2009). However, low flow periods are an important aspect of natural flow regime that may control introduced predatory and competitive species many of which are relatively intolerant to naturally harsh summer conditions in Australian waterways (Closs and Lake 1996; McNeil 2004; McNeil and Closs 2007).

1.4. Environmental Water Provisions in the WMLR

From 1996 to 2010 south-eastern Australia was subject to perhaps the worst drought since European colonisation (Murphy and Timbal 2008). This “millennium” mega-drought has provided a significant disturbance to a wide range of freshwater ecosystems and biota (Lake 2003; Bond *et al.* 2008) and has resulted in reduced rainfall, run-off and river flows; extended zero flow periods; reduced water quality; and, large scale desiccation of broad catchment areas, all of which are exacerbated by the existing disturbance imposed by anthropogenic impacts such as water extraction and flow regulation (Bond *et al.* 2008; McNeil *et al.* 2011b).

In the MLR, the increasing impacts of drought and high levels of river regulation led to the development of management actions and plans to address the decreasing level of freshwater flows, particularly in river reaches that were considered to possess high ecological value (Pikusa and Bald 2005b). In the Onkaparinga River, a significant effort was directed towards identifying the environmental water requirements of the catchment (SKM 2003). This included consideration of local native fish (SKM 2002) with a view to developing Environmental Water Provisions for the delivery of environmental flows (Gatti *et al.* 2005).

In 2005, all surface water, watercourses and groundwater in the MLR were prescribed by the Minister for Environment and Conservation, increasing the need for accurate assessment of environmental water requirements and effective mechanisms for delivering environmental water provisions. In response, a trial for delivering Environmental Water Provisions (EWP) was developed to apply environmental flow releases in a number of reaches across the South Para, Torrens and Onkaparinga Rivers (Pikusa and Bald 2005b).



This EWP program provided collaboration between the Department of Water, Land and Biodiversity Conservation (DWLBC, now the Department for Water or DFW) and the newly formed Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLRNRMB), in co-operation with SA-Water and the SA Murray-Darling Basin NRM Board. The EWP project planned trial flow releases from the South Para Reservoir, Gumeracha and Gorge Weirs on the Torrens and Clarendon Weir on the Onkaparinga River. Flow trials were divided into baseflow, freshening flows and flushing flows acknowledging the differential requirements of the environment for varying flow magnitude and timing, with volumes differing across target catchments in line with existing and historic flow volumes, and catchment capacity (Pikusa and Bald 2005b).

As well as developing plans and infrastructure for the delivery of environmental water provisions, this program sought to improve understanding of the ecological systems in target reaches and to assess the responses of aquatic biota to freshwater flows, particularly to flow releases delivered under the EWP trial. To this end, DWLBC and the AMLRNRMB commissioned projects to assess baseline ecological and biological knowledge regarding the four planned target reaches: the South Para River downstream of the South Para Reservoir; the River Torrens downstream of Gumeracha Weir and downstream of Gorge Weir; and the Onkaparinga River downstream of the Clarendon Weir.

The sustainability of native fish populations, their flow requirements and their responses to freshwater flow releases were selected as key indicators for ecological condition and to demonstrate environmental outcomes of the planned flow releases. A review of biological information regarding freshwater fishes of the Mount Lofty Ranges was produced (McNeil and Hammer 2007) and a project developed to collect baseline data on native fishes within target river reaches. This project would provide valuable 'before data' to support data collected during and after the delivery of environmental flows, improving the capacity to assess the outcomes of flow releases.

This project was designed to provide a long term monitoring strategy that would inform government and natural resource managers on the environmental outcomes of environmental flow provisions and identify potential failures and future directions to improve planning and design of highly efficient and effective environmental watering activities. Whilst the first trial flows under the EWP program were planned for spring 2007, drought contingency policies delayed planned EWPs indefinitely, and they have not yet been delivered under ongoing drought conditions, regardless of drought contingency EWP plans being adapted by the AMLRNRMB and DWLBC (Bald and Scholz 2007a).

Despite the postponement of EWP releases, the fish monitoring program continued to collect valuable baseline data which would be compared to post-flow data and improve the resolution and power of subsequent monitoring and evaluation activities. Prior to postponement however, a trial



flushing flow was released from Clarendon Weir during 2006 to test the delivery capacity and infrastructure (P. Schultz, AMLRNRMB, Pers. Comm.).

A key focus of the current project is to ascertain the status and general ecology of native fish within these reaches. Very little comprehensive ecological work has been conducted on fishes within the WMLR prior to this project. Most research has focused on distributional inventories of fish species within single catchments. Inventory 'snapshots' have been undertaken within the Torrens and Patawalonga catchments as part of the Adelaide Hills fish inventory for the Torrens Catchment Water Management Board, during 2004 (Hammer 2005) and in the Onkaparinga catchment for the Onkaparinga Catchment Water Management Board during 2001/2002 (SKM 2002).

Other spot surveys have been carried out in the Broughton, Light, Gawler and Wakefield catchments in the north (Hicks and Sheldon 1998; 1999c; b; a; Lloyd 2000; Lloyd 2001) and at single sites at Breakout Creek on the Torrens (Gray *et al.* 2005) with desktop reviews collated from existing published and unpublished observations for the Torrens catchment (Hicks and Hammer 2004) and the Onkaparinga estuary (Hammer 2006).

A comprehensive review of species distribution records was presented in (McNeil and Hammer 2007), based on records from state government agencies, the SA museum, Adelaide University, Native Fish Australia surveys and private collections as well as published records and data. Only a small amount of information is available from the Gawler River catchment (Hicks and Sheldon 1999b), except for a study of redfin perch and their impact on flathead gudgeon (*Philypnodon grandiceps*) that was conducted within the EWP target reach in the South Para River as part of the current project (Wilson *et al.* 2008). A summary of recent fish species records from each of the three EWP target catchments prior to the current project is presented below in Table 1.



Table 1. List of native and introduced species recorded in the Western Mount Lofty Ranges in the three target rivers (P=present knowledge base prior to this study).

Common Name	Scientific Name	South-Para	Torrens	Onkaparinga	Record Reliability
Pouched lamprey	<i>Geotria australis</i>	P	P	P	3
Shortheaded lamprey	<i>Mordacia mordax</i>	P	P	P	3
Freshwater catfish	<i>Tandanus tandanus</i>		P		3*
Smelt	<i>Retropinna semoni</i>			P	1
Climbing galaxias	<i>Galaxias brevipinnis</i>	P	P	P	3
Common galaxias	<i>Galaxias maculatus</i>	P	P	P	3
Mountain galaxias	<i>Galaxias olidus</i>	P	P	P	3
Murray rainbowfish	<i>Melanotaenia fluviatilis</i>		P		3*
Small-mouthed hardyhead	<i>Atherinosoma microstoma</i>		P	P	3
Murray cod	<i>Maccullochella peelii</i>		P		1*
Murray-Darling Golden perch	<i>Macquaria ambigua ambigua</i>			P	1*
Silver perch	<i>Bidyanus bidyanus</i>		P		1*
Barramundi	<i>Lates calcarifer</i>		P		3*
Congolli	<i>Pseudaphritis urvillii</i>	P	P	P	3
Midgley's carp gudgeon	<i>Hypseleotris</i> sp. 1		P		3*
Southern purple-spotted gudgeon	<i>Mogurnda adspersa</i>		P	P	2
Flathead gudgeon	<i>Philypnodon grandiceps</i>	P	P	P	3
Dwarf flathead gudgeon	<i>Philypnodon macrostomus</i>		P	P	3*
Western blue spot goby	<i>Pseudogobius olorum</i>		P	P	3
Goldfish	<i>Carassius auratus</i>	P	P		3**
Common carp	<i>Cyprinus carpio</i>	P	P		3**
Tench	<i>Tinca tinca</i>	P	P	P	3**
Rainbow trout	<i>Oncorhynchus mykiss</i>	P	P	P	3**
Brown trout	<i>Salmo trutta</i>	P	P	P	3**
Brook trout	<i>Salvelinus fontinalis</i>				1**
Gambusia	<i>Gambusia holbrooki</i>	P	P	P	3**
Redfin perch	<i>Perca fluviatilis</i>	P	P	P	3**

Sources: Hammer and Walker 2004, Hicks and Hammer 2004, Gray *et al.* 2005, Hammer 2005, Hammer 2006, McNeil and Hammer 2007.

* represents translocated species

** represents introduced species

Record reliability scale 1 = possible misidentification or very old record
 2 = reliable observation but no recent observation
 3 = reliable recent observation



1.5 Aims

This report outlines the findings of the first three years of the long-term fish monitoring project, provides baseline data on the status and ecology of native fishes within EWP trial reaches and informs the relationship between natural flow variability and fish ecology. The report also aims to provide knowledge regarding the flow responses of native and introduced fishes, informing the development of effective and efficient flow release strategies and to providing optimal benefit to the environment within the limited water volumes available. The project is not explicitly designed, however, to define the environmental water requirements and flow targets for native fish, but rather to provide the baseline knowledge from which these definitions and metrics may be derived.

The specific aims of the project were:

1. To implement and trial the long term fish monitoring strategy outlined in McNeil and Hammer (2007) within EWP target reaches;
2. To assess the baseline ecological structure and condition of native fish communities in EWP target reaches and update information presented in McNeil and Hammer (2007);
3. To identify issues that relate to the sustainability of native fishes within EWP reaches;
4. To inform management of the environmental water requirements pertaining to native fishes in the Western Mount Lofty Ranges; and
5. To inform the development and improvement of environmental watering strategies to optimise environmental outcomes.



2. METHODS

2.1. Site descriptions

Surveys were conducted within each of the four EWP target reaches, immediately downstream of the flow release points, across three river catchments. The South Para River was surveyed downstream of South Para Weir; the Torrens was sampled in two reaches, the first downstream of the Gumeracha Weir in the upper catchment and the second downstream of the Gorge Weir in the lower catchment. The Onkaparinga River was surveyed downstream of Clarendon Weir (Figure 1).

2.1.1. South Para River

The South Para River is located approximately 60 km to the north-east of Adelaide, beginning near Mount Crawford on the western slope of the Mount Lofty Ranges (Teoh 2006a). Before meeting the North Para River, the river flows north-west joining the North Para River at Gawler and flows east as the Gawler River before discharging into Gulf St Vincent (Walter 2005) (Figure 1). The natural flow regime in the South Para River has been heavily impacted by the impoundment and diversion of catchment water for domestic supply (Teoh 2006b). Four SA Water storages control the South Para catchment, namely the Warren Reservoir, the South Para Reservoir, the Barossa Diversion Weir and the Barossa Reservoir on the North Para River, into which water is diverted through the Barossa Diversion Weir (Pikusa and Bald 2005b). These water storages are controlled to provide water supplies to cater for Metropolitan Adelaide and the Northern Region. On average, 21000 ML of water per year is diverted from the catchment for water supply, 16800 ML originating from the catchment and 4200 ML sourced from the River Murray (Teoh 2006).

The study reach was located downstream of the South Para Reservoir (Figure 2) and Barossa Diversion Weir, and was located in the gorge reach encompassed by Crown land, national park (Parra Wirra) and private freehold. The gorge section has been heavily impacted by grazing and vegetation clearance since European settlement, but intact riparian vegetation remains in sections, particularly within the Para Wirra National Park and Crown land reach below the Barossa Diversion Weir (Pikusa and Bald 2005b). Within the survey reach the stream regularly dries into a series of isolated pools re-connecting primarily during significant local rainfall and large flood events such as occurred in November 2005 (Wilson *et al.* 2008). Overflows from the Barossa Diversion Weir are extremely rare and flows are derived primarily from local catchment runoff. Provision of year-round baseflow has been identified as the main environmental water requirement for this reach, which is believed to have formerly flowed perennially prior to regulation (Pikusa and Bald 2005b).



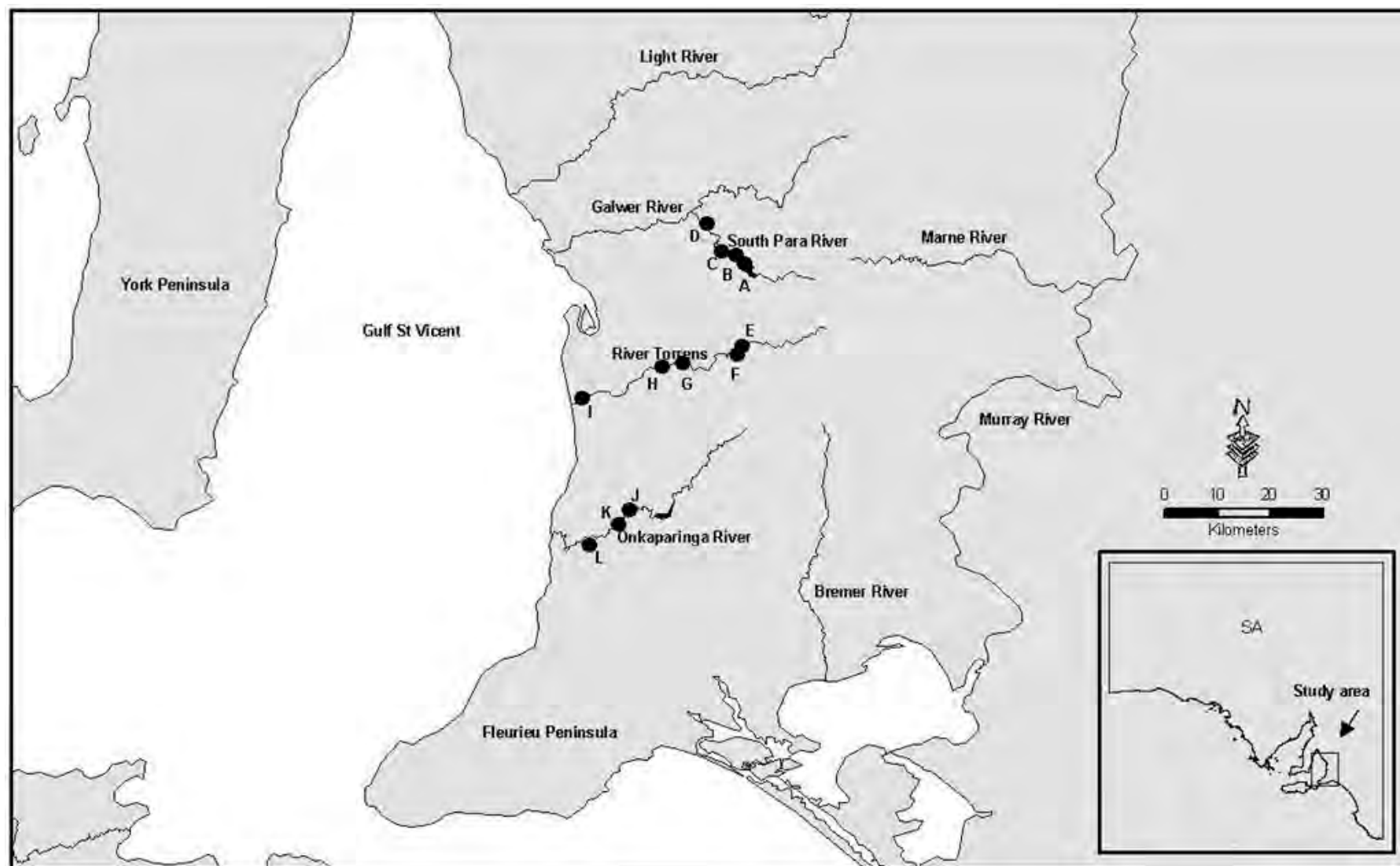


Figure 1. Map showing the location of all sample sites in the western Mount Lofty Ranges, South Australia. South Para River sites: A – South Para Weir, B – Para Wirra, C – Nolan’s, D – Woodlands Weir. River Torrens sites: E – Gumeracha Weir, F – Cudlee Creek, G – Gorge Weir, H – Silkes Rd and I – Torrens Mouth. Onkaparinga River sites: J – Clarendon Weir, K - Brooks Road, L – Old Noarlunga. Each sample site was sampled at three pools.



Figure 2. The South Para Reservoir regulating flows downstream into the study reach. The Barossa diversion weir, which is the release point for environmental flows for the south Para under the EWP program, is directly downstream of this weir.

Initially, three sites were sampled within the South Para River downstream of the South Para Reservoir (Figure 2); 'South Para Weir' was located directly downstream of the Barossa Diversion Weir, 'Parra Wirra' was located ~3km downstream within the Parra Wirra National Park and the third site, 'Nolan's' situated a further 3km downstream of the Parra Wirra sites (Figure 1).

The South Para Weir site was abandoned in year 2 in favour of adding a downstream site at Woodlands Weir due to similarities between the South Para Weir and Parra Wirra sites and the impending demolition of the Gawler Weir opening access between the sea and Woodlands Weir. Therefore, South Para Weir was surveyed in 2006 and Woodlands weir in 2007 and 2008.

At each site, three separate pools were selected for sampling (Figures 3-6, Table 2). All sites possessed similar habitat characteristics being located within the steep gorge with predominantly bedrock, cobble and gravel substrates with relatively intact but patchy riparian vegetation (poorer at Woodlands Weir). Many of the pools surveyed in the South Para Weir and Parra Wirra sites were also used for a related honours project investigating the role of redfin perch predation on flathead gudgeon (Wilson *et al.* 2008) and more regular assessments of physico-chemical and fish data are presented for some sites within that report.

Table 2. GPS co ordinates for the pools surveyed within each of the South Para River sites.

Site	Pool	Coordinates (UTM)
A - South Para Weir	1	54 H 302824 6159839
	2	54 H 302830 6160010
	3	54 H 302852 6160122
B - Para Wirra	1	54 H 301402 6161383
	2	54 H 301398 6161427
	3	54 H 301310 6161486
C - Nolan's Property	1	54 H 298573 6162010
	2	54 H 297995 6162167
	3	54 H 297800 6162163
D - Woodlands Weir	1	54 H 295447 6167085
	2	54 H 295418 6167108
	3	54 H 295138 6167016

**Figure 3. Location of the three monitoring pools at the South Para Weir site (A) on the South Para River.**



Figure 4. Location of the three monitoring pools at the Para Wirra site (B) on the South Para River.



Figure 5. Location of the three monitoring pools at Nolan's site (C) on the South Para River.



Figure 6. Location of the three monitoring pools at the Woodlands Weir site (D) on the South Para River.

2.1.2. River Torrens

The River Torrens flows through central Adelaide and suburbs and is therefore the most visible and accessible river on the Adelaide Coast. The Torrens catchment covers more than 620 square kilometres draining a large section of the western Mount Lofty Ranges before flowing westward across the Cowandilla plain and into Gulf St Vincent (Figure 1). Various groundwater systems underlay the catchment, including fractured rock aquifers in the hills areas and sedimentary aquifers on the plains (TCWMB 2005). The catchment is an important source of water for the Adelaide region supplying water for drinking supplies, agricultural industries, rural living, recreation and the environment. Natural features and drainage of the region have been greatly modified following European settlement. The River Torrens formerly fed large wetland areas to the west of Adelaide which in turn drained northwards through West Lakes and the Port River (Holmes and Iverson 1976). However, reclamation activities have led to the rapid draining of the area via Breakout Creek, a constructed conduit that drains the Lower Torrens westward into the sea at Henley Beach (Hicks and Hammer 2004; Gray *et al.* 2005). In addition, a number of weirs and reservoirs have been constructed within the Torrens catchment for the purpose of water storage.

The River Torrens is controlled by numerous reservoirs with a total storage capacity of 39 GL. River Murray water is also pumped into the Torrens at Mt Pleasant and Angas Creek to meet the demands of the public water supply (Bald and Scholz 2007a). The most significant storages are the Gumeracha Weir (Figure 7), Kangaroo Creek Reservoir, Millbrook reservoir and Gorge Weir (Figure 8), with water diverted to out of catchment storage at Happy Valley Reservoir (Pikusa and Bald 2005b). This regulation of flow in the River Torrens has led to dramatic changes in the natural flow regime of the river, impacting on timing, duration of flows as well water quality and suspended sediment characteristics.



Figure 7. Gumeracha Weir, one of the release points for EWPs in the Torrens River.



Figure 8. Gorge Weir release point.

The majority of Torrens River flows are diverted at Gumeracha Weir into Millbrook Reservoir via a tunnel. As a result, the Torrens below Gumeracha Weir has become almost completely dry except in large floods and was wet for only 121 days over the 8 yr period 1996-2003. Similarly, there have been significant reductions in flow immediately downstream of Gorge Weir. Loss of flow in these reaches has caused reductions in habitat and diversity of aquatic communities (Pikusa and Bald 2005a). Under the EWP trial program, these two reaches have been identified as priority sites for receiving environmental water allocations from SA Water reservoirs. Specifically, target reaches are the River Torrens between Gumeracha Weir and Kangaroo

Creek Reservoir (9.3km) and between Gorge Weir and the Torrens Lake (20km) (Pikusa and Bald 2005b). The principal objectives of flow provisions for these reaches are to maintain and further improve water quality, visual amenity, macroinvertebrate and fish habitat with low flows and to scour sediment build up and control encroaching vegetation with winter pulse flows (Pikusa and Bald 2005b). These objectives are currently being revised and updated (S. Gatti *pers comm*, 2011).

Two separate reaches were surveyed in the Torrens in line with the EWP target reaches, reflecting the fragmentation and differential management of individual reaches in this river system (Pikusa and Bald 2005b). In line with the project sampling design, at least two sites were selected within each reach with one site selected as close as possible to the weir/flow release point and another several km downstream. There were a total of five sites within the River Torrens. The first reach extended downstream of the Gumeracha Weir and included two sites, the first “Gumeracha Weir” was just below the weir and the second “Cudlee Creek” was downstream of the Cudlee Creek Reserve. This reach flows into the Kangaroo Creek Reservoir where water is re-captured to the system, and flows are not therefore transferred downstream of this storage.

The section of the Torrens between Kangaroo Creek Reservoir and the Gorge Weir was not surveyed due to extreme and unpredictable levels of flow regulation. The second survey reach was downstream of Gorge Weir extending through the inner north eastern suburbs of Adelaide. Two sites were selected “Gorge Weir” immediately downstream of the Gorge Weir below the water transfer pipeline, and “Silke’s Rd” a downstream site situated at the end of Silke’s road in Athelstone amid suburban development and parkland (Torrens Linear Park). A third site “Breakout Creek” was included to capture any impact of flow releases in delivering environmental services to coastal and diadromous fish populations in the lower reaches of the River Torrens and the estuarine habitat downstream of the Breakout Creek Weir (Figure 1).

The “Gumeracha Weir” site is situated approximately 1km downstream of the Gumeracha Weir wall (Table 3, Figure 9) with all three pools located within State controlled land accessed by the Gorge Rd. The Gumeracha reach lies within a highly regulated section of the Torrens and receives a high degree of Murray River water resulting in higher than usual turbidity for the catchment (Hammer 2005). Being upstream of major water storage in the Kangaroo Creek Reservoir, most of the water passing thorough the reach is for the purpose of urban and drinking water transfer, whilst upstream flows are highly regulated by large volume diversions at Gumeracha Weir. There has been some recent survey data collected from this reach, largely reported in (Hammer 2005). Those surveys have found low native biodiversity with strong presence of introduced species. The “Cudlee Creek” site is situated in the Cudlee Creek Conservation Reserve upstream of the Cudlee Creek Township (Table 3, Figure 10).

Table 3. GPS co ordinates for the pools surveyed within each of the South Para River sites.

Site	Pool	Coordinates (UTM)
E - Gumeracha Weir	1	54 H 303565 6144257
	2	54 H 303525 6144164
	3	54 H 303600 6144096
F - Cudlee Creek	1	54 H 302688 6142465
	2	54 H 302490 6142286
	3	54 H 302274 6142234
G - Gorge Weir	1	54 H 292474 6140264
	2	54 H 292383 6140187
	3	54 H 292255 6140124
H - Silke's Rd	1	54 H 288542 6139391
	2	54 H 288443 6139374
	3	54 H 288302 6139332
I - Breakout Creek	1	54 H 273633 6132520
	2	54 H 273591 6132064
	3	54 H 271546 6131289

**Figure 9. Location of the three monitoring pools at the Gumeracha site on the Torrens River.**



Figure 10. Location of the three monitoring pools at the Cudlee Creek site on the Torrens River.

The Gorge Weir reach consisted of two sites, one directly below the weir (Table 3, Figure 11) and another several kilometres downstream in suburban Athelstone at Silke's Rd (Figure 12). Whilst the Gorge Weir site is directly regulated by the weir, the reach below the site has regular levels of baseflow, largely due to tributary and stormwater inputs as well as some groundwater recharge (Pikusa and Bald 2005b).

The primary aim of EWPs in this reach is to maintain baseflows and provided permanent levels of connectivity and surface flow and to increase the frequency of flushing flows which are reduced via upstream regulation and water capture (Pikusa and Bald 2005b). This reach has been surveyed for fish previously, although most data stems from sites further downstream near the Adelaide CBD (Rowntree and Hammer 2004). Previous surveys have revealed low native species richness, dominated by translocated species and high abundances of introduced species, particularly large predatory fishes (Table 4) (Rowntree and Hammer 2004; Hammer 2005). The Silke's Rd site was located several kilometres downstream of the Gorge Weir amid suburban development in the Torrens Linear Park, and is maintained as a park by local council (Table 3, Figure 12)

Table 4. Previous Fish survey results for the Gorge Weir reach (from 1: Rowntree and Hammer 2004; and 2: Hammer 2005).

Species	Status	Source
Flathead gudgeon	Native	1,2
Blue spot goby	Native	1
Carp gudgeon	Native-translocated	1
Murray rainbowfish	Native-translocated	1
Freshwater catfish	Native-translocated	1
Goldfish	Introduced	1
Carp	Introduced	1,2
Gambusia	Introduced	1
Redfin perch	Introduced	2
Brown trout	Introduced	2

**Figure 11. Location of the three monitoring pools at the Gorge Weir site on the Torrens River.**



Figure 12. Location of the three monitoring pools at the Silke's Road site on the Torrens River.

Flows downstream of the Torrens Lake and through Breakout creek are controlled by the city weir at Torrens Lake in central Adelaide. Significantly, stormwater flows from eastern Adelaide are also directed into the Torrens River and through Breakout Creek. Although there are no current plans for delivering environmental water provisions to this reach, the assessment of fish was included for the purpose of identifying flow requirements of diadromous and estuarine fishes that may benefit from future provision of environmental water. A secondary aim was to establish the impact of the constructed fishway at the Torrens mouth in re-establishing native fish populations within this section of the River Torrens, which despite pre-European records have been absent from recent surveys (Table 5). A separate report has recently been produced presenting a more direct assessment of this fishway (McNeil *et al.* 2010b) but the current data provides an assessment of the effectiveness of the fishway in re-establishing populations of diadromous and estuarine species to this reach.

The Breakout Creek site (Table 3, Figure 13) was located within the constructed channel reach of the Torrens with sampling pools located just upstream and downstream of the Henley Beach Road Bridge. Pool 3 was located at the Breakout Creek Weir with both estuarine (below weir) and freshwater (above weir) habitats sampled depending on water levels above the weir, which often became completely dry.

Table 5. Fish Species Recorded from the lower River Torrens, downstream of city weir. Records are from: 1) Hammer (2005) (SA Museum records), 2) Gray *et al.* (2005) and 3) Scott (1962).

Species	Status	Historic records	Recent Records 1990-2006
Common galaxias	Native diadromous	1	
Short headed lamprey	Native diadromous	1	
Pouched lamprey	Native diadromous	1	1
Congolli	Native diadromous	1	
Purple spotted gudgeon	Native	1	
Flathead gudgeon	Native		1,2
Blue spot goby	Native	3	1
Carp gudgeon	Native-translocated		1,2
Murray rainbowfish	Native-translocated		1,2
Freshwater catfish	Native-translocated		1,2
Goldfish	Introduced		1,2
Carp	Introduced		1,2
Gambusia	Introduced		1,2



Figure 13. Location of the three monitoring pools at the Breakout Creek site on the Torrens River.

2.1.3. Onkaparinga River

The Onkaparinga catchment is the largest catchment area in the western Mount Lofty Ranges and is located approximately 25 km to the south-east of Adelaide (Figure 1). Covering an area of 560 km² the Onkaparinga catchment is the single largest (WMLR) contributor to Adelaide's water supply and additional water inputs come from the Murray River via a pipeline that discharges into the river near Hahndorf. The Onkaparinga provides water for domestic, agricultural, horticultural and industrial use with much of its surface water captured in farm dams, reservoirs and weirs (Kawalec and Roberts 2005). Large storages exist at the Mount Bold Reservoir and the Clarendon Weir (Figure 14) with additional off takes from Clarendon piped to Happy Valley Reservoir.



Figure 14. Clarendon Weir, the release point for lower Onkaparinga flows. This weir must be breached for upper catchment flows to reach the sea.

The construction of Mount Bold Reservoir has led to a drastic reduction in surface flows within the lower Onkaparinga downstream of Clarendon Weir with flows ceasing altogether during summer (Pikusa and Bald 2005a). In this reach, channel flows are now largely dependent upon local catchment rainfall runoff and input from a few small tributary streams, of which Kangarilla Creek is the only significant contributor, except under extreme rainfall and flow conditions when Clarendon Weir becomes breached (Kawalec and Roberts 2005). This section of the River is dominated by the Onkaparinga Gorge, much of which lies within the Onkaparinga National Park but has been historically modified for grazing. A number of large agricultural developments, in particular wineries, abstract water from pools in the main channel upstream of the park, stock impacts are also high throughout this reach. The riparian and gorge area is dominated by introduced weed species, although in sections, reasonable densities of native trees and shrubs remain, including river redgum (*Eucalyptus camaldulensis*), wattles (*Acacia* spp.), bottlebrush (*Callistemon sierberi*) and ti tree (*Leptospermum* spp.) (Nicol and Bald 2006). Below the gorge section immediately upstream of Old Noarlunga, the Onkaparinga River comes under estuarine

influence and is brackish or marine between Old Noarlunga and the sea with the principal freshwater/estuarine interface proximal to the Church Track causeway within the park.

The three fish monitoring sites in the lower Onkaparinga River are located downstream of Clarendon Weir. Sampling sites were established at 'Clarendon Oval', directly downstream of the weir; 'Brooks Road', situated within the central gorge several kilometres downstream of the weir and 'Old Noarlunga', at the foot of the gorge where freshwater reaches graduate into brackish and estuarine reaches under tidal influence, a further several kilometres downstream from Brooks Rd (Figure 15). As such, the Onkaparinga study reach covers the section between the Clarendon Weir and Onkaparinga estuary.

Table 6. GPS co ordinates for the pools surveyed within each of the Onkaparinga sites.

Site	Pool	Coordinates (UTM)
J - Clarendon Oval	1	54 H 283928 6112029
	2	54 H 284042 6111876
	3	54 H 284098 6111835
K - Brooks Road'	1	54 H 281900 6109139
	2	54 H 281803 6109080
	3	54 H 281777 6108952
L - Old Noarlunga	1	54 H 273694 6104752
	2	54 H 273188 6104393
	3	54 H 272735 6104409



Figure 15. Map showing the location of the 3 sampling sites on the Onkaparinga River. Each site consisted of three adjacent pools and interconnecting riffle/run reaches.

2.2. Field sampling design

Fish surveys were carried out twice a year, in autumn and spring of each year between April 2006 and December 2008. Surveys were conducted within each of the four EWP target reaches, immediately downstream of the flow release points, across three river catchments (see Section 2.1 for individual site descriptions). Sampling was carried out as close as possible to April (autumn) and November (spring) with all sites and catchments surveyed within a one month period.

The sampling design was based upon the monitoring framework developed in conjunction with the EWP project steering committee and presented in detail in (McNeil and Hammer 2007). The sampling design consisted of at least two sites within each of the four EWP target reaches; the first was within 1 km of each flow release point with the second positioned approximately 5 km downstream of the upstream site. In this way, data could be compared between sites that directly receive full e-flow releases, with those farther downstream that may receive lesser flow volumes from the same releases. In the Torrens and Onkaparinga Rivers, a third site was added at the very bottom of each catchment to assess the impact that e-flow releases may have on coastal and diadromous ecosystems and fish populations. In the second year of the survey, an additional downstream site was also included on the South Para River, the details of which will be discussed later.

At each site, three separate pools were selected for sampling, with all connecting riffle and run areas included if inundated. Each pool was sampled with a consistent sampling design outlined in Figure 16. Each pool was set with four small fyke nets, two large fyke nets and two double winged fyke nets placed at either end of each pool to capture any fish moving through or into the reach. Small fykes consisted of a 3 m leader and 3 m cod-end with two valves and 3 mm stretch mesh (Figure 17a), 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 (Figure 17b). 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. In earlier surveys, small bait traps were also used but this was discontinued due to similarity in catches between these and small fykes. The 'set' of fyke nets was sufficient to saturate smaller pools whilst in some larger pools nets were set to cover all major habitat types (Figure 18). In very small pools (such as during drought summers in 2007/08, the four small fykes were used as a base level of sampling with large fykes and then double winged fykes not set. This maintained a base level of comparable data across small fyke catches at each site. In extreme drying cases, very shallow pools were dip netted and/or seined using a 2 x 1 m seine net with 2 mm mesh.

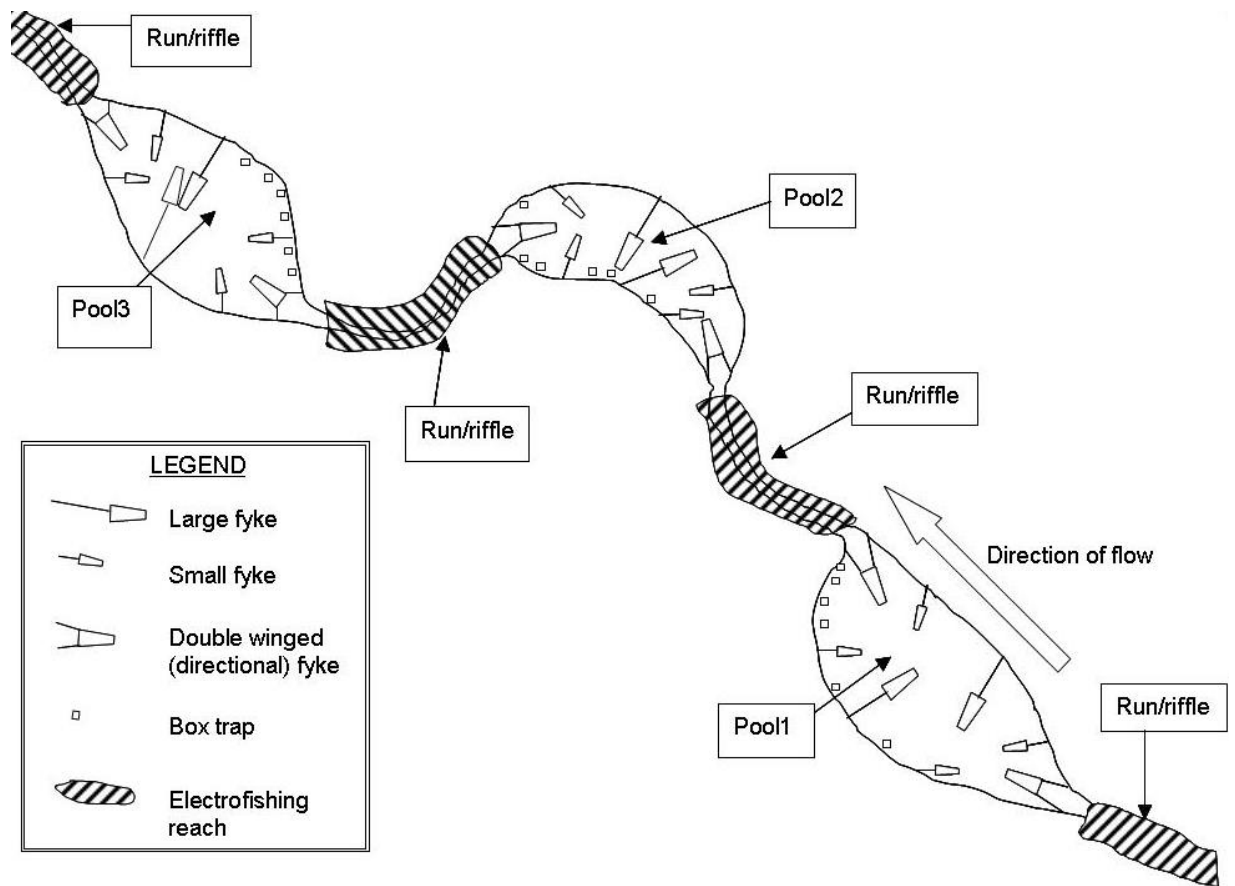


Figure 16. Site sampling design consisting of three netted pools interspersed with riffle/run reaches sampled using backpack electrofishing when inundated. Reproduced from McNeil and Hammer (2007).



Figure 17. Fyke nets used for field sampling, a) small fyke and b) double winged fyke.

At all sites areas connecting the three pools were also sampled with a backpack electrofisher consisting of four sets of 250 second shots with frequency, voltage and duty-cycle set independently based on local conditions. When connecting sections were dry, electrofishing was carried out within the nearest possible fishable sections both upstream and downstream of the reach.



Figure 18. A set of fyke nets in a pool at Brooks Rd in the Onkaparinga.

The principal focus of the sampling strategy was: a) to provide comprehensive data on species presence and b) to gain an idea of the relative abundance of fish species across sites and seasons. Each site was set for ~24 hours with a single site (i.e. three pools) set in a single day and retrieved the following day. Electrofishing was usually carried out at the same time as netting, although on some occasions, time limitations required that electrofishing was carried out up to a week after the netting survey.

All nets were emptied into holding buckets, fish were then identified and measured; breeding condition and the presence of disease or parasites was also recorded. All fish were identified and total numbers for each species was recorded. Where very large numbers of fish were collected size measurements were only taken from a sub-sample. Sub-sampling was conducted by ensuring that at least the first fifty fish of each species were measured; however in all cases, all fish within the selected net were measured, even if more than fifty were present. This ensured that sub-sampling errors did not result in very large or small individuals within a catch being neglected during measurement. Breeding condition was assessed by 'squeezing' the underbelly of each fish and recording the presence of eggs or sperm issuing from the vent. For new records or uncertain classifications, some voucher species were retained and in the case of novel species, submitted to the South Australian Museum, Adelaide. All nets were washed thoroughly in mild bleach and/or sea water between catchments to ensure against the incidental translocation of algae, parasites or pest species through contaminated netting. Snakes, turtles, water hen, ducks and water rats were occasionally collected in nets and were released unharmed at the site of capture.

2.3. Physical and chemical site characteristics

At each site a number of physical characteristics were estimated for each sampling event. Some physical characteristics were not expected to change greatly over the course of the survey including the percent cover and composition of riparian vegetation, size structure of streambed substrates, maximum depth and the number of snags within each pool. These estimates were taken each season and average values were used in site summary tables to allow for inter-sample variability in the estimation of physical values and to account for differences between subjective estimates made each season.

A number of physical, chemical and flow parameters were expected to vary across years and these were assessed independently for each sampling season. These measurements included the percent cover and composition of aquatic macrophytes, the maximum depth, dissolved oxygen, pH, salinity and water temperature as well as flow condition and antecedent flow regime.

The composition of aquatic macrophytes and riparian vegetation was determined using (Sainty and Jacobs 1994) cross checked with previous vegetation records where possible (i.e. Nicol and Bald 2006). Subjective estimates of cover were made in relation to pool surface area (e.g. area of pool surface covered by macrophytes). Whilst this was excellent for non-emergent macrophytes, assessment of emergent cover was found to vary between estimators and a protocol was developed whereby, stems protruding from the water were counted in macrophyte cover estimates, ignoring stems that may be present upon banks but not available as physical fish habitat at the time of sampling. As a result of difficulties in locating the waters edge below emergent beds, some estimates of macrophyte cover may be overestimated, particularly for cumbungi (*Typha domingensis*) and common reed (*Phragmites australis*).

Maximum depth was recorded at the same point each season using measuring tape pinned to a fyke net chain, lowered to the substrate at the deepest point in each pool (at which absolute maximum depth was recorded). Water temperature, pH, dissolved oxygen and conductivity were assessed during each sampling trip with a TPS water quality multi-meter. Water quality was measured around 15 cm below the water surface in a central part of each pool and where depth was sufficient, additional samples were taken for each parameter at 50 cm depth intervals until the probes touched the substrate. For consistent comparison, the surface water quality values only are presented in site summary tables; although in some cases results may refer to values from deeper stations. It should be noted that surface values presented are not necessarily consistent with water quality in deeper sections and that stratification will not be accounted for using these surface data. As a result, deeper waters may be more hypoxic and/or saline than values obtained at the surface and caution should be taken in using surface value only as indicative of the total volume of the pool. Flow condition was categorized for each

pool and each sampling season as either 'No flow', 'Low flow', or 'High flow' via visual assessment made at the downstream extent of survey pools. Antecedent flow conditions relate to the six month period preceding each sampling trip in an effort to capture the recent flow conditions prior to sampling for each season. Antecedent flow conditions were assessed using hydrographs provided by Water Data Services (WDS) recorded from DWLBC and AMLRNRMB hydrometric stations. These conditions were classified based on the EWP flow classes determined for each target river (Bald and Scholz 2007a) as no flow, very low flows, low flows, freshes and flushes. Additional categories were added to account for low and very low flow conditions that occurred over the sampling period. These low flow categories differentiated between small and/or infrequent periods of flow and extended periods of baseflow as set out in the EWP proposal (Bald and Scholz 2007a).

2.4. Data analysis

A multivariate statistical approach was used to investigate the relationship between fish community with flow, water quality and habitat variables. In general, the temporal variability of the existing data sets are likely to be too small to pick up large scale trends, which may be obscured by short term variables such as seasonal recruitment, abundance etc. However, the analytical approach was applied here as a trial to investigate the applicability of this approach to the long term monitoring program that is envisaged under the MLR EWP trial. In addition, the approach may reveal factors that are heavily influencing fish community structure over the three year sampling period represented in this report. As 'before' flow data, the approach can also be applied to comparing pre and post EWP data and may be useful for determining the numbers and locations of sites can be used for post flow monitoring.

Multivariate analyses of fish community data were undertaken using non-metric multidimensional scaling (NMDS); i.e. a means to cluster similar sites with similar fish communities. NMDS was performed using PC-ORD v.5.12 (McCune and Mefford 2006) (Bray-Curtis (1957) distance measure, 40 real runs, 400 iterations). Measured environmental variables, water quality parameters, and flow metrics such as maximum flow, average and total flow were correlated to the axes of the NMDS to identify which variables co-vary with fish community. NMDS data was plotted with environmental variables that correlated with fish assemblage axes at an R-squared value of greater than 0.1. Analysis was conducted independently for each EWP reach and plots presented show the relationship across pools and sites based on fish community data, with correlated vectors representing the degree and direction of influence that they have on the data.

3. RESULTS

3.1. South Para River

The fish community in the South Para River showed the lowest species richness of the three target catchments with nine species caught in total throughout the survey (Table 7). Only four of the seven expected native species were caught with five introduced species present.

The distribution of species in the South Para River varied along a longitudinal gradient. Only flathead gudgeon and redfin perch were present throughout the steep gorge section upstream of Nolan's extending to the Barossa Diversion Weir at the top of the reach. Downstream of Parra Wirra at Nolan's, gambusia became a significant component of the fish assemblage, and although not caught in the main river channel, mountain galaxias were also captured in the Tenafeate Creek tributary.

The presence of only two species, redfin perch and flathead gudgeon, upstream of Nolan's led to the inclusion of a downstream site at Woodlands weir in year two. At Woodlands Weir, introduced tench, goldfish and carp were caught. Two native diadromous species in common galaxias and congolli were notable records, however both were reportedly translocated into the reach from below Gawler Weir during spring 2006 by the "Friends of the Gawler River" (Adrian Shackley, FOTGR, pers. Comm.).

NMDS orders sites that are characterized by multiple species so that similar sites are near each other and dissimilar sites are farther from each other. The relationships between the sites are then characterized graphically on the NMDS plot. Environmental covariates can then be overlain on the NMDS plot to explore relationships between species distribution and environmental variables. Patterns in the South Para fish community in the NMDS were associated with a weak salinity gradient upstream to downstream with a coefficient of determination (R^2) greater than 0.1 (Figure 19) but data deficiencies in the hydrograph meant that no strong relationship was established between flow and fish community. In other words, there were no flow correlates and only salinity (and a very weak temperature relationship) that were capable of explaining 10% of the variation in fish assemblage. This was largely due to the small number of replicates and the lack of contrast in the flow regime. There was a strong distinction between the upstream sites (South Para Weir and Para Wirra) and the downstream sites (Nolan's and Woodlands Weir) based primarily around the presence or absence of gambusia.

Table 7. Taxa which were present (P) and spawning (^s) for each site and season in the South Para River. The columns of native freshwater fish taxa are shaded green, those of exotic taxa shaded red and those of marine/estuarine taxa shaded blue.

Site	Sampling Season *	Common galaxias	Mountain galaxias	Flathead gudgeon	Gambusia	Redfin perch	Goldfish	Carp	Tench	Congolli
South Para Weir	2006A			P		P				
	2006S			P		P				
Para Wirra	2006A			P		P				
	2006S			P ^s		P				
	2007A			P						
	2007S			P		P				
	2008A			P		P				
	2008S			P		P				
Nolan's	2006A		P	P	P	P				
	2006S			P	P	P				
	2007A	P		P	P	P				
	2007S			P	P	P				
	2008A			P	P	P				
	2008S			P	P	P				
Woodlands Weir	2007A	P ^s		P	P					P
	2007S	P		P	P		P	P	P	P
	2008A	P		P	P					
	2008S	P		P	P		P			P

* A – Autumn, S – Spring

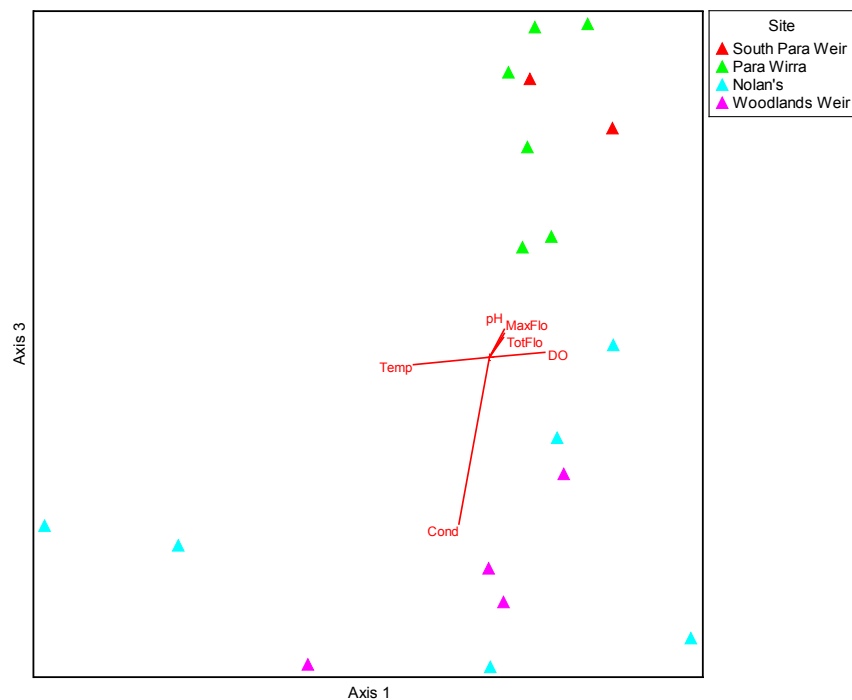


Figure 19. NMDS ordination of fish communities in the South Para River from autumn 2006 to spring 2008, overlain with correlated environmental vectors ($R^2 > 0.1$) and labelled by site.

3.1.1. South Para Weir

3.1.1.1. Site assessment

The South Para Weir site was located between the Plum Quarry track and the Barossa Diversion Weir, immediately downstream of the EWR flow release point. This site was dominated by dense riparian vegetation primarily of bottlebrush and redgum, and possessed a substrate dominated by bedrock and cobbles with mud present only at Pool 1 (Table 8). This site was somewhat difficult to access due to weeds and riparian vegetation and steep valley sides.

Table 8. Habitat characteristics of the three monitoring pools at South Para Weir in the South Para River.

South Para Weir	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	10+	25	1	2.5
Pool 2	10+	30	0	1.5
Pool 3	10+	60	0	1.2

Pool 1 was the deepest pool in the South Para Weir site. It was surrounded by dense riparian vegetation primarily of bottlebrush and redgum, and possessed a substrate dominated by bedrock and cobbles with some soil banks (Figure 20). Floods in November 2005 had scoured *Phragmites* beds and there were weeds rapidly regenerating in autumn 2006. Since that flood, there was very little flow before the autumn or spring 2006 surveys and there was no flow at the time of each survey. The pool had stable dissolved oxygen, pH and temperature for both surveys, while salinity almost doubled between the two surveys (Table 9).



Figure 20. South Para Weir Pool 1 in spring 2006.

Table 9. Water quality parameters recorded in South Para Weir Pool 1 during each survey

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	6.9	660	7.7	13	2.5	0	No flow	Flush, very low flow
2006	spring	9	1141	8	21.1	2.0	0	No flow	Low flow

Pool 2 was shallower, surrounded by dense riparian vegetation primarily of bottlebrush and redgum, and possessed a substrate dominated by bedrock and cobbles (Figure 21). After the November 2005 flood, there was very little flow before the autumn or spring 2006 surveys and there was no flow at the time of each survey. The pool had stable dissolved oxygen, pH and temperature for both surveys, while salinity almost doubled between the two surveys (Table 10).

**Figure 21. South Para Weir Pool 2 in Spring 2006.****Table 10. Water quality parameters recorded in South Para Weir Pool 2 during each survey**

Pool 2	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	7.4	710	6.9	13.2	1.5	0	No flow	Flush, very low flow
2006	spring	8.2	1349	7.8	21.8	0.6	0	No flow	Low flow

Pool 3 was shallower again, surrounded by dense riparian vegetation primarily of bottlebrush and redgum, and possessed a substrate dominated by bedrock and cobbles covered in thick algae (Figure 22). After the November 2005 flood, there was very little flow before the autumn or spring 2006 surveys and there was no flow at the time of each survey. The pool had stable dissolved oxygen, pH and temperature for both surveys, and salinity had a moderate increase between the two surveys (Table 11).



Figure 22. South Para Weir Pool 3

Table 11. Water quality parameters recorded in Para Weir Pool 3 during each survey

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	9.9	581	7.8	14.2	1.2	0	No flow	Flush, very low flow
2006	spring	11	889	8.8	18.8	0.7	0	No flow	Low flow

3.1.1.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.1.1.3. Hydrology

The water level was low for both surveys conducted at this site in autumn 2006, on May 10 and spring 2006, conducted on November 7. The survey pools were disconnected during both surveys. The gauge at South Para Weir was damaged during high flows in November 2005 and no hydrological data was available over the duration that the present surveys were being conducted.

3.1.1.4. Fish community

Only two fish taxa were captured at South Para Weir during the two surveys conducted at this site, in autumn 2006 and spring 2006 (Figure 23). In autumn 2006 redfin perch were more commonly captured than flathead gudgeon, but in spring 2006 this dominance pattern was reversed. Surveying of South Para Weir was discontinued after 2006, as the species poor fish community at this site was similar to that at Para Wirra.

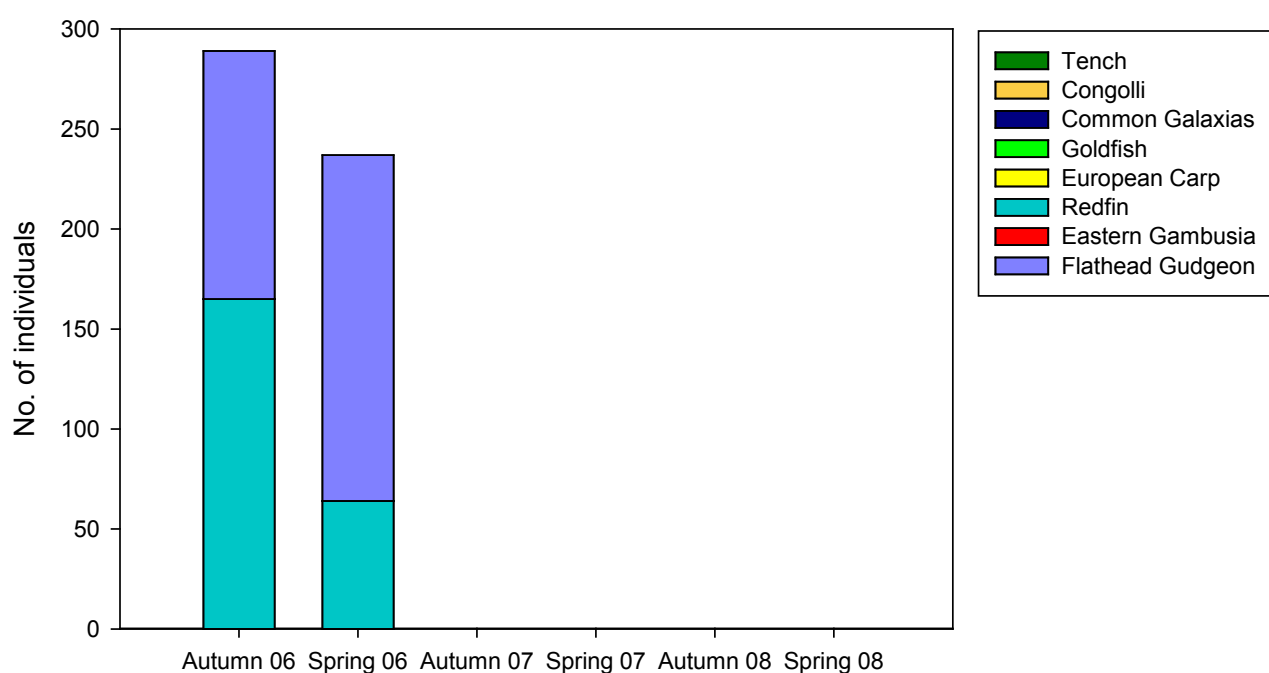


Figure 23. Abundances of each taxa present in the fish communities at South Para Weir over two survey seasons. Surveys were discontinued at this site after spring 2006.

3.1.2. Para Wirra

3.1.2.1. Site assessment

Para Wirra sites were relatively inaccessible and as a result, riparian vegetation was largely intact and was perhaps the most 'natural' in condition of any of the survey sites. Riparian stands of bottlebrush and redgum overhung most pools, although due to the predominance of bedrock and cliff edges on pool margins, large sections were naturally devoid of riparian vegetation, and riparian cover was consistently at around 30% (Table 12). Substrate ranged from cobble and gravel in Pool 1 with increasing bedrock in Pool 2 and predominantly bedrock in Pool 3. Pools increased in depth in a downstream fashion with Pool 1 shallowest and Pool 3 deepest. Snags were not present in any of the pools.

Table 12. Habitat characteristics of the three monitoring pools at Para Wirra in the South Para River.

Para Wirra	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	10+	25	0	1.2
Pool 2	Bedrock-10+	30	0	2.0
Pool 3	Bedrock-10+	30	0	2.5

Pool 1 (Figure 24) was the shallowest of the three Parra Wirra pools with water depth fluctuating widely between seasons, ranging from 1.2m when full to 0.5m during dry periods (Table 13). Although marginally salty, dissolved oxygen and pH were fairly consistent with only slight acidity occurring in spring 2007. This pool had a tendency to become very warm in spring; with temperature rising above 30°C in spring 2007 associated with low pH and slightly reduced oxygen levels.

There were no macrophytes in this pool and stream flows were recorded only in the autumn 2007 and 2008 surveys. Antecedent hydrology was predominantly very low flows with the exception of large flushes in autumn 2006 and low flows prior to autumn 2008. Pool 1 was a watering spot for kangaroos and red-bellied black snakes were commonly found in the water or on rocks and occasionally caught in fyke nets.



Figure 24. Para Wirra Pool 1 in a) spring 2007 and b) autumn 2008.

Table 13. Water quality parameters recorded in Para Wirra Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1030	8	12.1	0.5	0	No flow	Flushes
2006	spring	10	2201	8	23.0	1.2	0	No flow	Very low flows
2007	autumn	10	700	8	13.4	1.2	0	Low flow	Very low flows
2007	spring	6	1767	5	30.5	0.7	0	No flow	Very low flows
2008	autumn	11	900	8	16.7	1.2	0	Low flow	Low flows
2008	spring	7	1323	8	21.9	0.5	0	No Flow	Very low flows

Pool 2, situated on a sharp bend was bordered by sharp bedrock cliff on the outside (right) bank with sand and rocks on the depositional inside bank (Figure 25). Whilst a deep hole (up to 2 m) was present under the cliff, the depth across the pool was generally no more than 1 m. The

maximum depth fluctuated across seasons becoming as shallow as 0.5 m during the dry spring of 2007 (Table 14).

Salinity fluctuated throughout the study, becoming mildly saline during spring each year and also in autumn 2008. Temperatures became moderately warm in spring but did not peak as sharply as Pool 1. Pool 2 became somewhat acidic during spring 2007, as with Pool 1 during the dry summer of 2007. A few very small individual *Vallisneria* (ribbon weed) were present in 2006 in the shallower area at the downstream end of the pool, but subsequently disappeared from the pool. Stream flows were recorded only in the autumn 2007 and 2008 surveys and antecedent hydrology was predominantly very low flows with the exception of large flushes in autumn 2006 and low flows prior to autumn 2008.

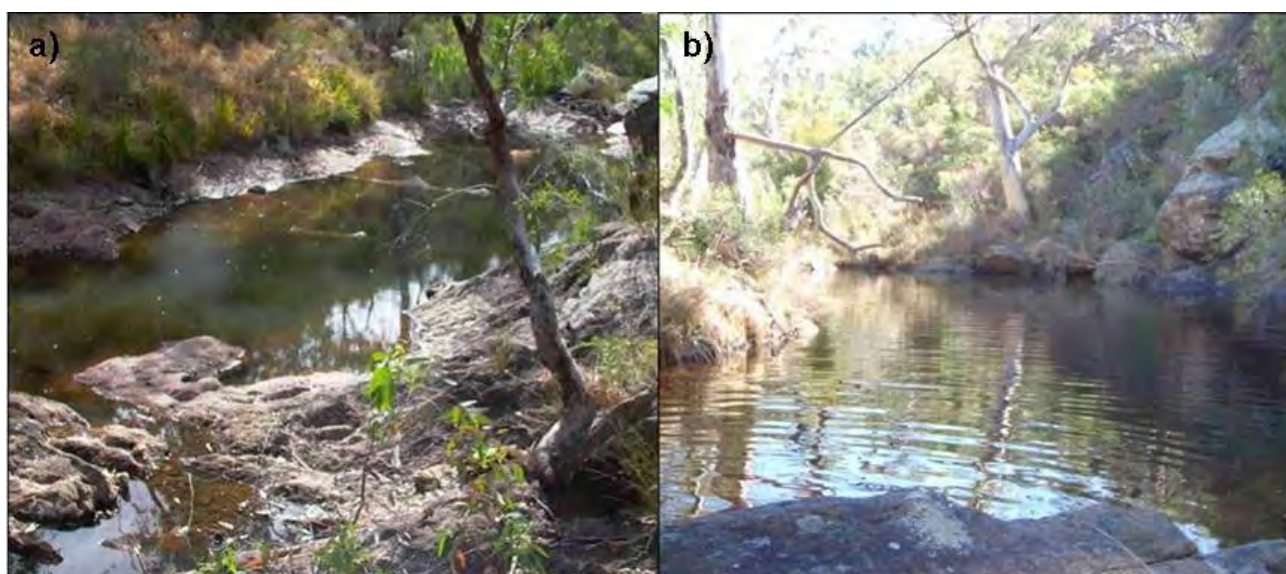


Figure 25. Para Wirra Pool 2 in a) spring 2007 and b) autumn 2008.

Table 14. Water quality parameters recorded in Para Wirra Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1130	8	12.3	2.0	0.5	No flow	Flushes
2006	spring	9	2060	8	22.2	0.6	0.1	No flow	Very low flows
2007	autumn	9	689	8	14.2	1.8	0	Low flow	Very low flows
2007	spring	8	1816	5	24.6	0.5	0	No flow	Very low flows
2008	autumn	12	1400	8	16.3	1.5	0	Low flow	Low flows
2008	spring	8.6	1293	8.1	21.3	0.8	0	No flow	Very low flows

Pool 3 (Figure 26) was the largest and deepest and coolest (Table 15) of the three Parra Wirra pools with a vertical bedrock cliff forming the inside (left) bank and rock and mud forming the right bank, increasing at the downstream end of the pool. Pool depth fluctuated between 2.5m in autumn and ~1m in spring (Table 15), with deep holes present under the cliff face but a depth of 1-1.5 m was more common across the pool.

Conductivity was consistently over 1000 $\mu\text{S}/\text{cm}$ becoming fresher in autumn 2007. Pool 3 also became acidic during the spring of 2007. *Vallisneria* was present at the downstream end of the pool where siltation was highest although macrophyte cover was never high. Similar to Pool 1 and Pool 2 stream flows were recorded only in the autumn 2007 and 2008 surveys and antecedent hydrology was predominantly very low flows with the exception of large flushes in autumn 2006 and low flows prior to autumn 2008.



Figure 26. Para Wirra Pool 3 in a) spring 2007 and b) autumn 2008.

Table 15. Water quality parameters recorded in Para Wirra Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1435	8	12.5	2.5	5	No flow	Flushes
2006	spring	8	1970	8	16.8	0.7	1	No flow	Very low flows
2007	autumn	9	688	8	14.8	2.5	0	Low flow	Very low flows
2007	spring	7	2065	4	23.2	1.0	0	No flow	Very low flows
2008	autumn	8	1100	6	15.8	2.5	5	Low flow	Low flows
2008	spring	7.95	1510	7.6	21.7	1	0	No Flow	Very low flows

3.1.2.2. Water Quality

The acidification of pools during extremely low flows in 2007 is likely to impact on fish health as levels recorded here can cause damage to gill tissues and lead to an inability to cope with hypoxic episodes and in extreme cases to suffocation (Gehrke *et al.* 1993). Salinity was frequently high enough to impact on sensitive invertebrate species, but all levels recorded are suitable for the maintenance of native fish.

3.1.2.3. Hydrology

The water level at Para Wirra was low throughout the survey period, and connectivity between the sites was intermittent. The survey pools were disconnected during autumn and spring 2006. The same pattern was followed in 2007 and 2008, where low flows reconnected the pools in autumn followed by a disconnection in spring.

There was no recordable flow at Para Wirra from September 8, 2006, to spring 2006, on November 10 (Figure 27). This lack of flow continued over summer and to late April 2007. There were very low flows during the first week of May, followed by two weeks of no recordable flow, and another three days of very low flows (<1 ML/day) immediately prior to the autumn 2007 surveys, conducted on May 24. Over winter the flow was very low, only rarely exceeding 1 ML/day and with a number of weeks in which no flow was recorded.

From late August until the spring 2007 surveys, conducted on December 12, there was no flow recorded at the Para Wirra gauge. Flows did not resume at the site until the end of April, but this flow was only a brief pulse, and there was no recordable flow during the week immediately prior to the autumn 2008 surveys, conducted on May 9. Low flow resumed in July 2008, ceased in October 2008 and did not recommence by the time of the final survey November 25.

3.1.2.4. Fish community

Only two species of fish were captured at Para Wirra (Figure 28). Large numbers of the native flathead gudgeon were captured during each of the first four surveys, from autumn 2006 to spring 2007. Changes in community structure amongst pools and survey seasons were largely driven by fluctuations in the numbers of these fish. The largest total numbers of flathead gudgeon occurred during autumn 2006 and spring of both 2006 and 2007, when the pools were not flowing. In contrast, higher numbers of redfin perch were recorded during autumn and spring 2008.

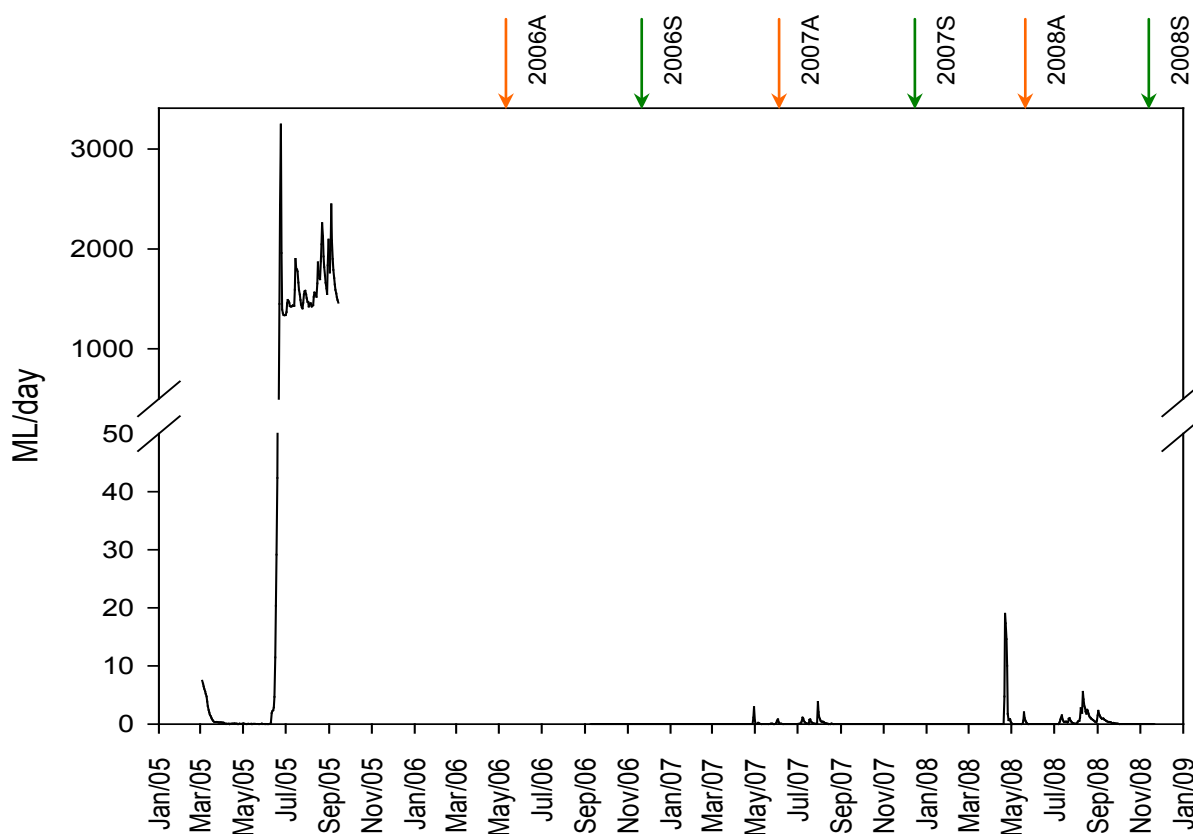


Figure 27. Hydrograph for flow in South Para River at Para Wirra. Flow data (ML/day) was collected downstream of Para Wirra Recreational Park (gauge number A5051003) from September 8, 2006 (indicated by blue arrow). The timing of each survey season is also shown above the figure.

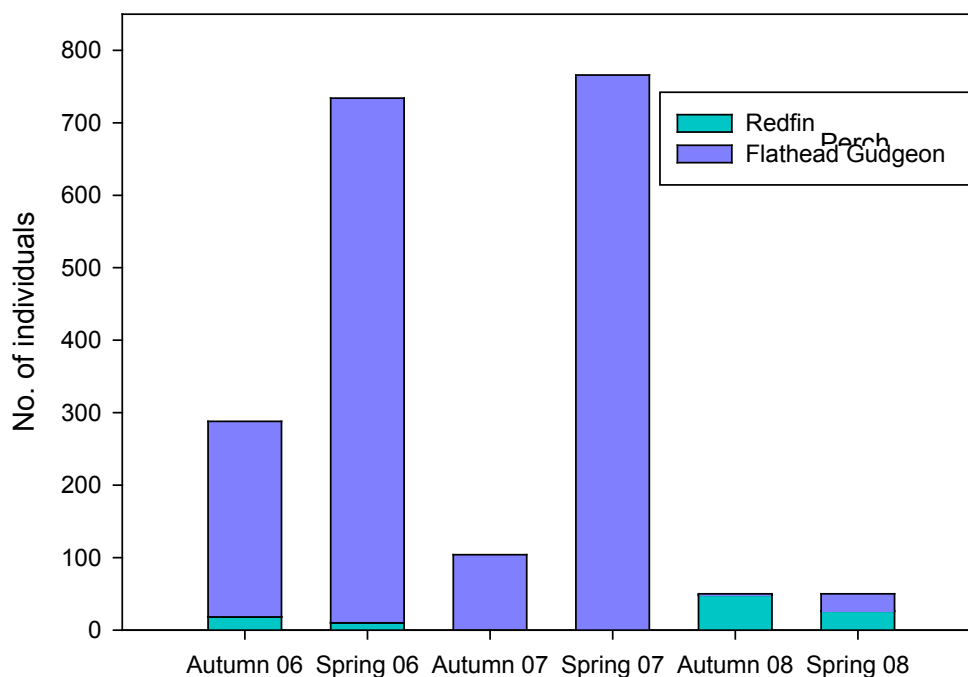


Figure 28. Abundances of each taxa present in the fish communities at Para Wirra (South Para River) over six survey seasons.

3.1.2.5. Fish population structure

There were high captures of small individuals in both autumn and spring of 2006. Despite a lower number of flathead gudgeon being captured in autumn 2007, the largest numbers of small individuals and a substantial number of medium to large individuals were captured in spring 2007. Only two individuals (one medium-sized and one large) were captured during autumn 2008. In the spring 2008, only medium to large flathead gudgeon were present. A wide range of sizes of flathead gudgeon were captured at Para Wirra in 2006-2007 (Figure 29).

Small numbers of medium to large redfin perch were captured at Para Wirra in 2006, but none were captured in autumn 2007 and only one redfin perch was captured in spring 2007. In autumn 2008 large numbers of small redfin perch were captured at Para Wirra, and in spring the same cohort was present in similar numbers with no larger or smaller fish present.

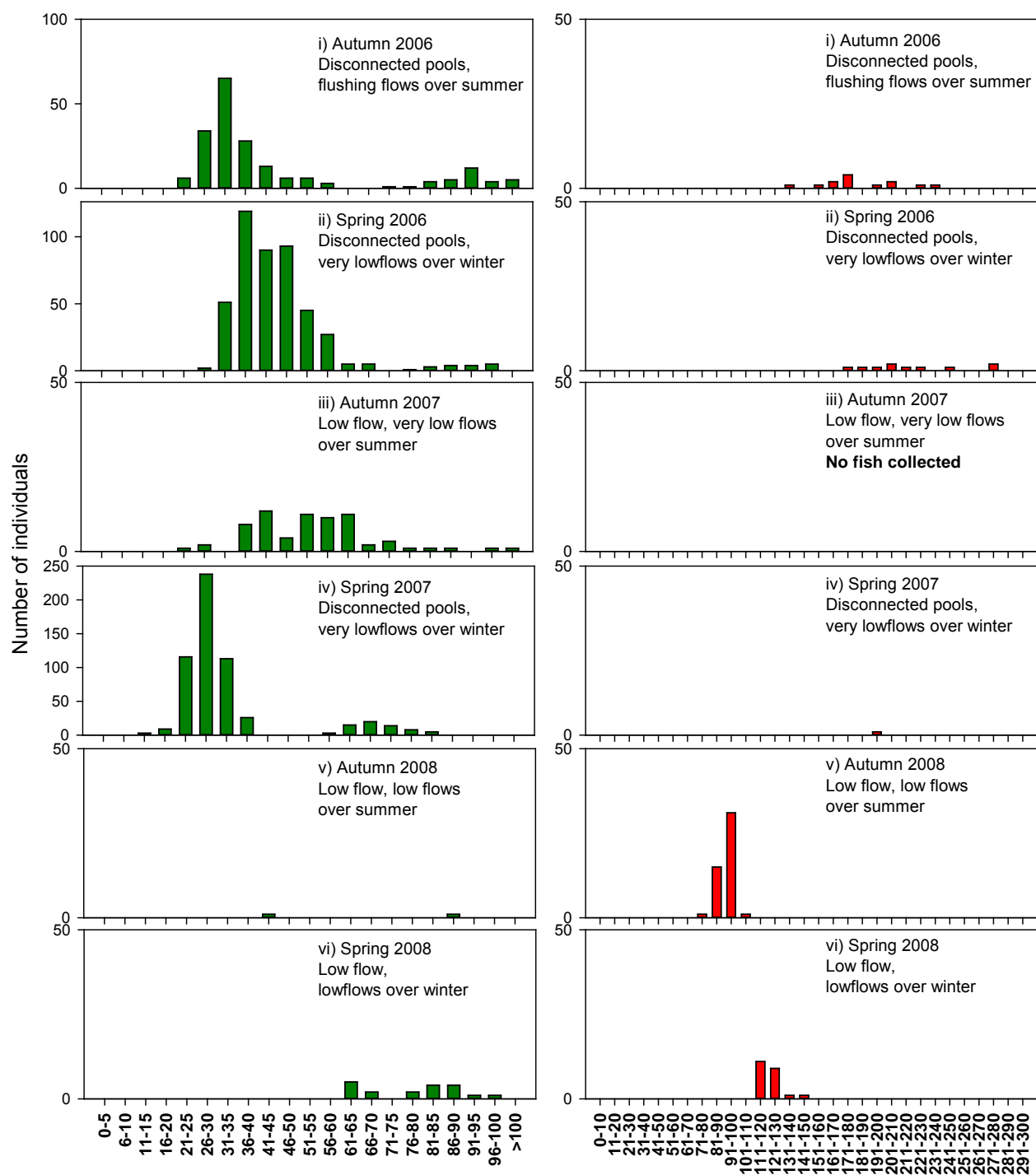


Figure 29. Lengths of flathead gudgeon (*P. grandiceps*) and redfin perch (*P. fluviatilis*) at Para Wirra (South Para River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

3.1.3. Nolan's

3.1.3.1. Site assessment

The Nolan's site was located in a more accessible section of the South Para Gorge less than two kilometres downstream from the Para Wirra Recreation Park. The site was on a cattle grazing property and the surrounding vegetation was either cleared completely or impacted by grazing. Riparian vegetation around the pools consisted predominantly of large remnant redgums and fringing juncus (common rush). The substrate in pools 1 and 2 was predominantly cobble while pool 2 was mostly bedrock and large cobble (Table 16). There was only one snag observed at the Nolan's site in pool 2.

Table 16. Habitat characteristics of the three monitoring pools at Nolan's in the South Para River.

Nolan's	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	5-10+	70	None	1.5
Pool 2	10+-Bedrock	100	1	1.5
Pool 3	5-10+	55	None	1.5

Pool 1 (Figure 30) was the largest pool at Nolan's site with depths ranging from 1.5m to 1.0m. The pool became marginally salty each spring but pH and dissolved oxygen remained stable (Table 17). There were no submerged or emergent macrophytes recorded at this site and the hydrology during sampling was usually no flow or very low flow (Table 17). The antecedent flows were predominantly very low flows with the exceptions of small freshes prior to the autumn 2006 and 2008 surveys. Pool 1 had a pump to extract water for farming purposes.

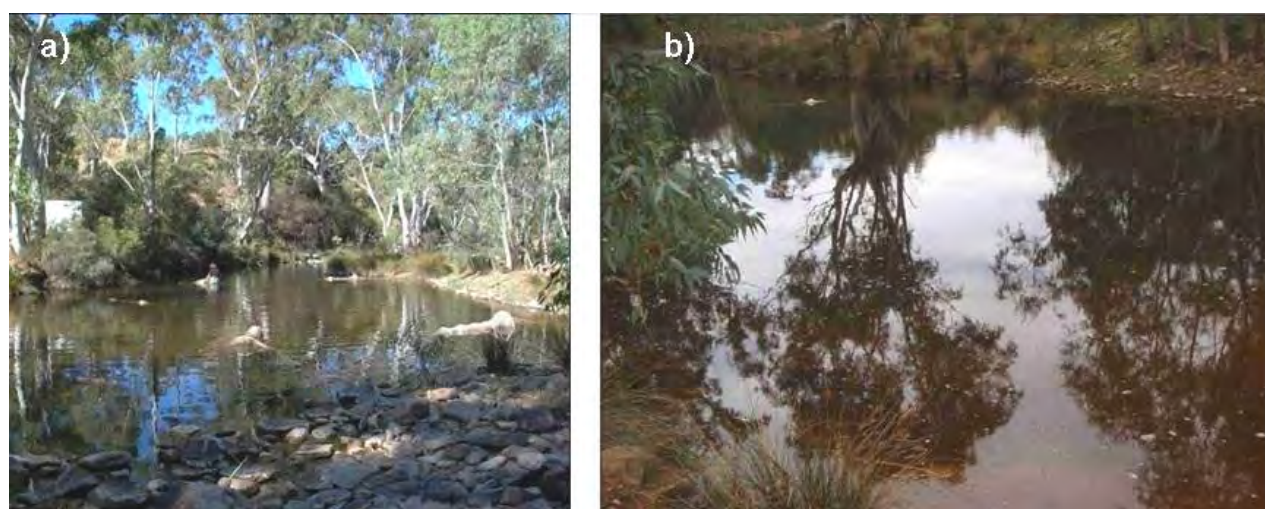
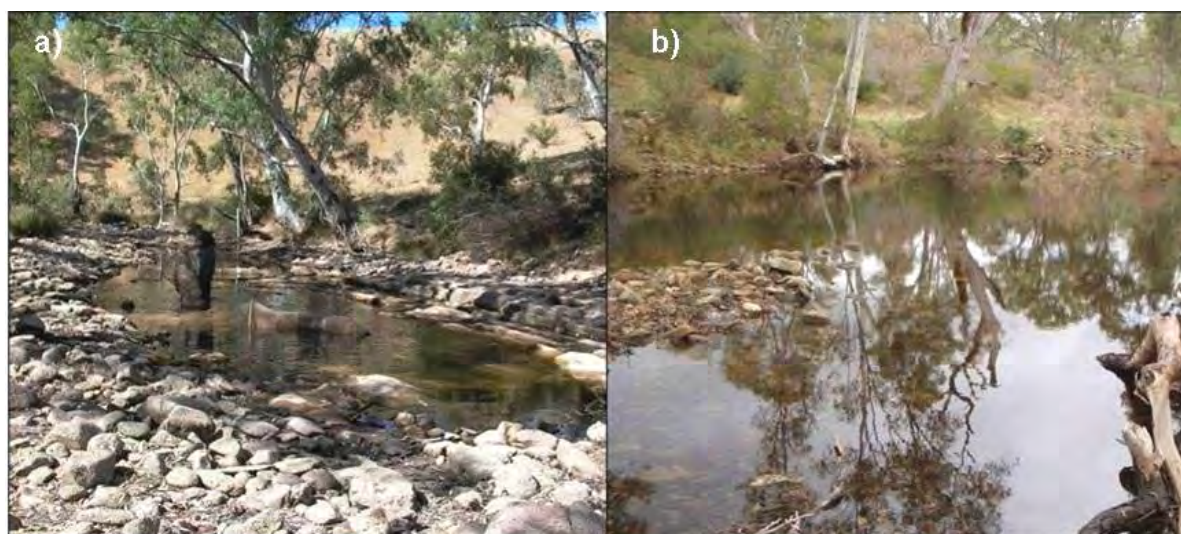


Figure 30. Nolan's Pool 1 in a) spring 2007 and b) autumn 2008.

Table 17. Water quality parameters recorded in Nolan's Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1700	8	10.3	1.4	0	Low flow	Flush, very low flow
2006	spring	8	1909	8	24.6	1.0	0	No flow	Low flow
2007	autumn	8	1793	8	14.4	1.3	0	Low flow	Very low flow
2007	spring	7	2490	6	24.5	1.5	0	No flow	Very low flow
2008	autumn	8	1400	6	13.9	1.0	0	No flow	Fresh, very low flow
2008	spring	6	3395	7.6	20.7	1.0	0	No flow	Low flow

Pool 2 (Figure 31) was a smaller pool and was prone to shrink down into a series of small shallow pools with depths ranging from 1.5m to 0.2m. The pool became marginally salty each spring and especially salty in spring 2008 when it was almost dry, but pH and dissolved oxygen remained stable. There were no submerged or emergent macrophytes recorded at this site and the hydrology during sampling was usually no flow or very low flow (Table 18). The antecedent flows were predominantly very low flows with the exceptions of small freshes prior to the autumn 2006 and 2008 surveys. There is a small cave above pool 2 containing aboriginal paintings protected by a locked cage.

**Figure 31. Nolan's Pool 2 in a) spring 2007 and b) autumn 2008.****Table 18. Water quality parameters recorded in Nolan's Pool 2 during each survey.**

Pool 2	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	12	1680	8	10.1	1.1	0	Low flow	Flush, very low flow
2006	spring	8	2010	8	22.5	1.3	0	No flow	Low flow
2007	autumn	7	1970	8	13.9	1.5	0	Low flow	Very low flow
2007	spring	5	2730	6	23.5	0.3	0	No flow	Very low flow
2008	autumn	9	1800	6	14.7	1.0	0	No flow	Fresh, very low flow
2008	spring	6	7550	7.3	18.1	0.2	0	No flow	Low flow

Pool 3 (Figure 32) was a smaller pool and was also prone to shrink down into a series of small shallow pools with depths ranging from 1.5m to 0.3m. The pool became marginally salty each spring but pH and dissolved oxygen remained stable. There were no submerged or emergent macrophytes recorded at this site and the hydrology during sampling was usually no flow or very low flow. The antecedent flows were predominantly very low flows with the exceptions of small freshes prior to the autumn 2006 and 2008 surveys. Red-bellied black snakes were occasionally caught in fyke nets.



Figure 32. Nolan's Pool 3 in a) spring 2007 and b) autumn 2008.

Table 19. Water quality parameters recorded in Nolan's Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1723	7	11	1.4	0	Low flow	Flush, very low flow
2006	spring	8	2300	7	23.0	0.6	0	No flow	Low flow
2007	autumn	7	1979	8	12.3	1.5	0	Low flow	Very low flow
2007	spring	6	2740	5	25.4	0.3	0	No flow	Very low flow
2008	autumn	13	1400	7	14.9	0.7	0	No flow	Fresh, very low flow
2008	spring	9	1870	7.6	23.1	0.4	0	No flow	Low flow

3.1.3.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.1.3.3. Hydrology

During 2006 and 2007 the survey pools were connected by low flow in each autumn, but were disconnected in each spring. In 2008 the pools were disconnected during both autumn and spring. There was very low flow (average of <1 ML/day) recorded upstream of Nolan's over the first seven weeks in 2006, but no data was available from this gauge between February 22 and October 27 of that year (Figure 33). From this time until spring 2006 surveys, conducted on November 9, there was no recordable flow. This lack of flow continued through summer and on to the end of April 2007. The flow throughout May was generally below 1 ML/day, up to autumn 2007 surveys, conducted on May 24. Other than a few pulses of flow above 10 ML/day, the flow was low throughout winter. Flow declined even further, with an average of <1 ML/day from the start of September to mid-October, no readable flow from mid-October to the start of November, ten days of flow under 0.5 ML/day in early November, and no readable flow from mid-November until spring 2007 surveys, conducted on December 11. This lack of flow continued over summer, until April 21, 2008. There was a fresh in late April, followed by low flows at the site up to the autumn 2008 surveys, conducted on May 6. Very low flows continued over winter, ceased in October and did not recommence by the time of the final survey on November 25.

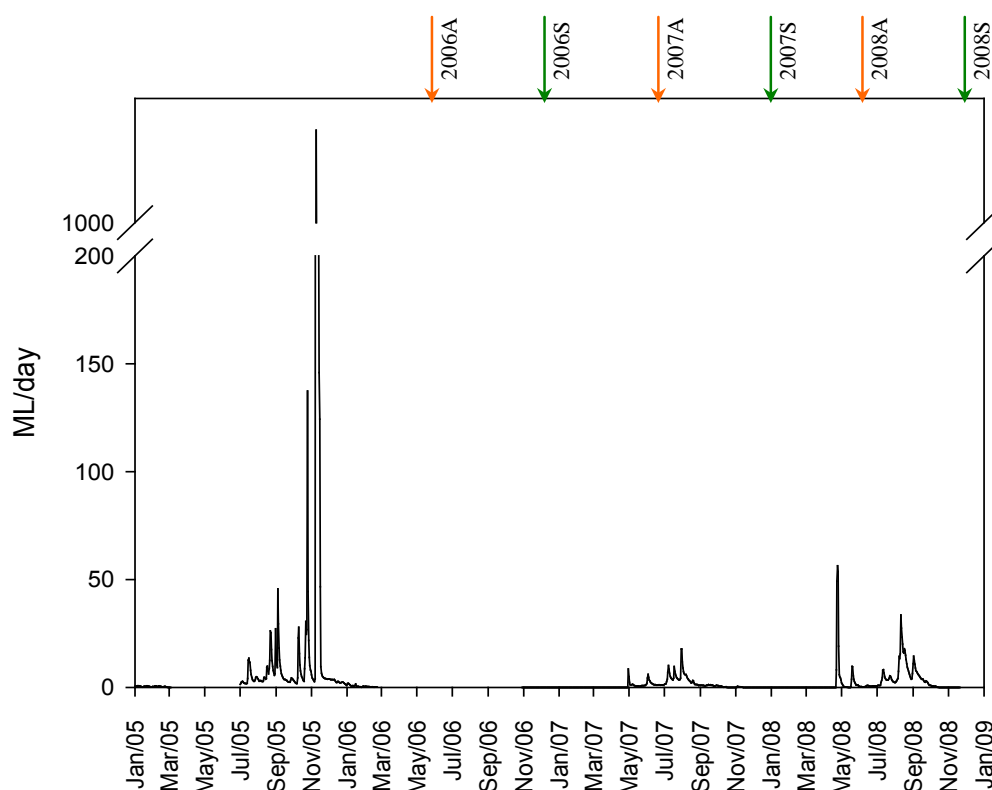


Figure 33. Hydrograph for flow at Nolan's in the South Para River. Flow data (ML/day) from upstream of Tenafeate Creek (A5051004) is reported from January 1, 2005, but there was no data collected from February 22 to October 27, 2006. The timing of each survey season is also shown above the figure.

3.1.3.4. Fish community

Three native and two introduced fish species were captured at Nolan's over the five survey seasons (Figure 34). Distinct changes in the structures of fish communities between seasons in each year were driven largely by fluctuations in the numbers of gambusia captured during each survey. Gambusia was one of the most regularly captured species across all surveys, with particularly high numbers during each spring survey.

Seasonal changes in community structure in 2006 and 2007 were associated with pools changing from being connected by low flows in each autumn to becoming disconnected and shallow in each spring. Relatively high numbers of flathead gudgeon were captured at this site in 2006 and 2007, particularly in autumn. However, in autumn of 2008 only two individuals of this species were captured and the communities from different pools at that time formed a group which was discrete from the previous two years.

This survey was the only one preceded by a fresh, but also the only autumn during which the pools were not connected at the time of surveys. Four mountain galaxias were captured whilst electrofishing in riffles in autumn 2006, and two common galaxias were captured in the downstream pool in autumn 2007. Small numbers of redfin perch were captured throughout the surveys. Flathead gudgeon were the only dominant native fish regularly captured.

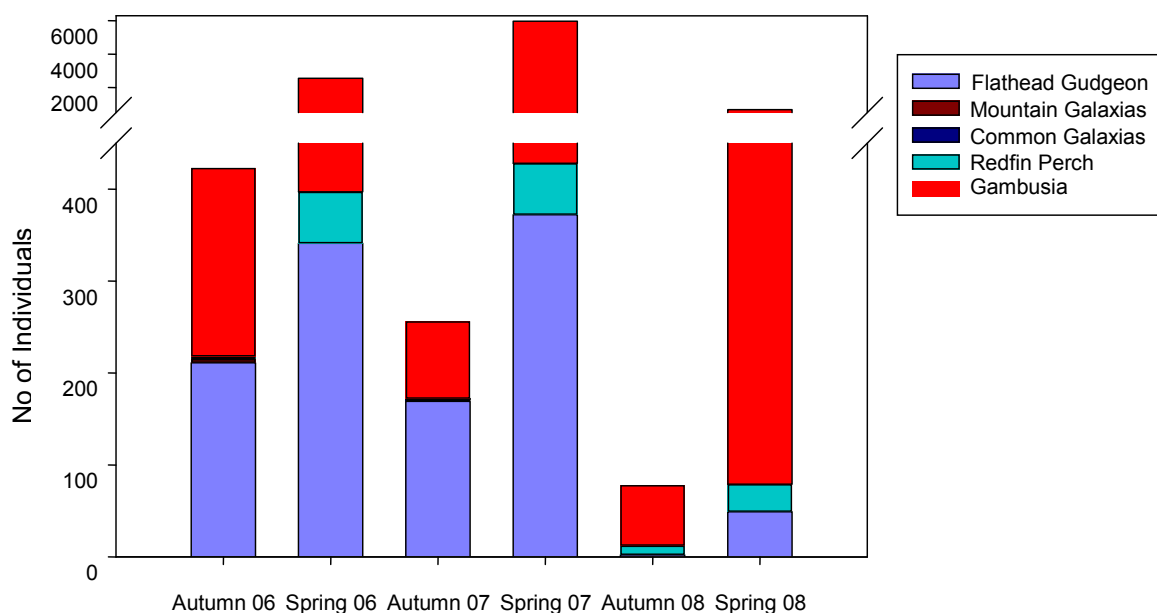


Figure 34. Abundances of each taxa present in the fish communities at Nolan's (South Para River) over six survey seasons.

3.1.3.5. Fish population structure

During the first three survey seasons, from autumn 2006 to autumn 2007, there were high numbers of flathead gudgeon consisting of a wide range of size classes (Figure 35). Although there was only a small number of medium to large individuals captured in spring 2007, this was also the season with the highest number of small individuals. In autumn 2008 there were only two small flathead gudgeon captured from the upstream pool. In spring 2008 a moderate number of new recruits were caught, but the number was well down on previous recruitment levels. Only two adult common galaxias were captured in autumn 2007 and only four adult mountain galaxias in autumn 2006.

There were relatively large numbers of small and medium gambusia captured during all surveys (Figure 36). During each spring survey higher numbers of small individuals were captured than in autumn. Although only small numbers of medium to large redbfin perch were captured across all of the surveys in autumn, there were large numbers of small individuals, as well as small numbers of larger individuals, captured during all spring surveys (Figure 37).

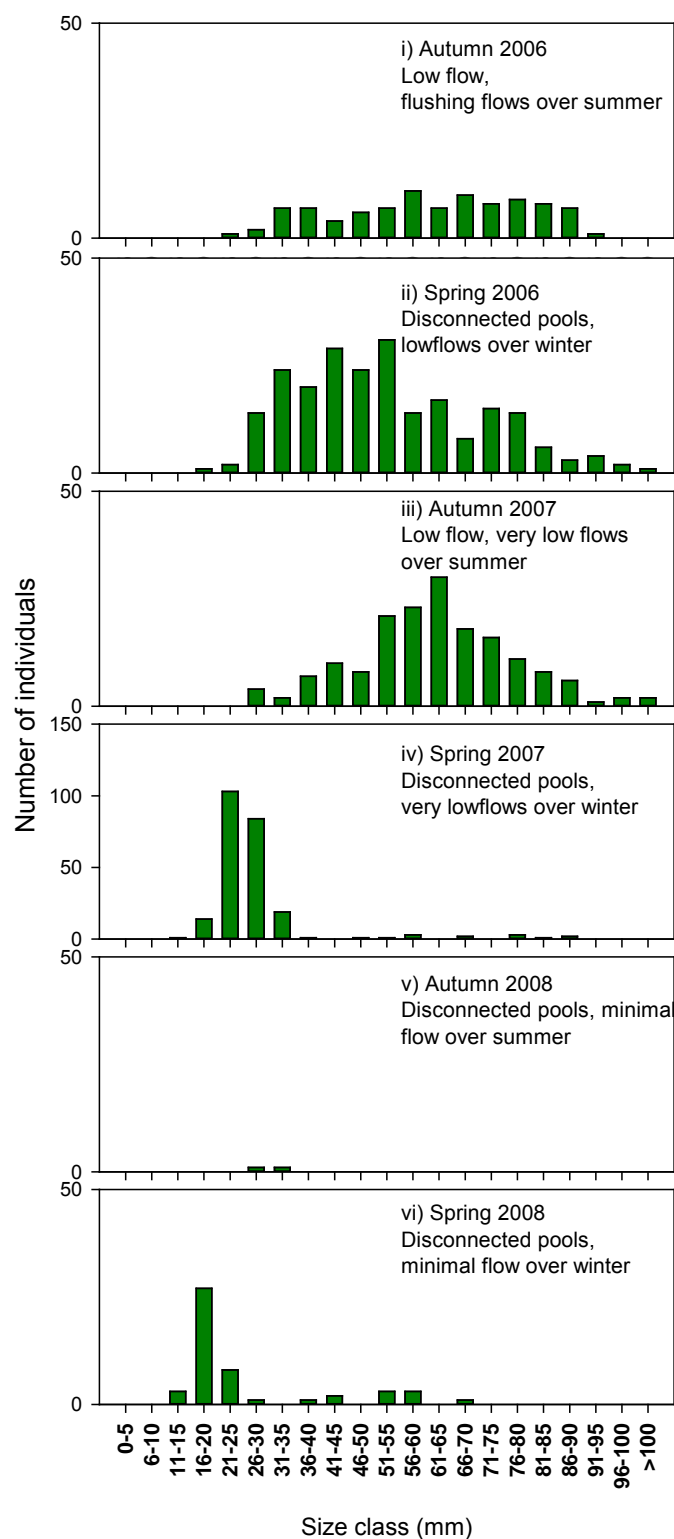


Figure 35. Lengths of flathead gudgeon (*P. grandiceps*) at Nolan's (South Para River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

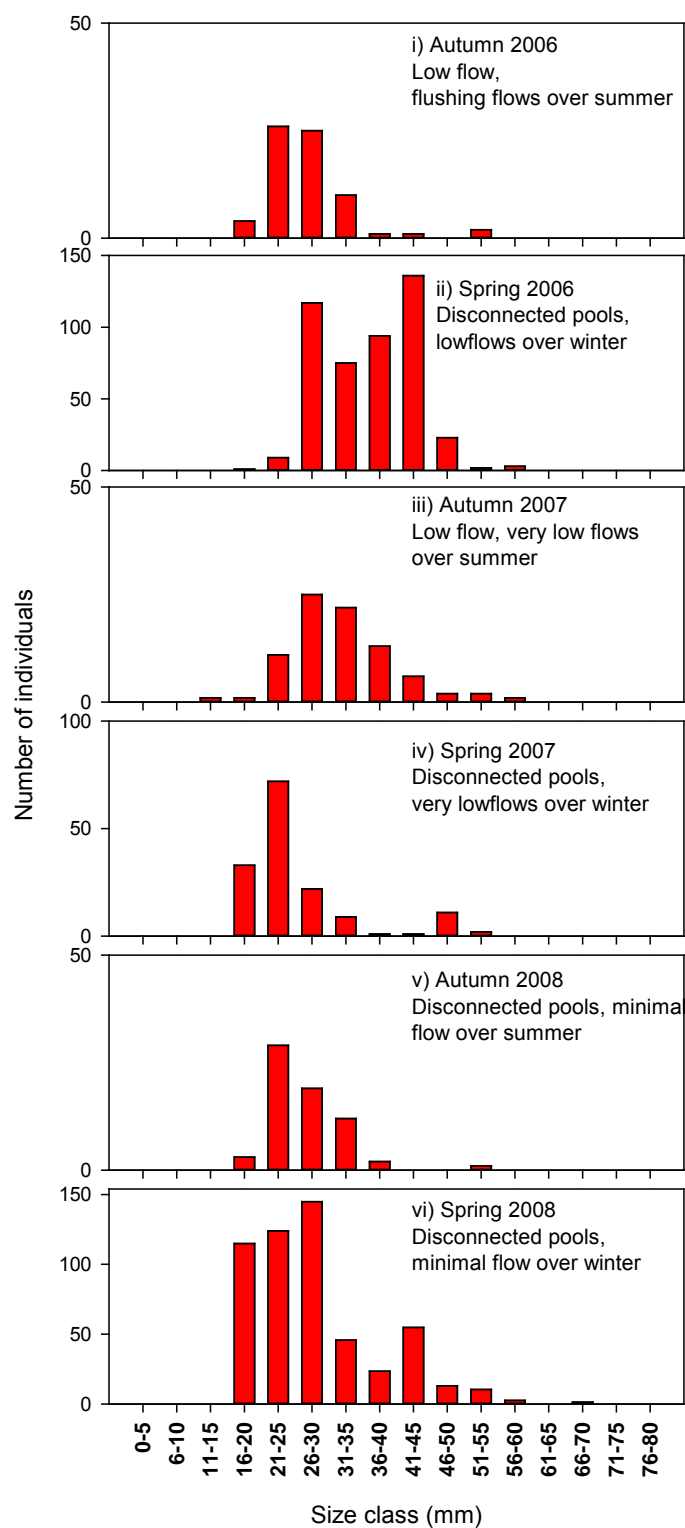


Figure 36. Lengths of gambusia (*G. holbrooki*) at Nolan's (South Para River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

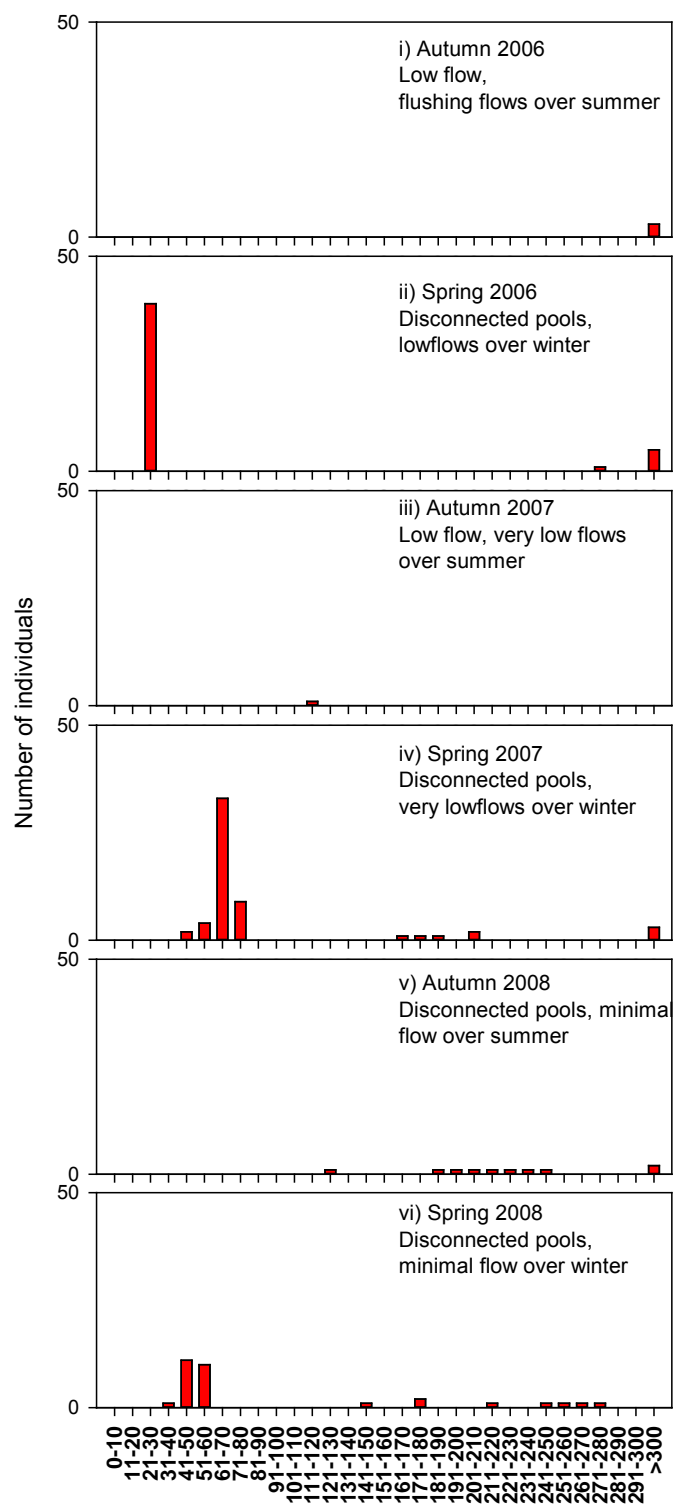


Figure 37. Lengths of redfin perch (*P. fluviatilis*) at Nolan's (South Para River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

3.1.4. Woodlands Weir

3.1.4.1. Site assessment

Woodlands Weir is located in the foothills above Gawler over 5 km from where the South Para joins up with the North Para River, becoming the Gawler River which flows out over the Adelaide Plains towards Gulf St Vincent. The site is on cleared grazing land with only a few large remnant redgums remaining. There is very little riparian vegetation or emergent macrophytes and the banks are impacted by stock grazing and access to the pools. The concrete weir forms a large vertical barrier between pool 1 above the weir and pools 2 and 3 below.

Table 20. Habitat characteristics of the three monitoring pools at Woodlands Weir in the South Para River.

Woodlands Weir	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	<1-10	<5	1	2.0
Pool 2	10+-Bedrock	<5	2	2.0
Pool 3	10+-Bedrock	25	0	2.0

Pool 1 (Figure 38) was contained by Woodlands Weir itself. It was a large pool with relatively consistent depth over the four surveys. The substrate was predominantly fine sediment accumulated above the weir. The pool contained emergent macrophytes at each survey although their cover varied greatly. Salinity in the pool was quite high, and became saltier as the water evaporated and the depth decreased, but temperature, pH and dissolved oxygen were relatively stable (Table 21).



Figure 38. Woodlands Weir Pool 1 in a) spring 2007 and b) autumn 2008.

Table 21. Water quality parameters recorded in Woodlands Weir Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2007	autumn	13	3120	8	15.3	1.8	<5	Connected	Low flows
2007	spring	11	5390	9	20.4	1.8	90	Isolated	Very low flows
2008	autumn	7	9500	7	15.5	1.8	50	Isolated	Very low flows
2008	spring	9.53	3600	8.54	22.7	1.5	5	Isolated	Very low flows

Pool 2 (Figure 39) was directly below the weir with a large deep section scoured by water spilling over the weir and shallower pools stretching beyond that for over 50m. The substrate was mostly bedrock in the deeper section and then cobble further downstream. The depth was at its maximum over the first three surveys due to a small amount of water trickling into the pool from the weir, and remained quite deep event in isolation for the final survey. Like the other Woodlands Weir sites, the pool was quite salty throughout the survey period. Dissolved oxygen, pH and temperature were relatively consistent over time (Table 22).

**Figure 39. Woodlands Weir Pool 2 in a) spring 2007 and b) autumn 2008.****Table 22. Water quality parameters recorded in Woodlands Weir Pool 2 during each survey.**

Pool 2	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Season	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2007	10	3480	8	15.4	autumn	2.0	20	Connected	Low flows
2007	7	6500	5	22	spring	2.0	5	Connected	Very low flows
2008	9	6500	7	17.2	autumn	2.0	6	Connected	Very low flows
2008	9	5480	7.8	21.4	spring	1.6	40	Isolated	Very low flows

Pool 3 (Figure 40) was directly below pool 2. The substrate was predominantly cobble and bedrock. The depth was at its maximum at each autumn survey and was shallower each spring.

Like the other Woodlands Weir sites, the pool was quite salty throughout the survey period. Dissolved oxygen, pH and temperature were relatively consistent over time. Pool 3 had greater and more consistent macrophyte cover (Table 23).



Figure 40. Woodlands Weir Pool 3 in a) spring 2007 and b) autumn 2008.

Table 23. Water quality parameters recorded in Woodlands Weir Pool 3 during each survey.

Pool 3	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Season	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2007	9	3460	8	14.9	autumn	1.5	80	Connected	Low flows
2007	7	6000	6	23	spring	1.2	70	Isolated	Very low flows
2008	11	8700	9	16.5	autumn	2.0	70	Isolated	Very low flows
2008	8	5440	7.8	23.2	spring	1.2	50	Isolated	Very low flows

3.1.4.2. Water Quality

Salinity was recorded at levels that are high enough to impact on more sensitive species and life stages (e.g. eggs and larvae) of native fish. Flathead gudgeon, southern purple spotted gudgeon (now extinct) and dwarf flathead gudgeon are likely to suffer larval mortality and recruitment failure under the higher salinities experienced at this site (McNeil *et al.* 2010c, McNeil *et al.* 2010d). Past peaks in salinity may have excluded sensitive species from these sites (e.g. climbing and mountain galaxias, purple spotted gudgeon) and may have influenced the current assemblage structure in the absence of flushing flows from upstream. All species observed here are likely to be tolerant of recorded conditions, certainly as adults.

3.1.4.3. Hydrology

Water levels at Woodlands Weir were relatively high for each of the surveys, only decreasing significantly in spring 2008 after a year of very low flows. The flow at Woodlands Weir was very low (<0.1 ML/day) over the summer of 2006/07, and up to the end of April 2008. Flow was slightly higher in May, but still low, up the time of autumn 2007 surveys, conducted on May 22. Except for a small pulse of flow in early June, the flow remained low until there were two pulsed freshes in early and late July. Generally the flow decreased for the remainder of the year, with very low flows (<1 ML/day) from the end of September and to the end of November and no flows in December, up to the time of spring 2007 surveys, conducted on December 11. This lack of flow at the site continued over summer and up until the time of autumn 2008 surveys, conducted on May 7. Low flows resumed again in July and continued through to October except for two small freshes in September.

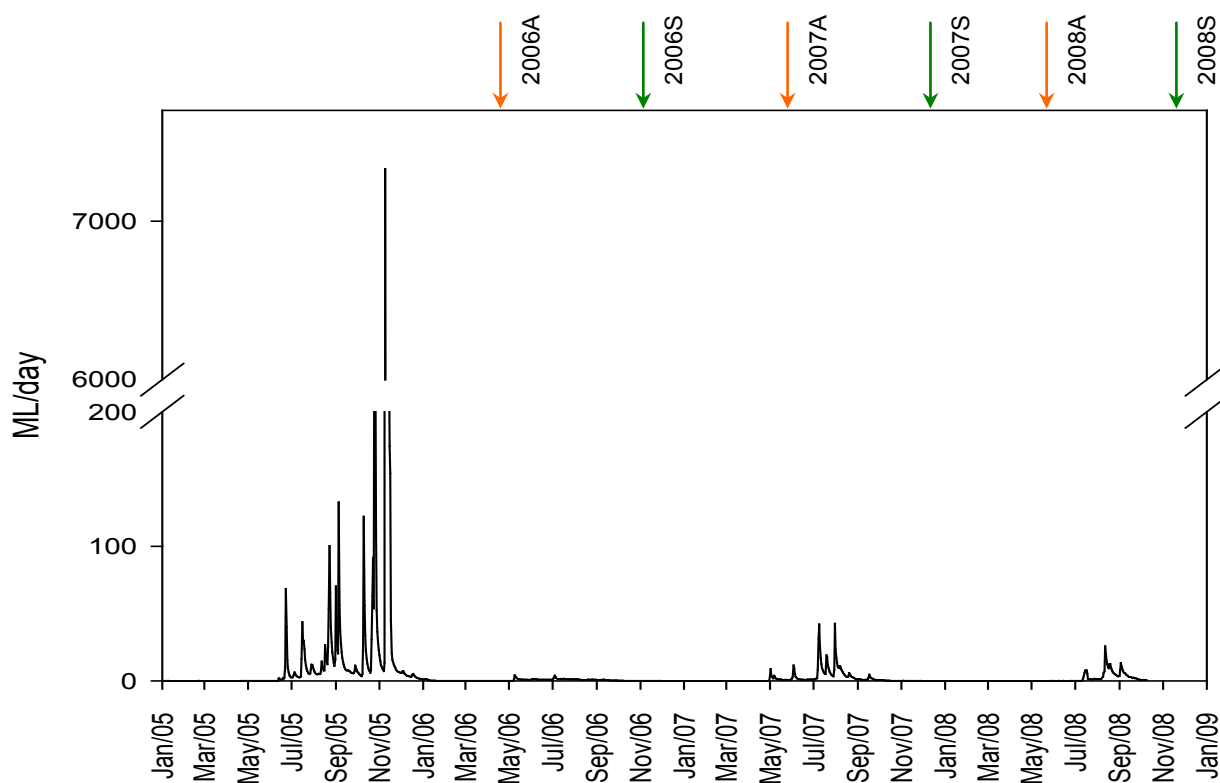


Figure 41. Hydrograph for flow in South Para River at Woodlands Weir. Flow data (ML/day) was collected from DWLBC gauge number A5050503. The timing of each survey season is also shown above the figure.

3.1.4.4. Fish community

Three native and five introduced fish taxa were captured at Woodlands Weir during the three surveys conducted at this site from autumn 2007 to spring 2008 (Figure 42). Large numbers of flathead gudgeon were captured during all four surveys. Over 50 individual common galaxias were captured at the site in autumn 2007, but only a small number were captured in spring 2007 (seven

individuals), autumn 2008 (two individuals) and spring 2008 (one individual). Small numbers of congolli were captured during both autumn and spring surveys conducted in 2007, but none were captured at the site in autumn 2008 and only one in spring 2008. The number of gambusia captured was relatively small in autumn 2007, however they dominated the community in spring 2007, and autumn and spring 2008. Small numbers of carp and goldfish were captured in spring 2007, but neither were captured during autumn 2008. Three goldfish were captured in spring 2008. One tench was captured at Woodlands Weir in spring 2007.

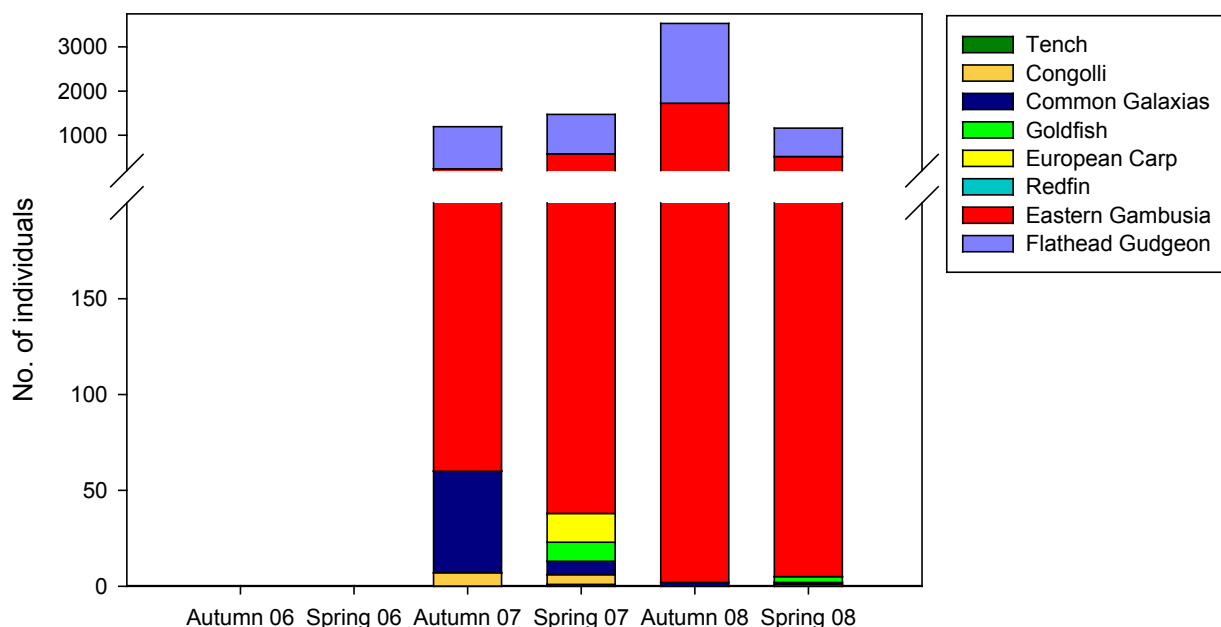


Figure 42. Abundances of each taxa present in the fish communities at Woodlands Weir (South Para River) over four survey seasons.

3.1.4.5. Fish population structure

There was a relatively large number of medium to large common galaxias captured during the initial survey, conducted in autumn 2007 (Figure 43). Large numbers of flathead gudgeon consisting of a wide range of sizes were captured at Woodlands Weir (Figure 44). The numbers of both small and medium sized individuals peaked during the spring 2007 survey, while in spring 2008 the number of small individuals was very low. However, the numbers of individuals declined over subsequent surveys, with only two adult individuals captured during the autumn 2008 survey and one adult in spring 2008. There were small numbers of medium to large congolli captured during autumn 2007 and spring 2007 (Figure 45). However, no congolli were captured during autumn 2008, and only one large adult captured in spring 2008. Most of the gambusia captured were small to medium sized individuals during all surveys (Figure 46).

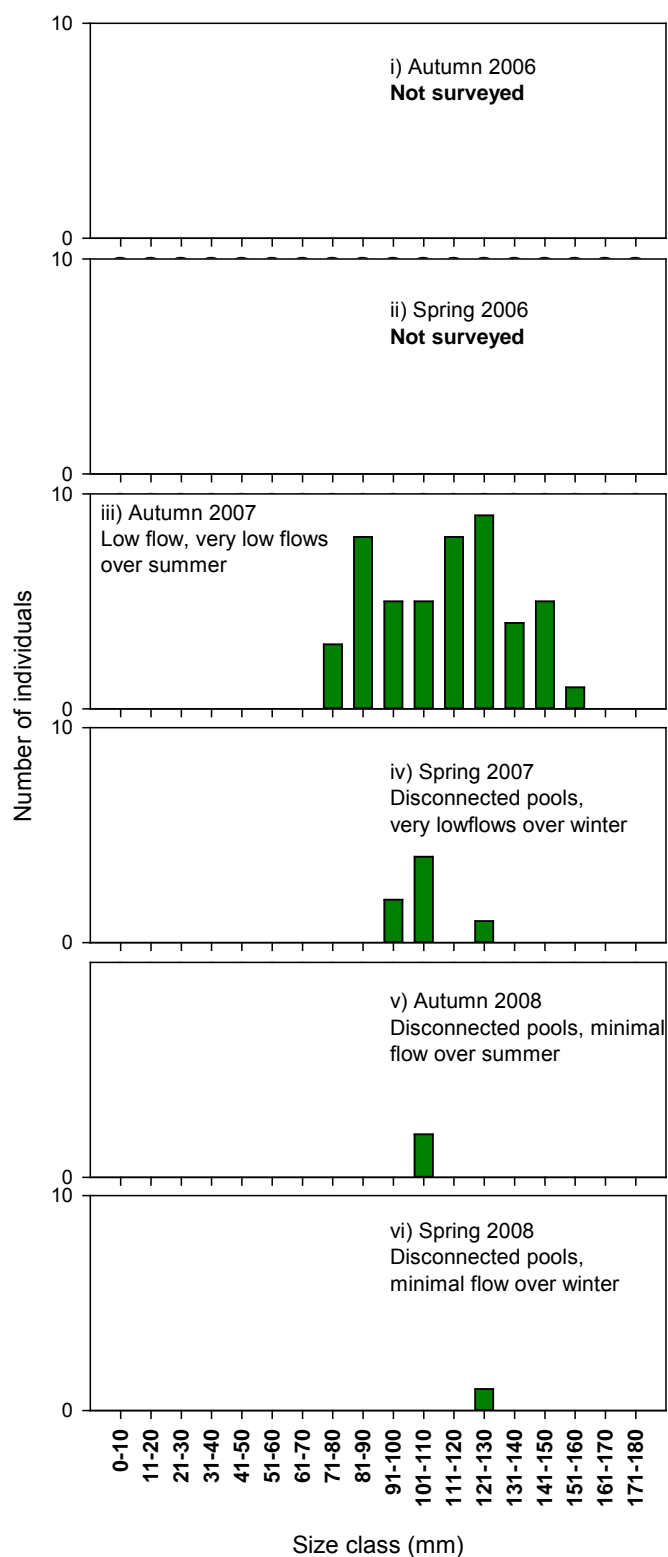


Figure 43. Lengths of common galaxias (*G. maculatus*) at Woodlands Weir (South Para River) over six survey seasons, from autumn 2007 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

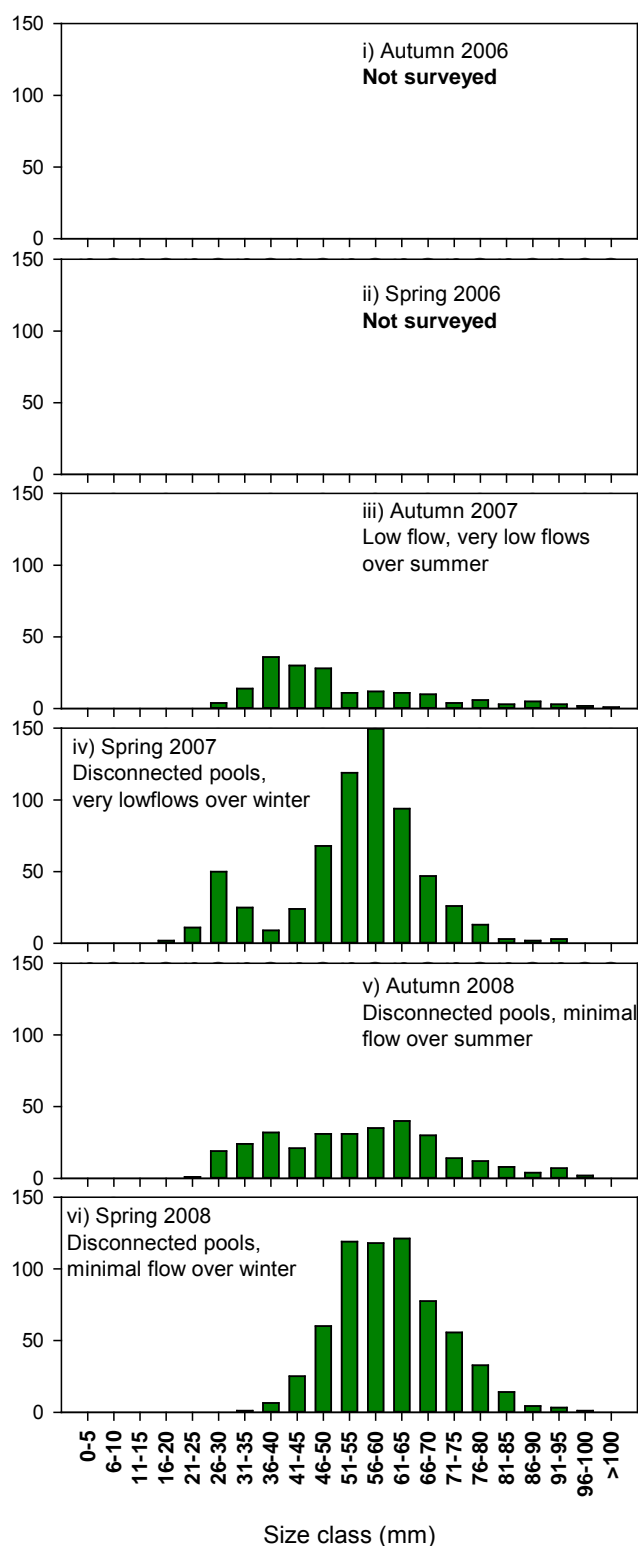


Figure 44. Lengths of flathead gudgeon (*P. grandiceps*) at Woodlands Weir (South Para River) over six survey seasons, from autumn 2007 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each.

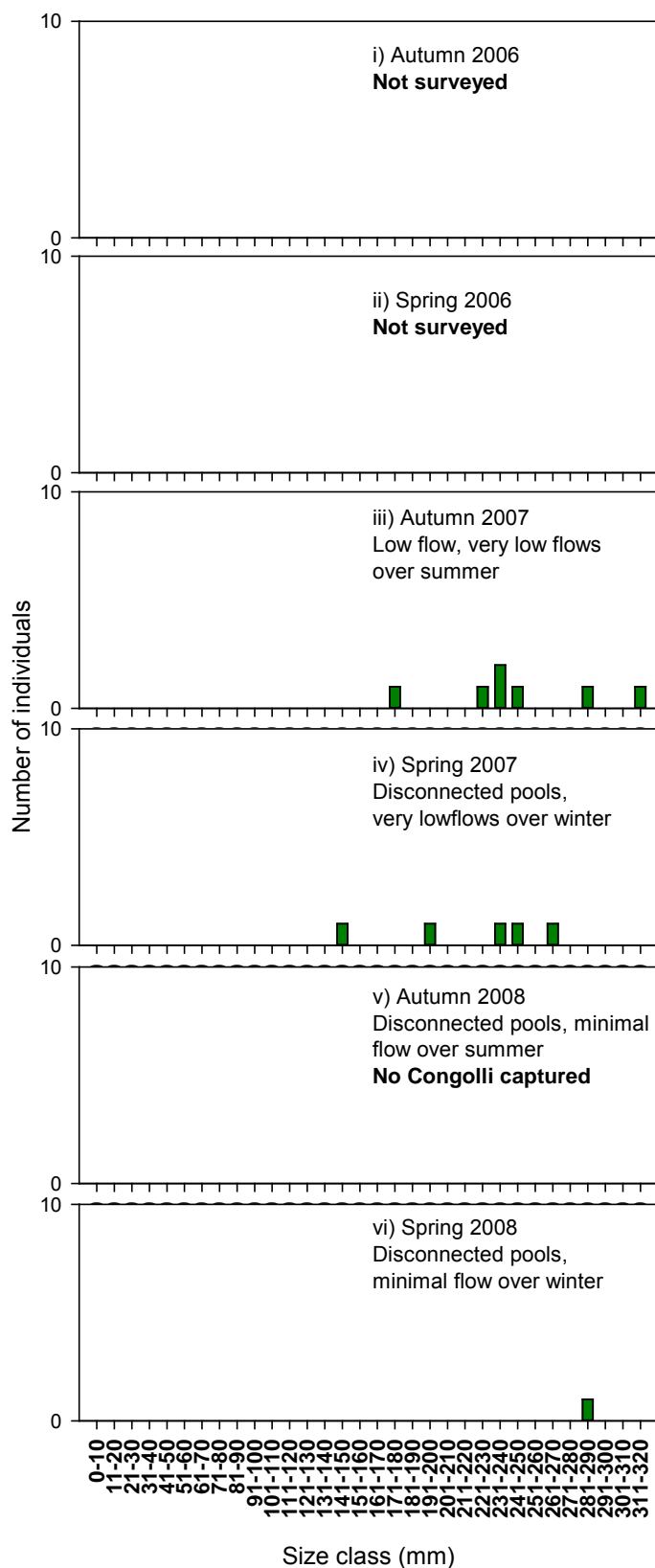


Figure 45. Lengths of congolli (*P. urvillii*) at Woodlands Weir (South Para River) over six survey seasons, from autumn 2007 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

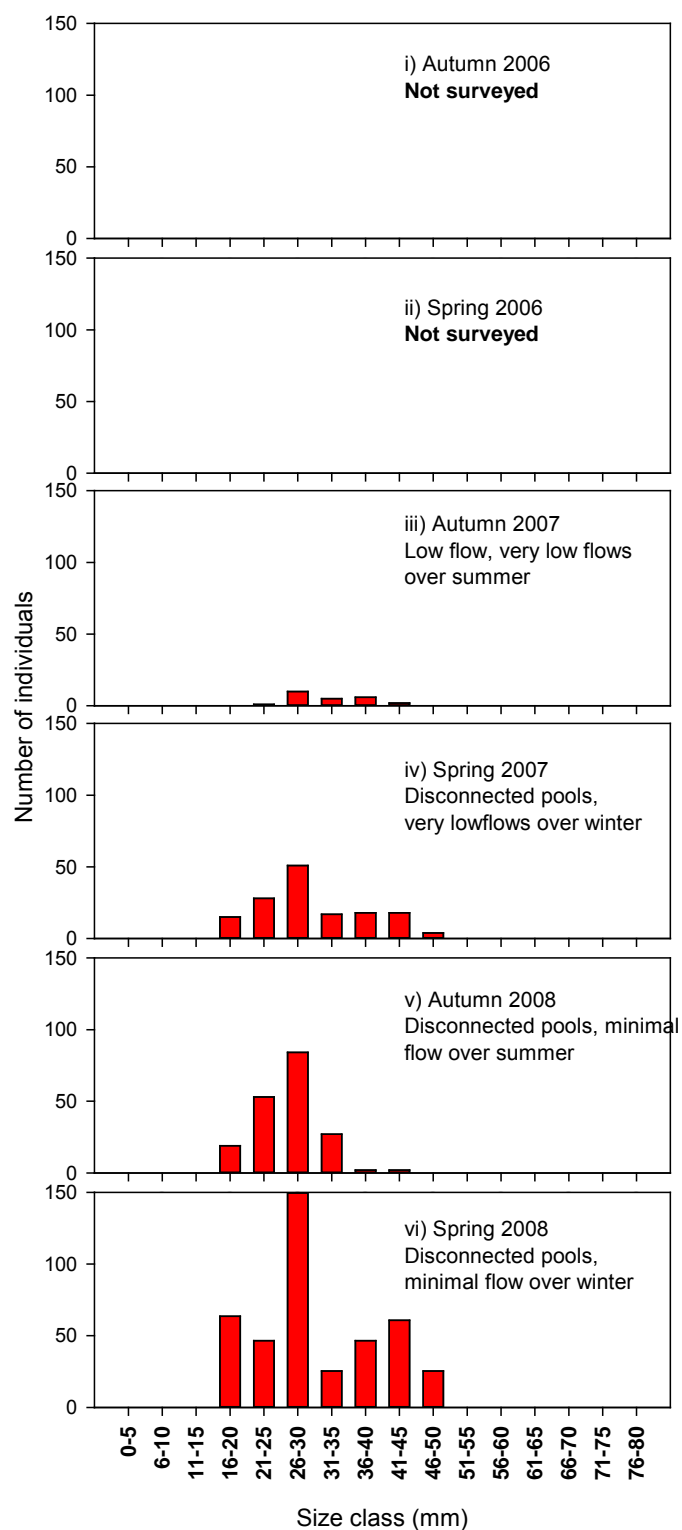


Figure 46. Lengths of gambusia (*G. holbrooki*) at Woodlands Weir (South Para River) over six survey seasons, from autumn 2007 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.

3.2. Torrens River

In total 29 species of fish were caught in the Torrens catchment during the duration of the survey. Of these, 12 were native species, although at least four of these, carp gudgeon, freshwater catfish, Murray rainbowfish and bony herring, are known to have been translocated into the Torrens from the Murray-Darling Basin (McNeil and Hammer 2007). The dwarf flathead gudgeon may have been translocated also, but as this species is only recently described from the flathead gudgeon (Hoese and Reader 2006), no data is available on its historical distribution in the WMLR prior to ~ 2002 (Hammer 2005). A further twelve species of marine or estuarine fishes were collected only from Breakout Creek, and only below the weir wall in the estuarine section of the reach (Table 24).

The present study has identified two native fish species not previously recorded from the Torrens catchment, WMLR or SA Gulf drainage (Hammer and Walker 2004; Hammer 2005). These new records are for the bony herring (*Nematalosa erebi*) and the short finned eel (*Anguilla australis australis*). The collection of short headed lamprey (*Mordacia mordax*) in autumn 2007 at the Torrens estuary is the first record in the catchment since 1958.

Two diadromous species, congolli and common galaxias were historically recorded as abundant in the lower River Torrens, but have not been recorded since 1886 and 1928 respectively. Recent records however, have found common galaxias above the Gorge Weir, possibly a landlocked remnant population (Hammer 2005), whilst other papers found common galaxias present in the Torrens estuary below breakout creek weir (Hicks and Hammer 2004).

Furthermore, recent fish surveys in Breakout Creek (upstream of the weir) failed to detect either species in the lower River Torrens (Gray *et al.* 2005). As such the records of both of these species from the lowland reach of the River Torrens represent the first reported collection of these species in the river since at least the 1920's. This result is almost certainly due to the construction of a fish ladder on the Breakout Creek Weir at the Torrens Mouth. The structure, built by the AMLNRMB to facilitate diadromous fish passage has recently been found to successfully allow the migration of juvenile congolli and common galaxias into the lower Torrens (McNeil *et al.* 2009). This survey establishes that both species were present in all seasons and years within the lower Torrens since autumn 2006.

The survey has re-enforced the locally extinct status of two native species; river blackfish (*Gadopsis marmoratus*) and purple spotted gudgeon (*Mogurnda adspersa*) both historically reported from the Torrens catchment (Hicks and Hammer 2004; Hammer 2005), although anecdotal information continues to suggest *G. marmoratus* populations may exist outside of the EWP reaches in the Onkaparinga catchment (J. McPhail - PIRSA Inland Fisheries Manager, *Pers. comm*). The survey did not detect pouched lamprey (*Geotria australis*) in the Torrens catchment despite recent records of the species from the lower river Torrens and Breakout Creek (Hammer

2005; McNeil *et al.* 2010b). All other species of native fish have been previously collected from the River Torrens although in some cases, not in the reaches surveys here. For example, the collection of climbing galaxias at Gorge Weir and Silke's Rd are much farther downstream than previous records indicate (Hammer 2005).

Six species of introduced fish were collected throughout the survey (Table 24). Of these, carp and gambusia were distributed across all sampling reaches, redfin perch were only present in the upper catchment upstream of Silke's Rd, whilst the opposite was true of goldfish captured at and downstream of Silke's Rd. Brown trout were found in all reaches except for Breakout Creek, whilst rainbow trout was only collected from Gorge Weir.

The suite of marine and estuarine species at Breakout Creek is reflected in the NMDS where those samples form a distinct cluster (Figure 47). The overlap between clusters at all other sites indicates no clear pattern in the distribution of species upstream in the Torrens. There were no environmental or flow variables significantly correlated with patterns in assemblage at R2 greater than 0.1. In other words, there were no environmental or flow correlates that were capable of explaining 10% of the variation in fish assemblage. This was largely due to the small number of replicates and the lack of contrast in the flow regime. Under the observed low flow regime and with significant barriers to fish movement, it appears that the upper Torrens fish assemblage is isolated from the assemblages downstream.

Table 24. Taxa which were present (P) in each site and season in the River Torrens. The columns of native freshwater and diadromous fish taxa are shaded green, those of exotic taxa shaded pink and those of marine/estuarine taxa shaded blue. (*) represents native species translocated into the Torrens Catchment from the Murray-Darling Basin.

Reach	Site Name	Sampling Season	Congolli	Common galaxias	Mountain galaxias	Climbing galaxias	Flathead gudgeon	Dwarf flathead gudgeon	Carp gudgeon *	Short-headed lamprey	Short-finned eel	Freshwater catfish *	Murray rainbowfish*	Bony herring*	Gambusia	Redfin perch	Goldfish	Carp	Brown trout	Rainbow trout	Unidentified gobies	Bridled goby goby	Blue spot goby	Tamar goby	Australian anchovy	Black bream	Jumping mullet	Yellow-eyed mullet	Yellowfin whiting	Sandy sprat	Smooth toadfish	Australian salmon
Gumeracha Weir	Gumeracha Weir	2006A					P	P							P	P																
		2006S	Not Sampled																													
		2007A			P		P	P							P	P		P														
		2007S			P	P	P	P							P	P																
		2008A			P		P	P						P	P	P				P												
	Cudlee Creek	2008S					P	P							P	P			P													
		2006A					P	P							P	P																
		2006S	Not Sampled																													
		2007A			P	P	P	P							P	P		P														
		2007S				P	P	P							P	P		P														
		2008A					P	P							P	P		P														
		2008S			P	P	P	P							P	P		P														
Gorge Weir	Gorge Weir	2006A		P	P		P									P		P	P													
		2006S					P									P		P	P	P												
		2007A		P			P									P			P													
		2007S	P				P									P			P	P	P											
		2008A					P	P								P			P	P												
	Silke's Road	2008S			P		P	P							P	P		P														
		2006A			P		P		P						P	P																
		2006S			P	P	P		P						P	P																
		2007A			P		P		P						P		P															
		2007S		P			P		P			P			P		P	P	P													
	Gorge Weir	2008A					P		P						P		P		P													
		2008S		P			P		P						P		P	P														
City Weir	Breakout Creek	2006A	P	P			P		P			P	P		P		P	P						P		P	P	P				
		2006S	P	P			P		P			P	P		P		P	P							P	P	P	P				
		2007A	P	P			P		P	P		P	P		P		P	P								P	P	P	P			
		2007S	P	P			P		P			P	P		P		P	P								P	P	P	P			
		2008A	P	P			P		P			P	P		P		P	P								P	P	P	P			
		2008S	P	P			P		P		P	P	P		P		P	P									P	P				

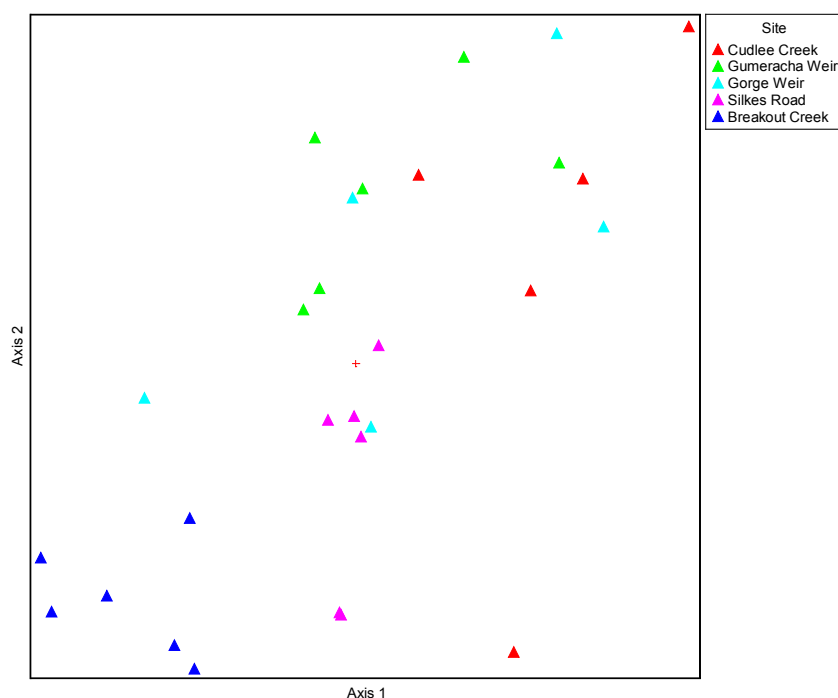


Figure 44. NMDS ordination of fish communities in the Torrens River from autumn 2006 to spring 2008, labelled by site. There were no significantly correlated environmental vectors ($R^2 > 0.1$).

3.2.1. Gumeracha Weir

3.2.1.1. Site assessment

The reach exists largely within relatively shallow gorge habitats, increasing in steepness downstream. Pools 2 and 3 were slightly deeper than Pool 1, whilst Pool 3 was the largest in surface area (Table 25). All three pools possessed rocky substrate with Pool 2 being dominated by bedrock. All sites possessed some woody debris with Pool 3 possessing at least eight moderately sized snags. Riparian cover was reasonable, particularly in Pools 1 and 2 with an overstorey of redgums and redgum saplings, as well as some wattle and bottlebrush, with small cumbungi beds present at each pool, but especially dominant in the intervening run/riffle areas.

Table 25. Habitat characteristics of the three monitoring pools at Gumeracha in the River Torrens.

Gumeracha	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	<1-5	35	2	1.6
Pool 2	<1-Bedrock	50	2	2.0
Pool 3	5-10+	5	8	2.0

Pool 1 (Figure 45) was fairly stable in regards to water quality parameters, with little variability in dissolved oxygen, pH, salinity (which remained ~500 – 1000 $\mu\text{S}/\text{cm}$) and water temperature which fluctuated very little from season to season (Table 26).



Macrophyte cover similarly showed little variability remaining between 5-15% cover and dominated by emergent cumbungi. This pool also showed consistent depth over the sampling period except during autumn 2008 (Figure 48) when the pool shrank dramatically to a depth of only 0.5m.

There was almost permanent flow at this site during surveys with no flow only recorded during autumn 2008 when the pool dried significantly. Antecedent flow conditions were similarly high compared to other sites and reaches with freshes and high flows occurring prior to most sampling seasons. The exception was during 2008 when very low flows preceded both sampling trips, although high flows had returned by spring sampling.



Figure 45. Gumeracha Pool 1 in autumn 2008 (left) and autumn 2006 (right).



Table 26. Water quality parameters recorded in Gumeracha Pool 1 during each survey. Note this pool was not sampled in spring 2006.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1063	7	13.5	1.6	5	Low flow	Flushes
2006	spring	Not sampled						High flow	High flows
2007	autumn	8	478	8	16.3	1.5	10	Low flow	Low flows/freshes
2007	spring	7	380	8	21.0	1.6	15	Low flow	Freshes
2008	autumn	7	1100	8	14.1	0.5	10	No flow	Very low flows
2008	spring	9.03	499	7.81	19.7	1.6	5	High flow	Very low flows

Pool 2 (Figure 49) remained at a consistent depth throughout the study with the exception of autumn 2008 when flows ceased, at which time the pool dropped only 0.5m in depth (Table 27). Dissolved oxygen conductivity and pH were all fairly stable at benign levels throughout the three years with water temperature fluctuating within 7°C between spring and autumn each year. Macrophyte cover varied little across survey seasons primarily with the levels of emergent *Phragmites* and cumbungi. There was almost permanent flow at this site during surveys with no flow only recorded during autumn 2008. Antecedent flow conditions were similarly high compared to other sites and reaches with freshes and high flows occurring prior to most sampling seasons.



Figure 49. Gumeracha Pool 2 in autumn 2008 looking downstream (left) and .in autumn 2007 looking upstream. Note water mark on *Phragmites* stems in 2007 following antecedent high water levels resulting from transfer flows (which prevented sampling in spring 2006.



Table 27. Water quality parameters recorded in Gumeracha Pool 2 during each survey. Note this pool was not sampled in spring 2006.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	9	1106	8	13.3	2.0	10	Low flow	Flushes
2006	spring	Not sampled						High flow	High flows
2007	autumn	8	405	8	16.2	2.0	10	Low flow	Low flows/freshes
2007	spring	7	350	8	22.0	2.0	10	Low flow	Freshes
2008	autumn	8	900	8	14.5	1.5	5	No flow	Very low flows
2008	spring	7.5	509	7.8	21	2.0	10	High flow	Very low flows

Pool 3 (Figure 50) was the largest of the three pools and was generally deeper over much its area, although maximum depth fluctuated to a higher degree than the other two pools. Riparian vegetation was patchy with the left bank almost completely overgrown with blackberries and patchy redgum saplings and grasses on the right bank. The substrate was cobbled and macrophyte cover was generally low with cumbungi beds at the up- and down-stream extent of the pool inundated at higher water levels (Table 28). Temperature varied seasonally within 8°C, whilst pH, dissolved oxygen and conductivity remained consistently at benign levels. There was almost permanent flow at this site during surveys with no flow only recorded during autumn 2008. Antecedent flow conditions were similarly high compared to other sites and reaches with freshes and high flows occurring prior to most sampling seasons.

**Figure 50. Gumeracha Pool 3 in autumn 2008.**

Table 28. Water quality parameters recorded in Gumeracha Pool 3 during each survey. Note this pool was not sampled in spring 2006.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1097	8	13.1	1.0	5	Low flow	Flushes
2006	spring	Not sampled						High flow	High flows
2007	autumn	8	506	8	17.2	1.2	5	Low flow	Low flows/freshes
2007	spring	7	350	8	21.0	2.0	5	Low flow	Freshes
2008	autumn	12	1100	9	15.2	1.5	1	No flow	Very low flows
2008	spring	8.5	506	7.7	20	2.0	5	High flow	Very low flows

3.2.1.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.2.1.3. Hydrology

The water level at Gumeracha Weir was low at the time that autumn 2006 surveys were conducted. In spring 2006 the discharge was too high for nets to be set. The water level was again low during autumn 2007, and was moderate during spring 2007 surveys. During the autumn 2008 survey, the pools were disconnected and there had been no flow over summer. Over winter, low baseflows resumed and pools were connected by strong flow in spring 2008. Much of the flow from upstream is intercepted by Gumeracha Weir, and does not reach the survey site below the weir (Figure 51). The gauge data collected at Cudlee Creek was used to evaluate the hydrology below the weir. A detailed description of this hydrology is provided below (see results for Cudlee Creek).

3.2.1.4. Fish community

Five native and four introduced species were captured at Gumeracha Weir over the five survey seasons (Figure 52). Typically, only relatively low numbers of most taxa were captured at this site in each season. However, in autumn 2006 and autumn and spring 2008 the fish community at Gumeracha Weir was dominated by very high numbers of flathead gudgeon. The structure of this community in autumn 2007 was dominated by exotic taxa. This dominance by exotics was again evident in spring 2007, and was associated with relatively high flows, as well as high temperature and low conductivity at the time of the surveys. The site became drier in 2008, with no freshes or flushes over summer and minimal surface water in the isolated pools in autumn. By this time the community structure had moved back somewhat to that occurring in 2006, with relatively high



numbers of flathead gudgeon, but also with relatively high numbers of gambusia. In the last survey in spring 2008 baseflows had returned to this reach and the pools were connected.

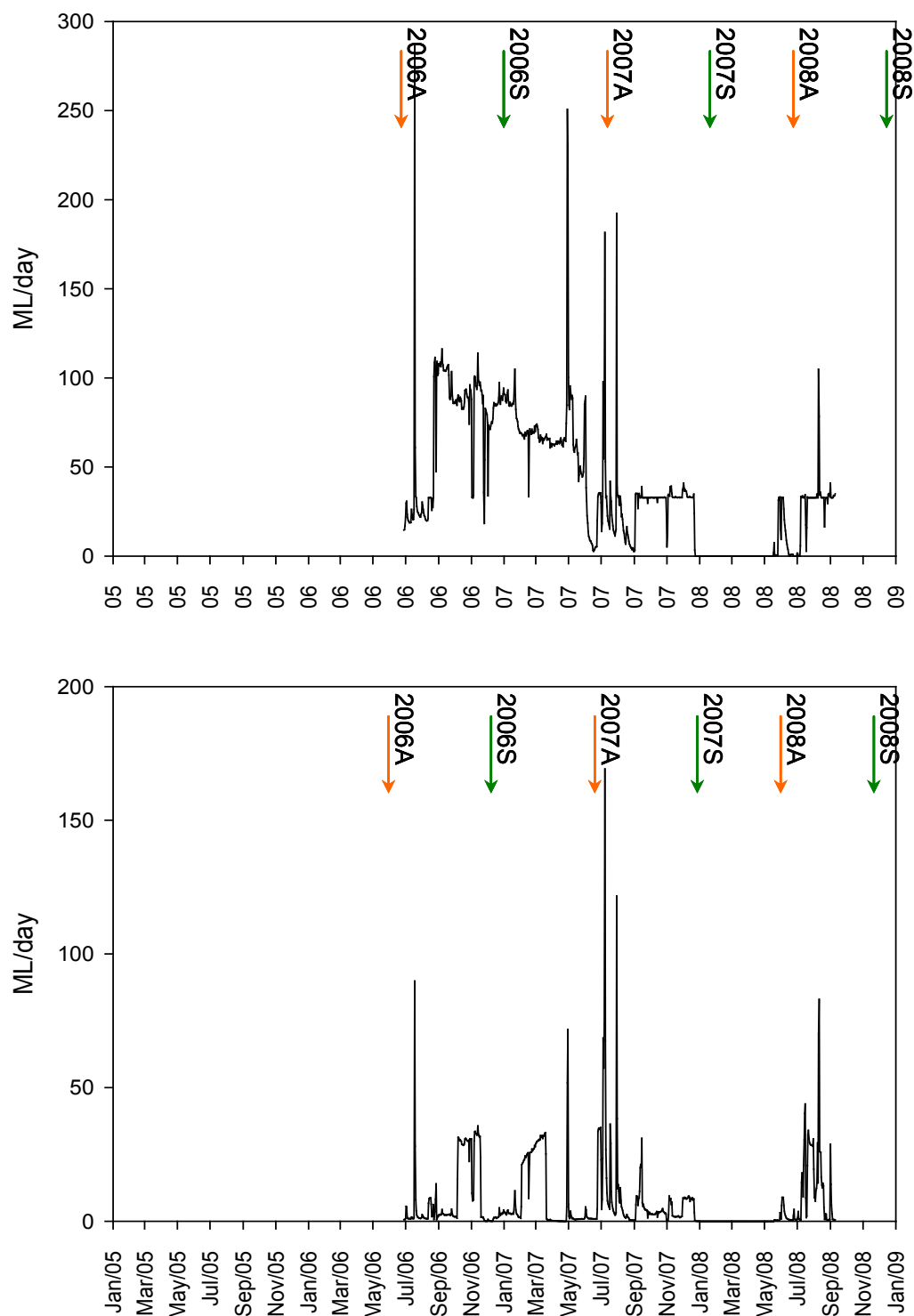


Figure 51. Hydrographs for a) flow in Torrens River above Gumeracha Weir survey site (top graph), and b) flow below Gumeracha Weir (bottom graph). Flow data (ML/day) for the survey site was collected at both Cudlee Creek (gauge number A5041019) and upstream of Gumeracha Weir (gauge number A5041020) from June 27, 2006. The timing of each survey season is also shown above the figures. Note that no survey was possible during spring 2006 due to the prevailing high discharge at the survey site.



Large numbers of flathead gudgeon were captured along with moderate numbers of redfin perch and brown trout, but gambusia were absent. Small numbers of mountain galaxias were captured in each of the three surveys from autumn 2007 to autumn 2008, whilst only one climbing galaxias was captured at Gumeracha Weir during the present surveys, in spring 2007. One bony herring was captured at Gumeracha Weir during the autumn 2008 survey; this is the first record of the species in the WMLR and is a likely translocation via water pumped from the Murray River.

The most common fish captured during the three surveys from autumn 2007 to autumn 2008 were introduced taxa. Gambusia numbers varied, both seasonally and across surveys. Only one carp was captured in spring 2007; however numbers of carp at the site had increased by spring 2008. A single brown trout was also captured in autumn 2008.

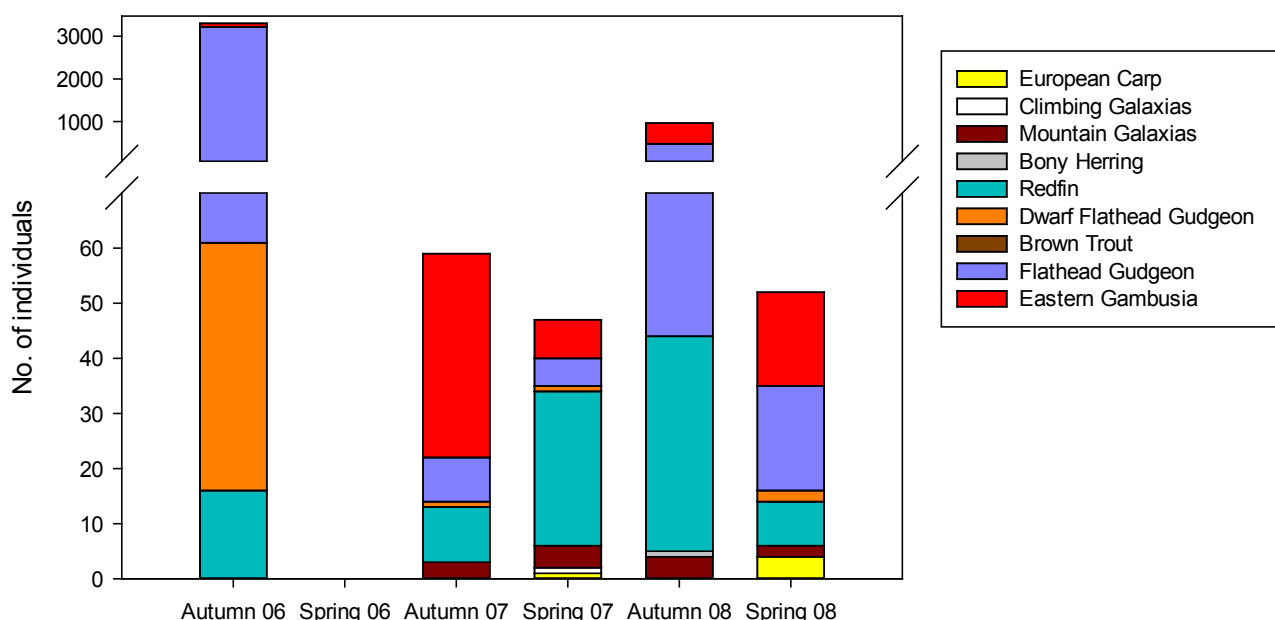


Figure 52. Abundances of each taxa present in the fish communities at Gumeracha Weir (Torrens River) over six survey seasons. There was no survey data for this site in spring 2006 due to very high flow.

3.2.1.5. Fish population structure

There was a very large number of small to medium sized flathead gudgeon captured during autumn 2006 (Figure 53). However, in both autumn and spring 2007 only a small number of mainly medium sized individuals were captured. In autumn 2008, a very high number of juvenile recruits were captured and by spring had matured into adults. There were relatively high numbers of small to medium sized dwarf flathead gudgeon captured during autumn 2006 (Figure 54). However, only one fish was captured during each of the surveys conducted in 2007, and no fish were captured in autumn or spring 2008.



Mountain galaxias were only captured at Gumeracha Weir in 2007 (Figure 55). Small numbers were captured, with medium sized fish captured in autumn and smaller fish captured in spring. During spring 2007 one small climbing galaxias was captured (Figure 56)

The pattern for captures of gambusia was similar to that for flathead gudgeon (although during the initial survey the numbers of gambusia captured were much lower (Figure 57). High numbers of small to medium sized gambusia were captured in autumn 2006 and 2008, with far fewer captured during either survey in 2007 and in spring 2008.

Only medium to large redfin perch were captured during autumn 2006 and autumn 2007 (Figure 58). There were relatively high numbers of new recruits caught in spring 2007 and of small to medium sized individuals in autumn 2008. In spring 2008, only medium to large redfin perch were captured. In addition 10 adult brown trout were captured in autumn 2008 ranging in size from 275-335 mm.



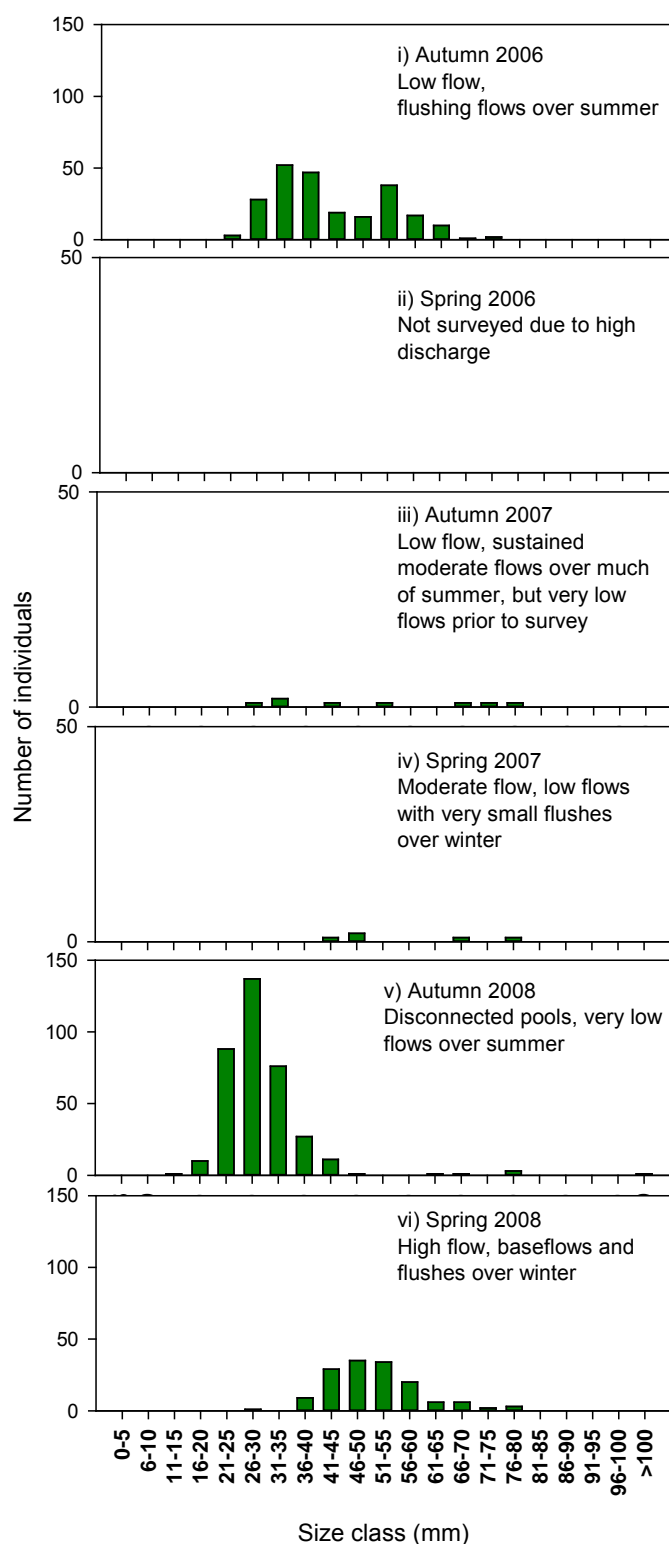


Figure 53. Lengths of flathead gudgeon (*P. grandiceps*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



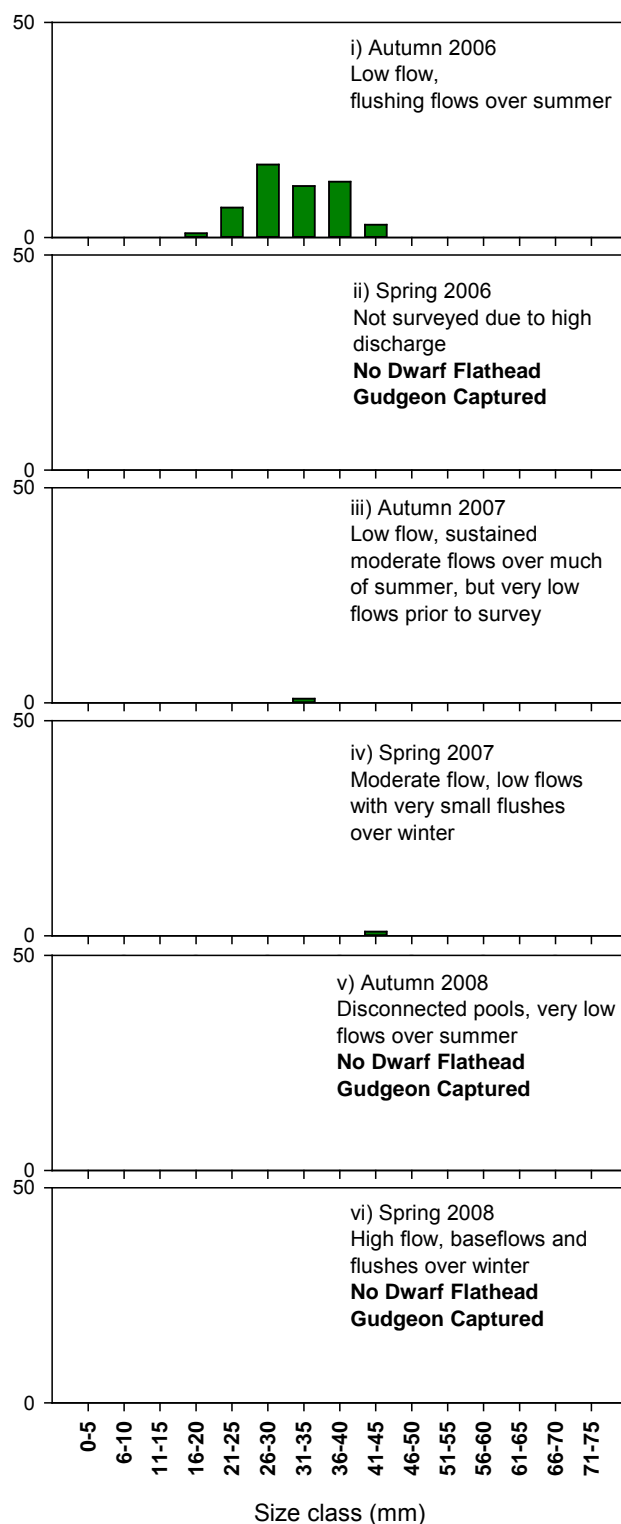


Figure 54. Lengths of dwarf flathead gudgeon (*P. macrostomus*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



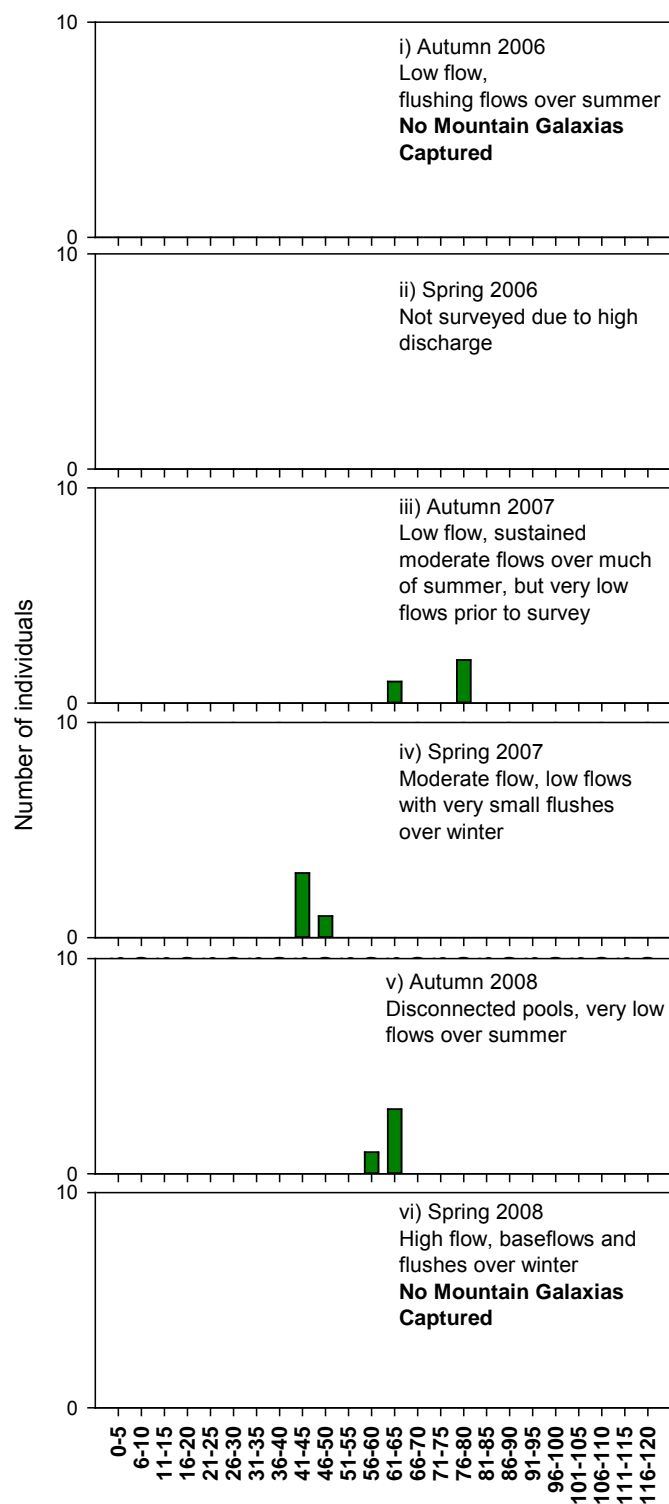


Figure 55. Lengths of mountain galaxias (*G. olidus*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



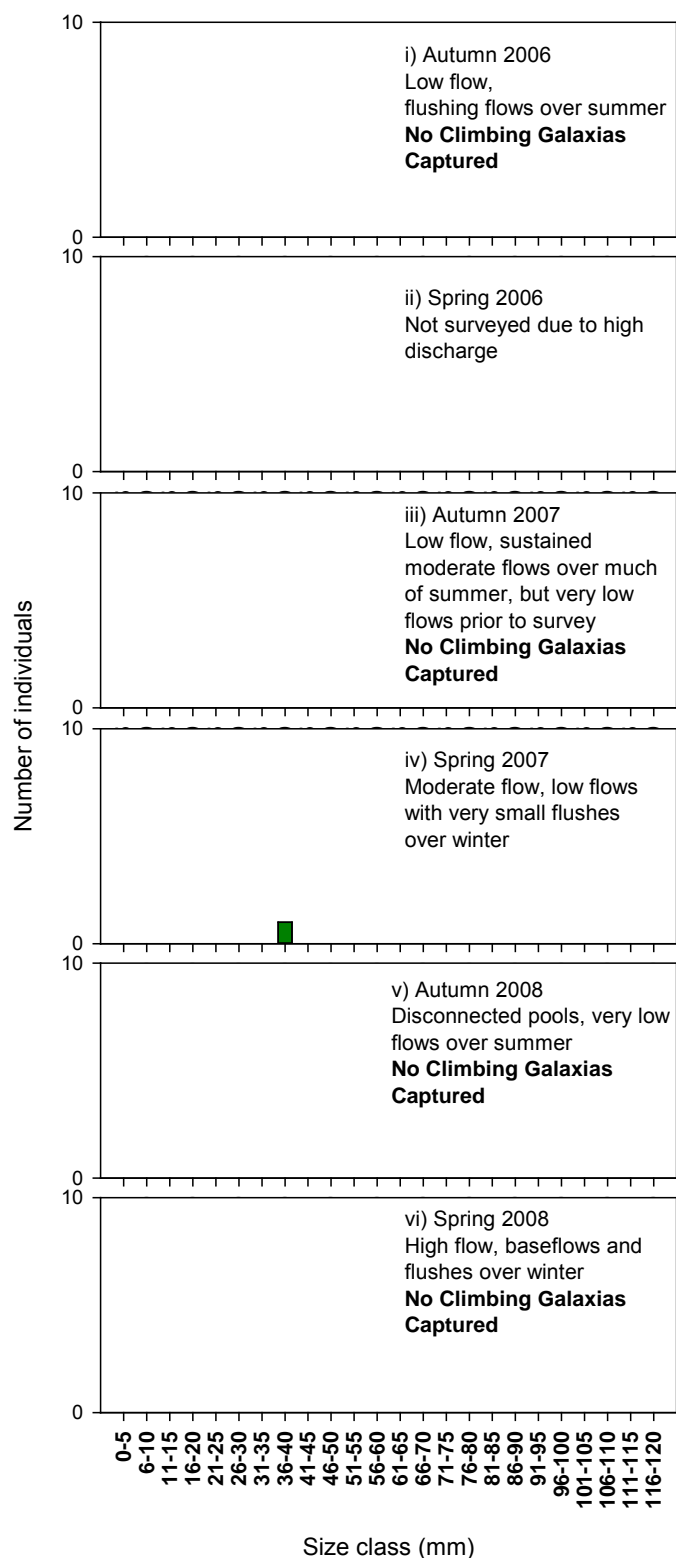


Figure 56. Lengths of climbing galaxias (*G. brevipinnis*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



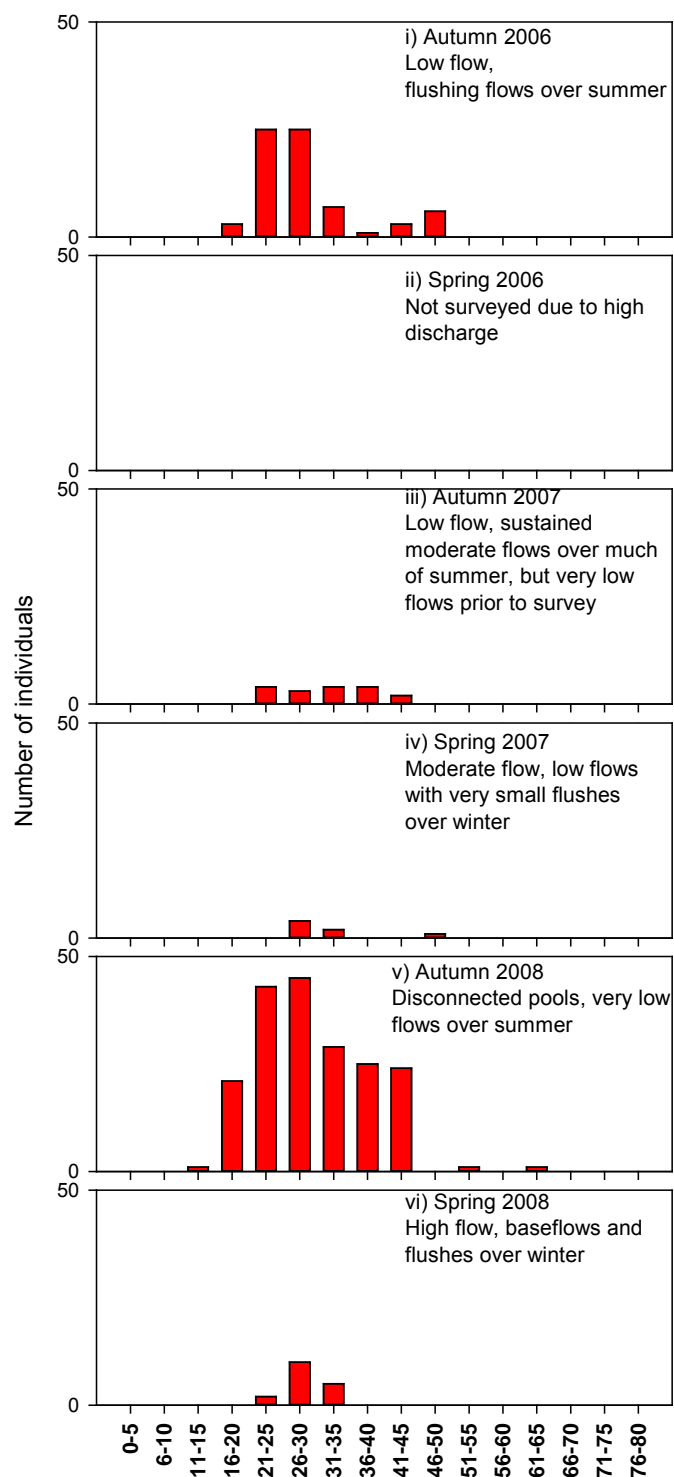


Figure 57. Lengths of gambusia (*G. holbrooki*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



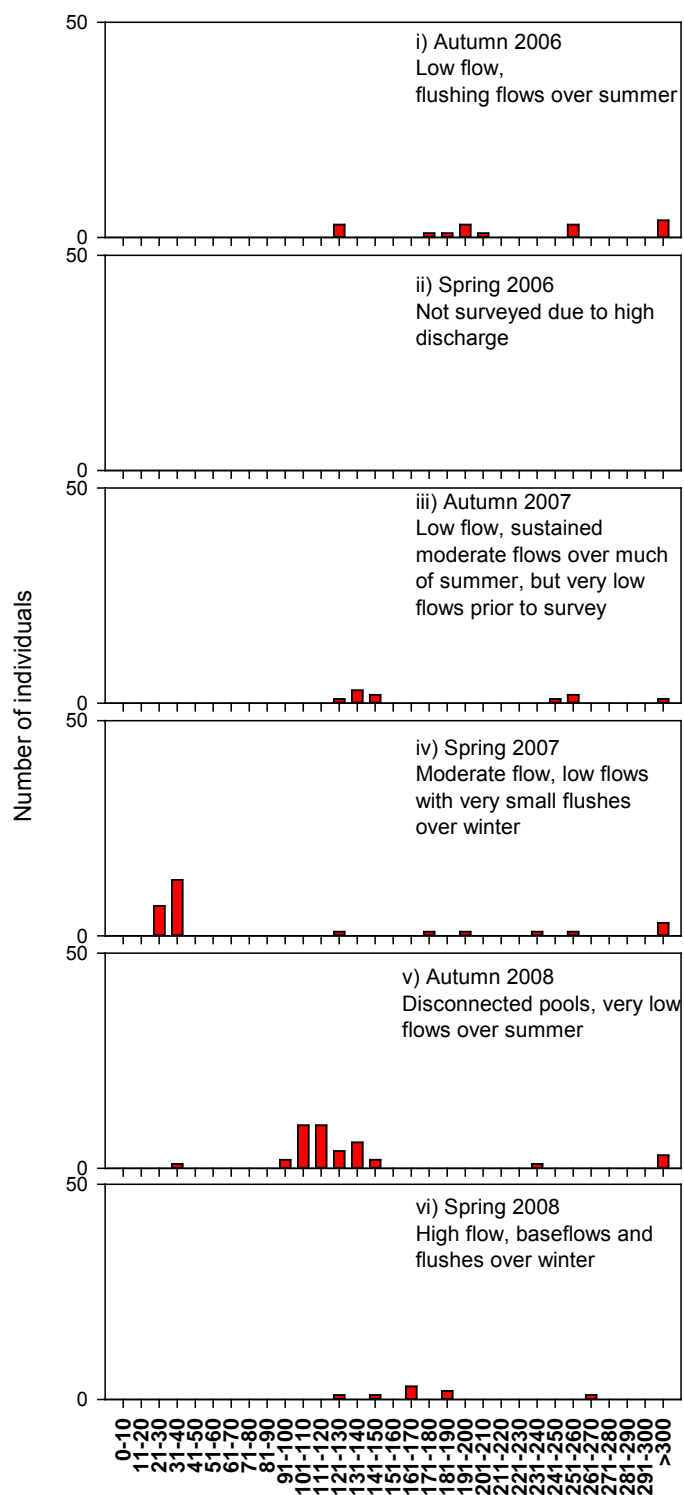


Figure 58. Lengths of redfin perch (*P. fluviatilis*) at Gumeracha Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.2.2. Cudlee Creek

3.2.2.1. Site assessment

The Cudlee Creek site is situated in the Cudlee Creek Conservation Reserve upstream of the Cudlee Creek township. All three pools are situated within a 1km reach with Pools 1 and 2 connected when full, and Pool 3 separated by a ~100m run riffle reach downstream of Pool 2 which is densely packed with *Phragmites*. The substrate of all three pools is rocky cobbles, with slightly smaller particle size in Pool 3 (Table 29). All pools were similar in depth and riparian cover with sparse overstorey of redgum and some bottlebrush with reasonable densities of *Phragmites*. Pools 1 and 3 had low densities of snags. Electrofishing was conducted upstream and downstream of the site when inundated as well as in the run between Pools 2 and 3. Pool 1 was not sampled during autumn 2008 as the pool was too shallow for fyke nets and the field team was concerned that active sampling with seines/electrofishing may endanger stressed fish within such a shallow pool.

Table 29. Habitat characteristics of the three monitoring pools at Cudlee Creek in the River Torrens.

Cudlee Creek	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	10+	10	3	1.8
Pool 2	10+	5	0	1.8
Pool 3	5-10	10	2	2.0

Pool 1 (Figure 59) consisted of a run riffle at the upstream extent becoming gradually deeper and at higher water levels joining with Pool 2. Due to consistently high water levels, Pools 1 and two only separated in autumn 2008. Dissolved oxygen, pH and water temperature remained at benign levels over the course of the study with little variation. Temperature fluctuated seasonally within 6 °C, whilst conductivity peaked in spring 2008 at 5080 µS/cm following the drying event in autumn that year (Table 30), although the impact of these salinity levels on fish is likely to be relatively low (McNeil *et al.* 2010a).

This site was not measured in spring 2006 due to very high transfer flows or in autumn 2008 due to extreme drying. Macrophyte cover remained relatively low and consistent and was largely represented by emergent *Phragmites* that fluctuated in cover with water levels. For the first four seasons, this site enjoyed flushes and freshes and was flowing to some degree when sampled before becoming isolated over summer 2008 and drying significantly, being reconnected in the following spring when high flows returned at the time of sampling.





Figure 59. Cudlee Creek Pool 1 in autumn 2008. Note this pool was not sampled in 2008 as water levels were too low to set nets (~10cm).

Table 30. Water quality parameters recorded in Cudlee Creek Pool 1 during each survey. Note this pool was not sampled in spring 2006 and autumn 2008.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1029	7	13.2	1.8	15	Baseflow	Flushes
2006	spring	Not sampled				(2m+)	-	High flow	Flushes
2007	autumn	7	646	7	16.4	1.8	10	Low flow	Freshes
2007	spring	8	364	8	20.3	1.2	10	Low flow	Freshes
2008	autumn	Not sampled				0.2	0	No flow	low flows
2008	spring	9.2	5080	7.6	18.4	1.5	10	High flow	low flows

The physical characteristics of Pool 2 (Figure 60) were very similar to Pool 1 with dissolved oxygen, pH, water temperature and conductivity following almost identical patterns (Table 31). Macrophyte cover, again due largely to emergent *Phragmites* beds was relatively low, whilst maximum depth varied little except for extreme drying of the pool in autumn 2008 (see Figure 60). Flushes and freshes occurred in the first four seasons and pool 2 was flowing to some degree when sampled before becoming isolated over summer 2008 and drying significantly, being reconnected in the following spring when high flows returned at the time of sampling.





Figure 60. Cudlee Creek Pool 2 in a) autumn 2007 and b) autumn 2008.

Table 31. Water quality parameters recorded in Cudlee Creek Pool 2 during each survey. Note this pool was not sampled in spring 2006.

Pool 2	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1031	7	13.3	1.8	10	Baseflow	Flushes
2006	spring	Not sampled				2.0+	-	High flow	Flushes
2007	autumn	8	551	8	15.3	1.8	5	Low flow	Freshes
2007	spring	9	358	8	21.0	1.8	5	Low flow	Freshes
2008	autumn	9	1500	8	13.8	0.3	0	No flow	Very low flows
2008	spring	9	5040	7.7	18.7	1.8	1	High flow	low flows

Pool 3 (Figure 61) varied little in regards to dissolved oxygen, pH, water temperature (with seasonal fluctuations) and conductivity (Table 32). Macrophyte cover was primarily emergent *Phragmites* which varied little also between sampling seasons. As with the other pools, this pool enjoyed flushes and freshes for the first four seasons and was flowing to some degree when sampled before becoming isolated over summer 2008 and drying somewhat, being reconnected in the following spring when high flows returned at the time of sampling. Pool 3 was less impacted by drought and maintained a depth of ~1m during autumn 2008, making this the most permanent of the three Cudlee Creek pools.





Figure 61. Cudlee Creek Pool 3 in a) spring and b) autumn 2008.

Table 32. Water quality parameters recorded in Cudlee Creek Pool 3 during each survey. Note this pool was not sampled in spring 2006.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	11	985	8	14.3	2.0	20	Baseflow	Flushes
2008	spring	Not sampled				(2.0+)	-	High flow	Flushes
2007	autumn	10	523	8	15.2	2.0	10	Low flow	Freshes
2007	spring	10	325	8	21	1.6	5	Low flow	Freshes
2008	autumn	13	1400	8	13.3	1.0	0	No flow	Very low flows
2008	spring	Not sampled				2.0	5	High flow	low flows

3.2.2.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.2.2.3. Hydrology

The water level at Cudlee Creek was relatively high, compared to the other sites during the present surveys. In 2006 the water level was moderate during autumn, and was too high to allow nets to be set in spring. In autumn 2007 the water level was low, but it was moderate in spring 2007. The only time that the pools at Cudlee Creek were disconnected was during the autumn 2008 survey. In spring 2008, the water level was high.

Except for a pulsed fresh in mid-July, flow was typically low at the Cudlee Creek gauge from the time that data was collected in late June 2006 until early October 2006 (Figure 62). There was then



a sustained fresh from October 6 to November 17, 2006, and flow was too high to allow nets to be set at this site in the spring. Flows were low at the gauge for most of the remainder of the year. In 2007, baseflows were maintained throughout January, followed by a sustained fresh from the beginning of February until mid-March. There were then low flows from this time until mid-April, followed by a brief period of zero flow, which was alleviated by a large fresh (>70 ML) on April 29. From this time there were low flows at Cudlee Creek up to the autumn 2007 surveys, conducted on May 8.

Low flows continued until late June, followed by sustained baseflow plus a number of freshes and flushes from late June until the end of July. Flows declined from baseflows in early August to low flows by mid-August. However, baseflows returned from early September to November 11. This was followed by a week and a half of low flows up to the spring 2007 surveys, conducted on November 22. Baseflows returned for three weeks after these surveys, but there was no readable flow by the beginning of 2008. This absence of flow continued until the autumn 2008 surveys, conducted on April 17. Over winter 2008 there were good baseflows and some freshes. The flow ended in September, and resumed shortly before November 2008.

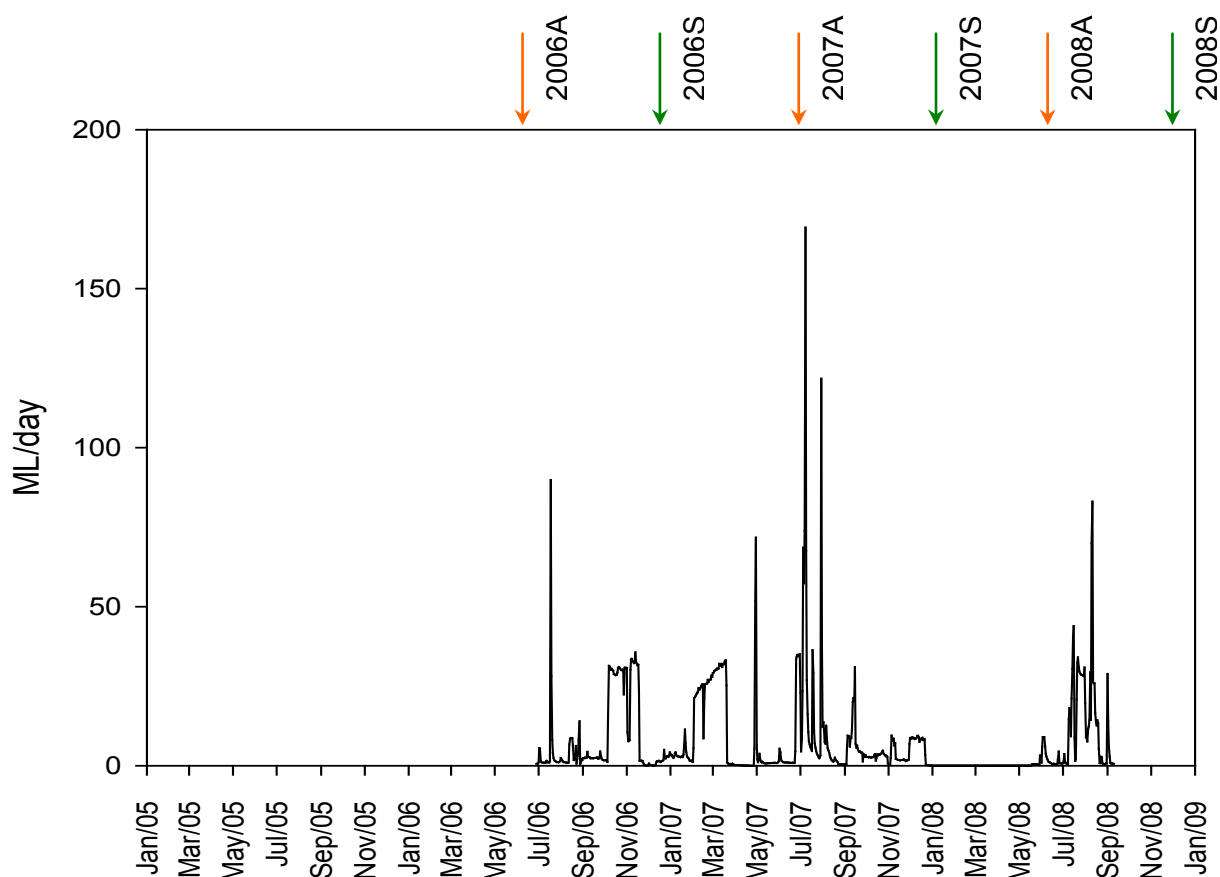


Figure 62. Hydrograph for flow in Torrens River at Cudlee Creek. Flow data (ML/day) was collected at Cudlee Creek (gauge number A5041019) from June 27, 2006 (indicated by blue arrow). The timing of each survey season is also shown above the figure. Note that no survey was possible during spring 2006 due to the prevailing high discharge at the survey site.



3.2.2.4. Fish community

Four native and three introduced fish species were captured at Cudlee Creek over the five survey seasons (Figure 63). In most seasons there were only relatively small numbers of fish captured, and there was considerable variation in the proportions of each taxa captured across seasons. During the first survey season, in autumn 2006, 90% of the total capture consisted of similar numbers of flathead gudgeon and redfin perch. These numbers decreased in each subsequent survey. Small numbers of dwarf flathead gudgeon were captured during all surveys, whereas climbing galaxias were captured only during autumn and spring 2007, and spring 2008. During the last four surveys a large proportion of gambusia were captured, and were the most common fish captured over the last two autumns. Small numbers of carp were also captured during the past four surveys.

Across successive autumns, from 2006 to 2008, the fish community at Cudlee Creek changed from being dominated by flathead gudgeon and redfin perch to being dominated by gambusia. This dominance by gambusia during autumn 2008 was closely associated with pools becoming disconnected and having low water depths at the time of surveys. During spring surveys there were few fish captured and considerable variability in the structure of the communities among pools. The site-scale community structure during spring was distinctly different from that occurring during all autumn surveys, reflecting the comparatively high temperatures and disconnection prior to autumn and the pulsed high flows prior to the spring surveys.

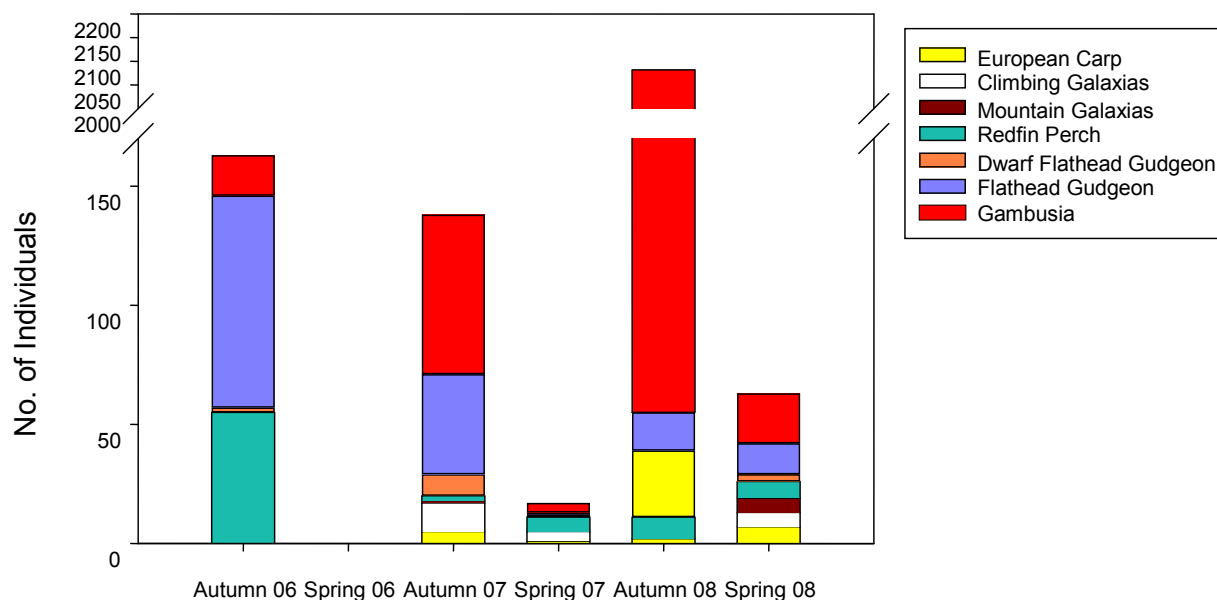


Figure 63. Abundances of each taxa present in the fish communities at Cudlee Creek (Torrens River) over six survey seasons. There was no survey data for this site in spring 2006 due to very high flow related to River Murray water transfers.



3.2.2.5. Fish Population Structure

A large number of small flathead gudgeon, as well as a number of larger individuals from a wide range of size classes, were captured during the initial surveys conducted at Cudlee Creek in autumn 2006 (Figure 64). Many medium sized individuals were captured in spring 2006. However, there were far fewer small individuals captured in autumn 2007, and a low number of large individuals captured in spring 2007. In autumn 2008 there was again a large number of small individuals. These smaller fish appear to have persisted at the site and matured to larger individuals. A small number of dwarf flathead gudgeon were captured (Figure 65) with the highest number occurring during autumn 2008. The size class captured in spring 2008 was similar to that captured in the preceding autumn.

Climbing galaxias were captured in 2007, with large individuals in reproductive condition captured in autumn and small individuals captured in spring (Figure 66). In 2008, climbing galaxias were absent in the autumn survey, but a cohort of new recruits did appear in spring. There was only one adult mountain galaxias captured during autumn 2007 (Figure 67). However, with the increased flows prior to the spring 2008 survey, a large number of new recruits were captured.

There was much fluctuation in the numbers of gambusia captured amongst survey seasons (Figure 68). The size distribution during each survey did not vary a great deal, reflecting the constant recruitment typical of this species.

A large number of medium to large sized redbfin perch were captured during autumn 2006 (Figure 69). However, in all subsequent surveys there were only a small number of individuals recorded. A small number of new recruits were evident in spring 2008.



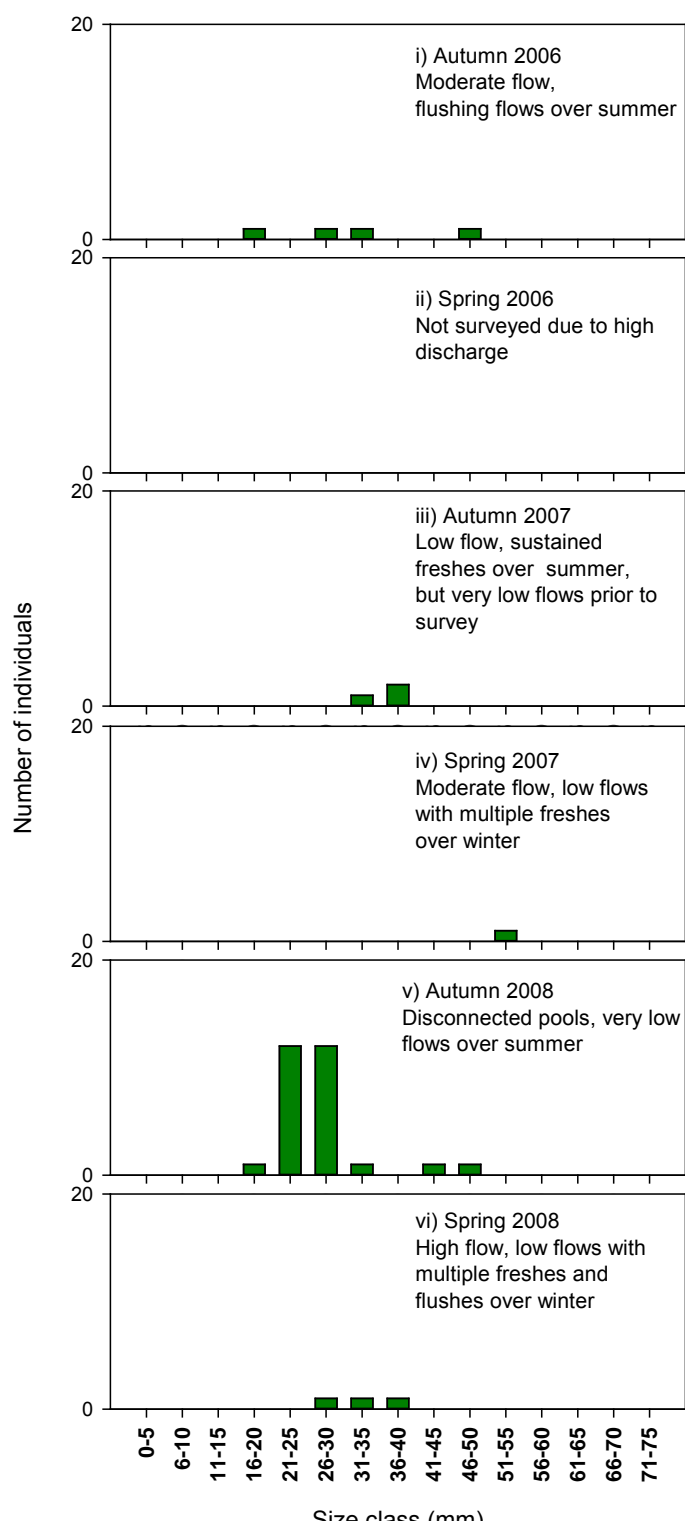


Figure 64. Lengths of dwarf flathead gudgeon (*P. macrostomus*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



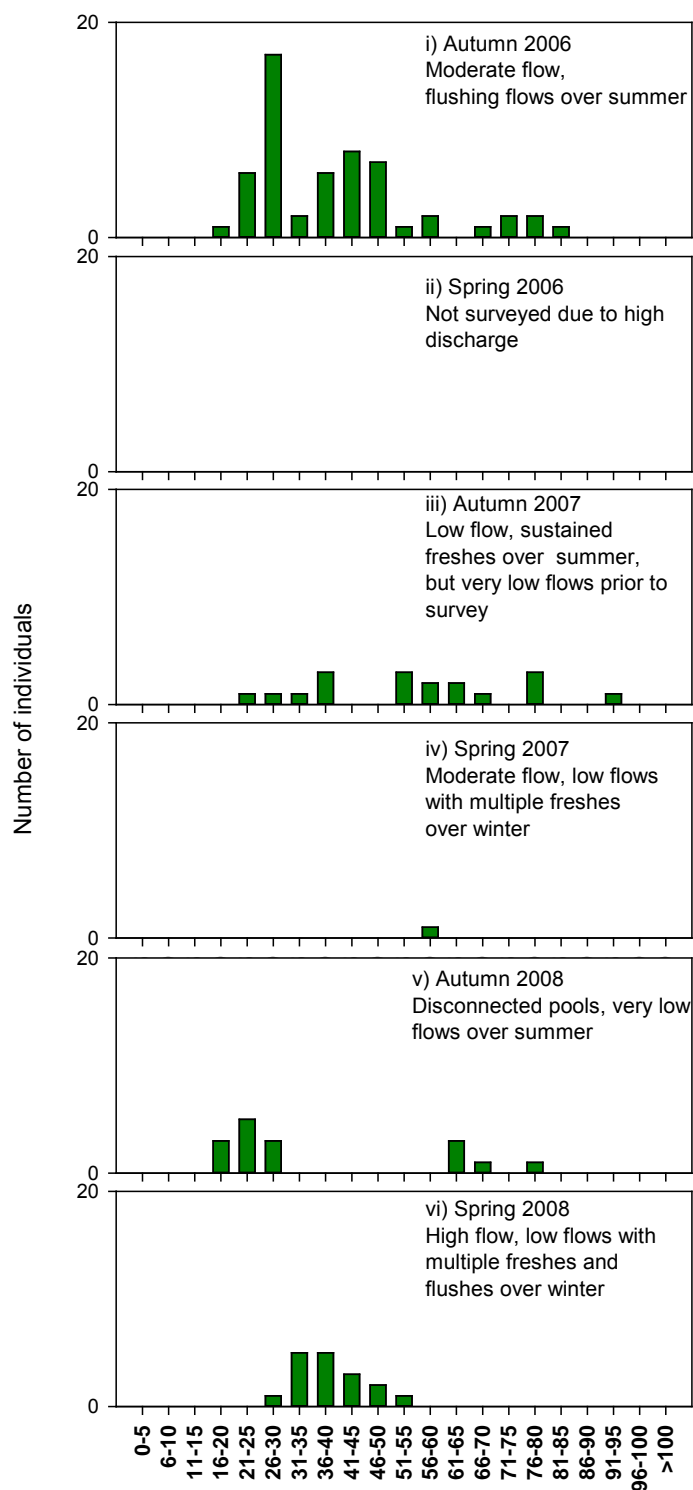


Figure 65. Lengths of flathead gudgeon (*P. grandiceps*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



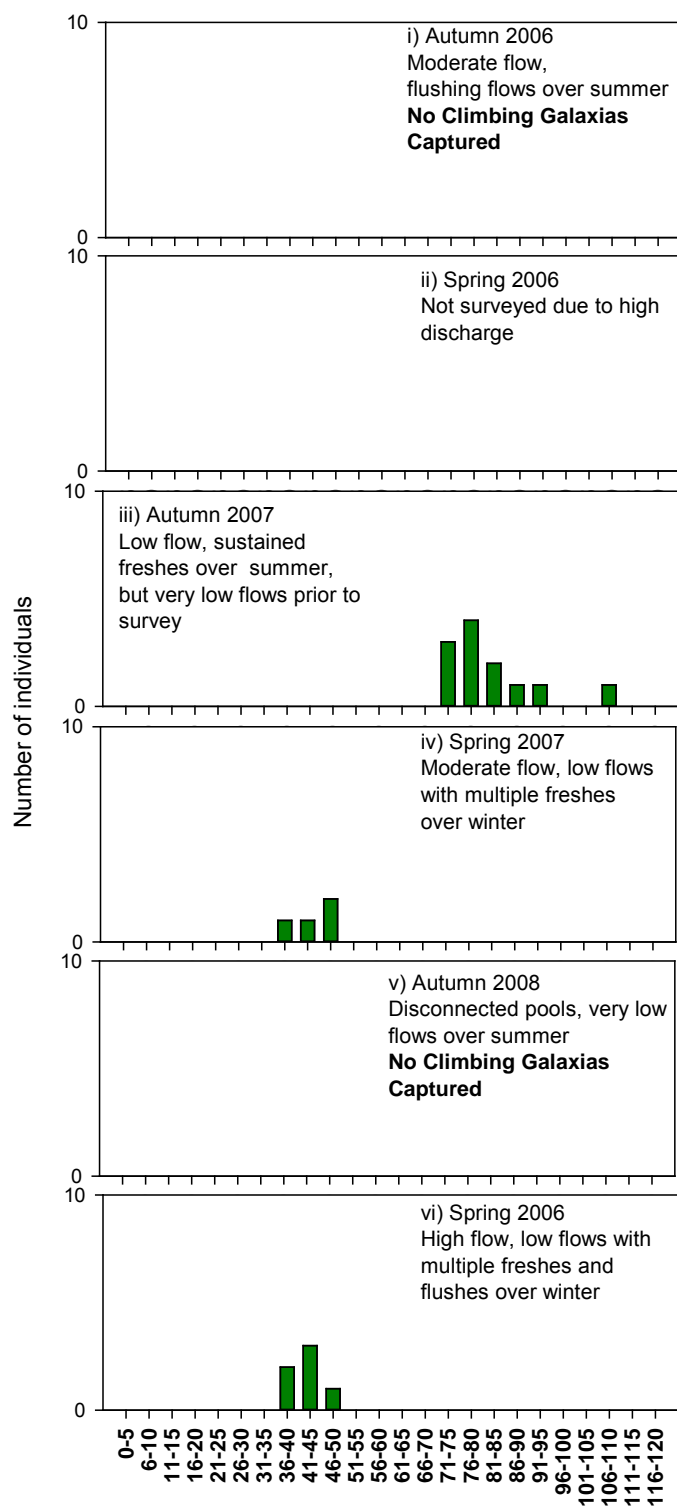


Figure 66. Lengths of climbing galaxias (*G. brevipinnis*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



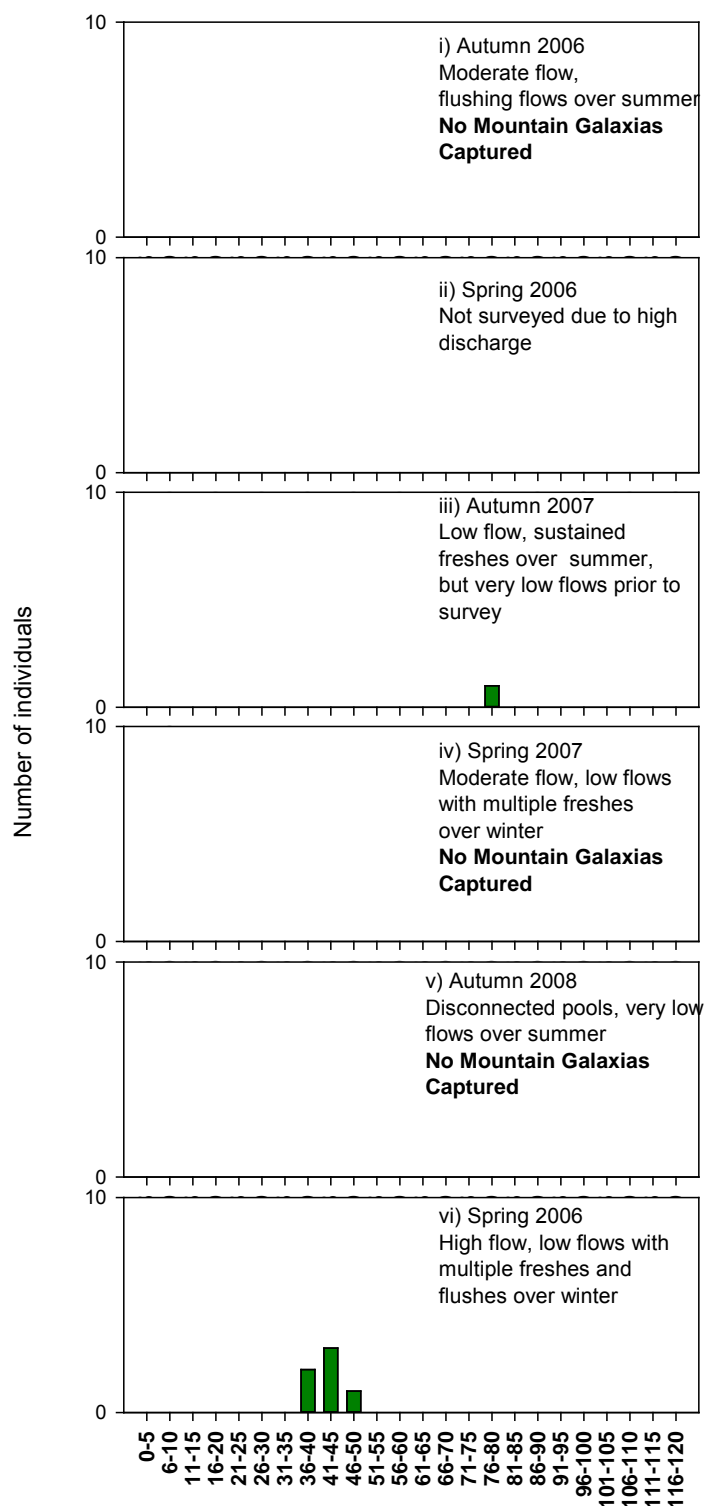


Figure 67. Lengths of mountain galaxias (*G. olidus*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



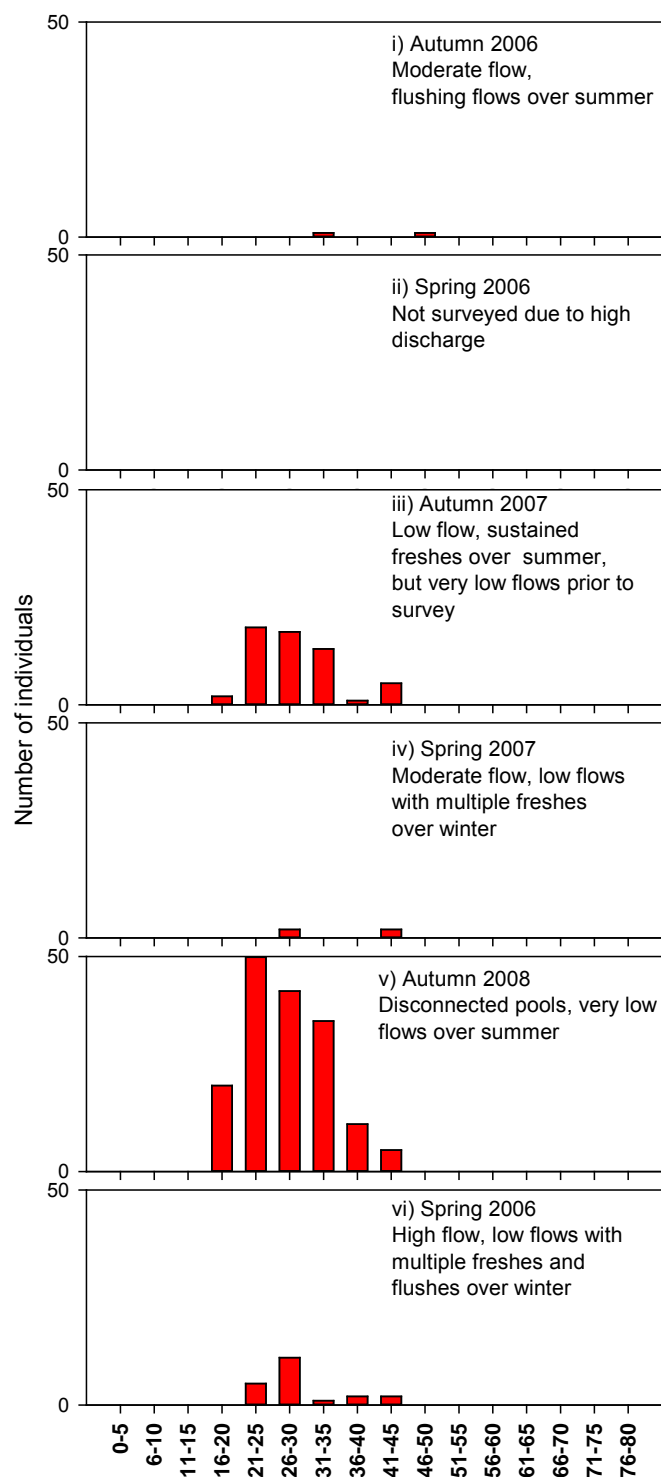


Figure 68. Lengths of gambusia (*G. holbrooki*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



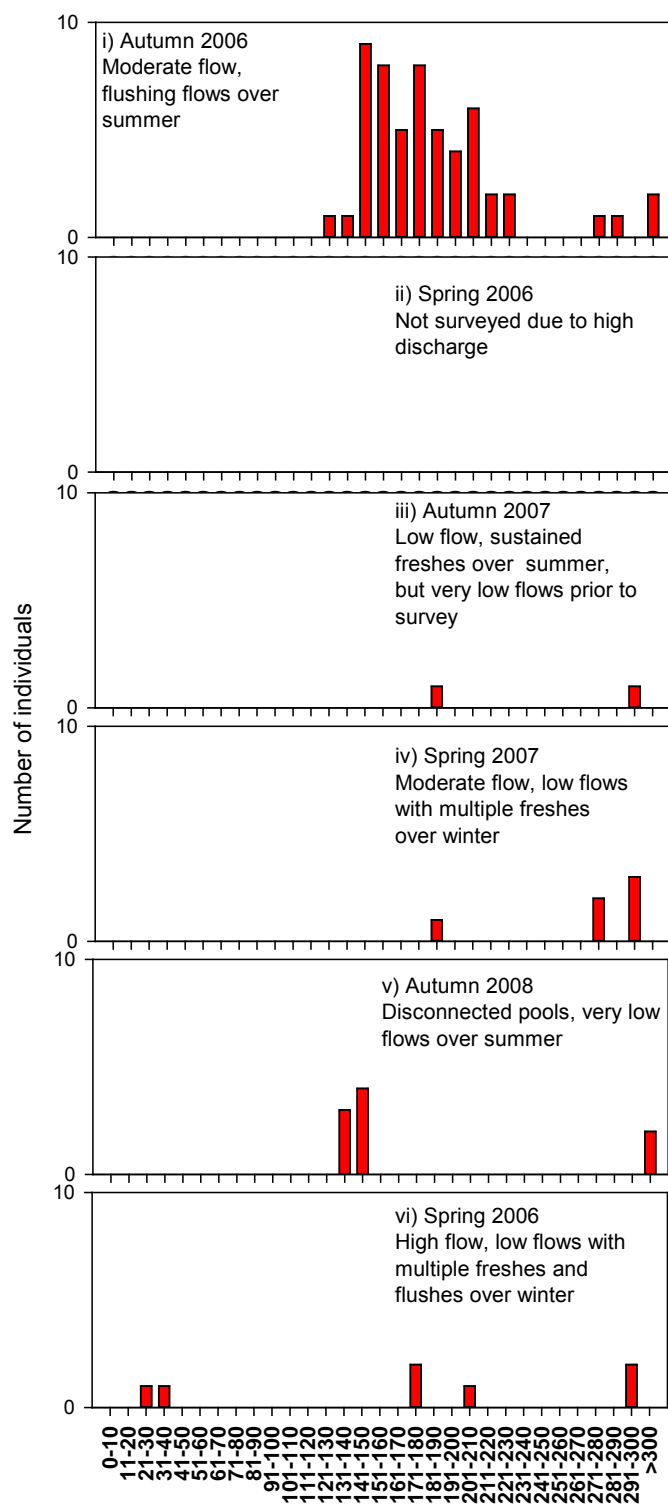


Figure 69. Lengths of redfin perch (*P. fluviatilis*) at Cudlee Creek (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.2.3. Gorge Weir

3.2.3.1. Site assessment

The three pools were situated directly below the Gorge Weir. All pools possessed cobbled and gravel substrates, low levels of snags and dense riparian vegetation (Table 33); even though the riparian overstorey was somewhat sparse and introduced vegetation was dominant. Electrofishing was conducted between upstream and downstream of the sampling pools all of which had run/riffle reaches dominated by *Phragmites*. Pool 1 was the deepest and largest pool, with Pool 2 being the shallowest at ~1.5m maximum depth.

Table 33. Habitat characteristics of the three monitoring pools at Gorge Weir in the River Torrens.

Gorge Weir	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	<1-10	30	0	3.0
Pool 2	<1-10+	80	1	1.5
Pool 3	<1-10+	80	2	2.0

Pool 1 (Figure 70) is located a few hundred metres downstream of the weir wall beneath the water transfer pipe beside the Gorge Rd. This pool was a deep and relatively large pool with benign and reasonably stable salinity, dissolved oxygen, pH, water temperature and depth (Table 34). Riparian cover is relatively sparse and predominantly exotic trees and shrubs (i.e. *Salix* spp.) with some eucalypts on higher on the banks. Macrophyte cover was relatively low and dominated by emergent *Phragmites* beds that varied with water depth. The flow conditions during sampling were always either low or no flow whilst the antecedent flow conditions consisted of baseflows and flushes across all seasons.

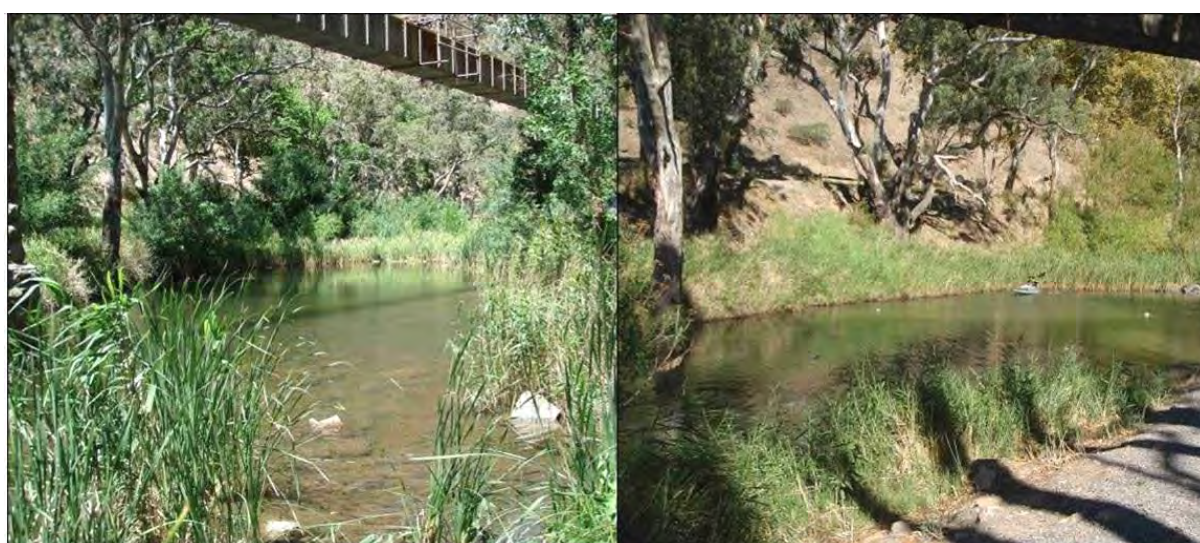


Figure 70. Gorge Weir Pool 1 in a) spring 2006 and b) autumn 2008.



Table 34. Water quality parameters recorded in Gorge Weir Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	909	8	13.8	2.5	10	Low flow	Flushes
2006	spring	8	1258	8	17.7	3.0	10	No flow	Baseflows
2007	autumn	8	615	7	16.5	2.5	5	Low flow	Base/Flushes
2007	spring	7	833	6	18.3	2.5	10	No flow	Flushes
2008	autumn	12	900	8	15.7	2.0	5	No flow	Baseflows
2008	spring	9	499	7.8	19.7	2.0	5	Low flow	Base/Flushes

Pool 2 (Figure 71) is located a few hundred metres downstream of Pool 1. This pool was a shallower and relatively small pool with benign and reasonably stable salinity, dissolved oxygen, pH, water temperature and depth (Table 35). Riparian cover is relatively dense and predominantly eucalypts. Macrophyte cover was relatively high and dominated by emergent *Phragmites* and cumbungi beds that varied with water depth. The flow conditions during sampling were always either low or no flow whilst the antecedent flow conditions consisted of baseflows and flushes across all seasons.

**Figure 71. Gorge Weir Pool 2 in a) spring 2006 and b) autumn 2008.**

Table 35. Water quality parameters recorded in Gorge Weir Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	815	8	12.8	1.5	40	Low flow	Flushes
2006	spring	4	1070	8	18.4	1.5	10	No flow	Baseflows
2007	autumn	7	646	7	16.4	1.4	10	Low flow	Baseflows + flush
2007	spring	8	857	5	17.4	1.5	5	No flow	Flushes
2008	autumn	10	800	8	14.9	1.5	5	No flow	Baseflows
2008	spring	7.5	509	7.8	21	1.5	30	No flow	Baseflows

Pool 3 (Figure 72) was narrower and shallower than Pool 1 and dominated by thick stands of riparian vegetation (predominantly exotic species) and emergent *Phragmites* beds on all sides which varied in cover between 5% and 30%. Whilst spring 2006 saw low dissolved oxygen levels and slightly increased salinities, water quality parameters were consistent and benign throughout the study (Table 36). Water depth did not fluctuate tremendously throughout the study, with flow conditions consistently low or still, whilst antecedent flow consisted of baseflows and/or flushes.

**Figure 72. Gorge Weir Pool 3 in a) spring 2006 and b) autumn 2008.**

Table 36. Water quality parameters recorded in Gorge Weir Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1093	8	13.5	2.0	20	Low flow	Flushes
2006	spring	4	1338	7	18.4	1.2	20	No flow	Baseflows
2007	autumn	5	800	7	16.7	2.0	30	Low flow	Baseflows/flushes
2007	spring	8	870	6	17.7	1.5	5	No flow	Flushes
2008	autumn	13	900	8	16.4	1.0	25	No flow	Baseflows
2008	spring	8.5	506	7.7	20	2.0	30	Low flow	Baseflows/flushes

3.2.3.2. Water Quality

Dissolved oxygen levels were low during 2006 and may have impacted on particularly sensitive species (McNeil and Closs 2007), although it is not expected that any species in the WMLR would be overly sensitive to recorded levels. Salinity was the only other water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.2.3.3. Hydrology

The water flow was low at Gorge Weir during the autumn surveys of 2006 and 2007, and the spring survey in 2008. Pools were disconnected during spring 2006 and 2007, and autumn 2008. Baseflow was maintained, and there was a small fresh, at Gorge Weir from the time that gauge data was collected at the end of June 2006 to the spring 2006 surveys, conducted on November 24 (Figure 73).

Baseflow continued through to the end of April 2007 and there was a small flushing flow of over 100 ML/day for two days the week before the autumn 2007 surveys were conducted, on May 3. The winter of 2007 was much wetter than that of 2006. There were three large flushing flows in June and July, followed by sustained freshes in August and high baseflows (>8 ML/day) throughout September. Flow then dropped and was low from mid-October until there was a small pulsed fresh of 12 ML two days prior to the spring 2007 surveys, conducted on November 20. Baseflow was maintained from this date until the autumn 2008 surveys, conducted on April 17. Subsequent to the autumn survey, there were very low flows right up to the spring survey apart from two large flushes.



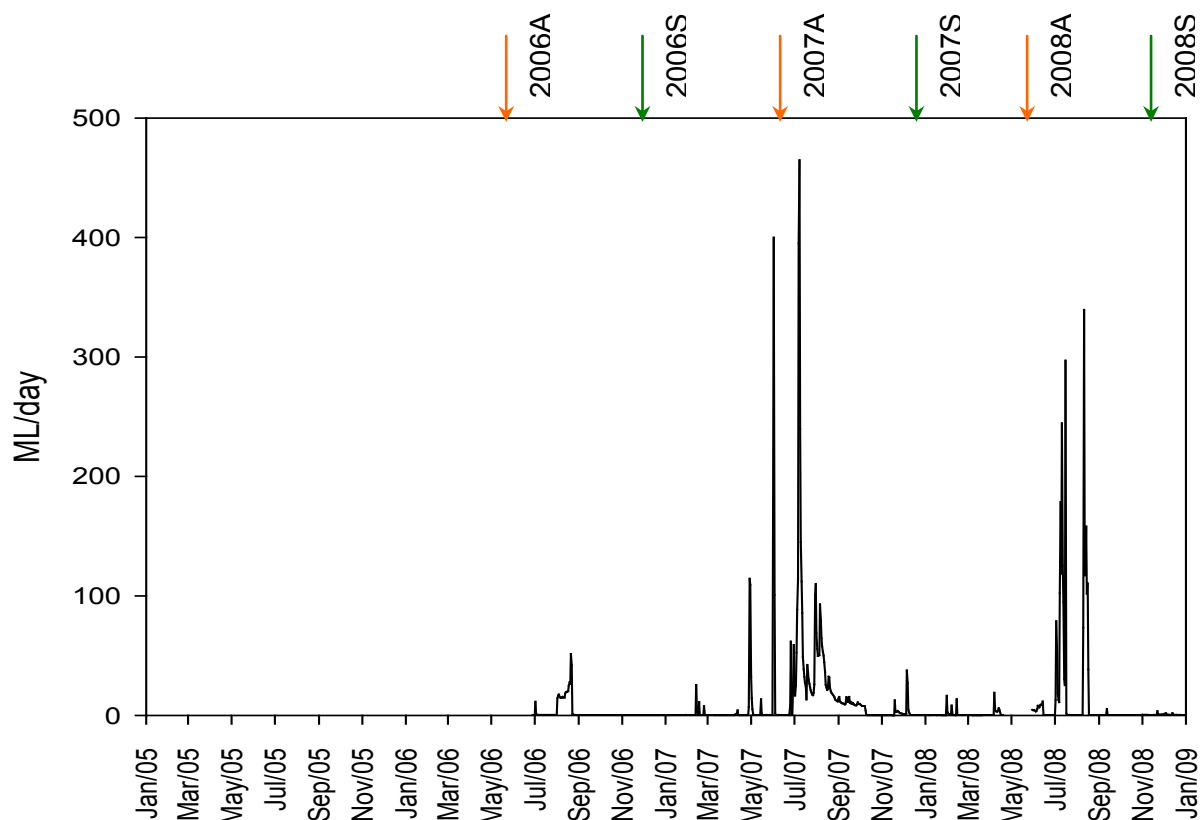


Figure 73. Hydrograph for flow in Torrens River at Gorge Weir. Flow data (ML/day) was collected at Gorge Weir (gauge number A5041018) from June 27, 2006 (indicated by blue arrow). The timing of each survey season is also shown above the figure.

3.2.3.4. Fish community

Six native and four introduced fish species were captured at Gorge Weir over the six survey seasons (Figure 74). Flathead gudgeon were the most commonly captured species during most survey seasons, with all other native taxa being rarely captured. Dwarf flathead gudgeon were captured in very low numbers during both 2008 surveys. Both common galaxias (one individual) and mountain galaxias (ten individuals) were captured in riffles during electrofishing surveys in autumn 2006. Only one congolli was captured in spring 2007. Redfin perch were captured during all surveys, and were the most commonly captured species in 2007, particularly in autumn. Lower numbers were also collected during both 2008 surveys. Small numbers of brown trout were captured during all surveys, although that number declined over the course of the project. Very low numbers of rainbow trout were captured in the 2006 and 2007 spring surveys. Carp were captured during spring 2006 and autumn 2008. In spring 2008, the Gorge Weir site continued to be dominated by flathead gudgeon with a strong contingent of introduced predators in redfin perch and brown trout and a notable absence of any native species diversity.



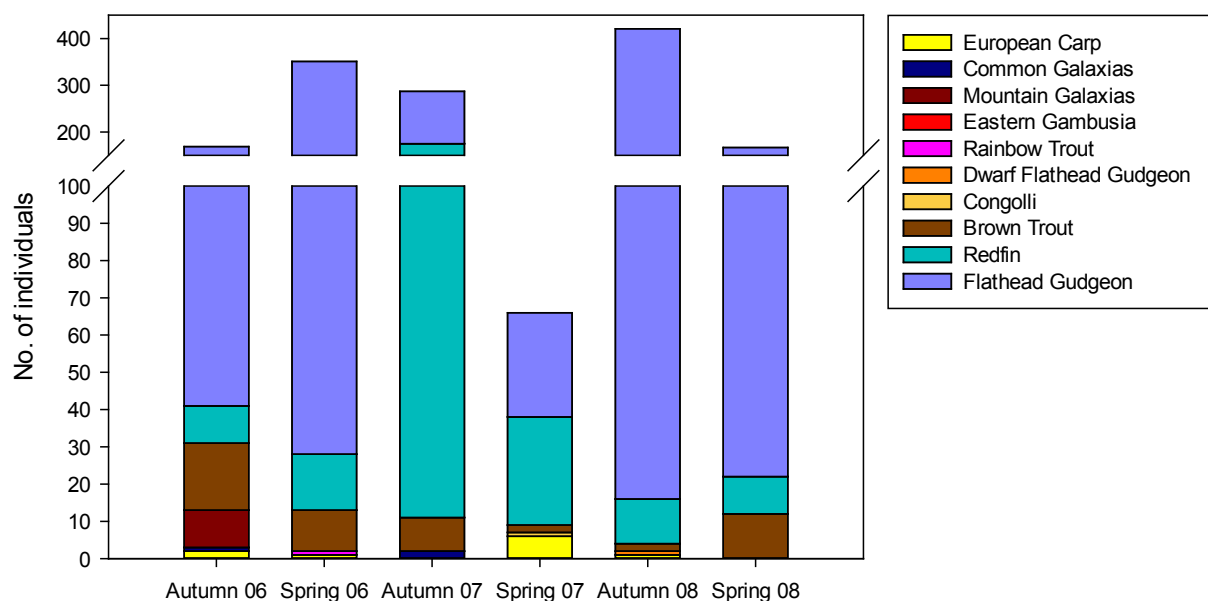


Figure 74. Abundances of each taxa present in the fish communities at Gorge Weir (Torrens River) over six survey seasons.

3.2.3.5. Fish population structure

Across surveys, there were large fluctuations in the numbers of flathead gudgeon captured at Gorge Weir. In 2006 there were large numbers of juveniles captured in autumn and of medium sized fish in spring (Figure 75). However, in 2007 there were no small flathead gudgeon captured in autumn and only a relatively small number of medium to large fish in spring. During autumn 2008, there were again large numbers of both small and large flathead gudgeon captured. In spring 2008, a range of sizes were present with the exception of larger individuals. There were three large individual common galaxias captured at Gorge Weir throughout the survey (Figure 76). Small and medium sized mountain galaxias were captured whilst electrofishing in autumn 2006 and again in spring 2008 (Figure 77)

The numbers of redfin perch captured peaked during autumn 2007, when large numbers of juveniles were captured (Figure 78). Relatively small numbers of redfin perch, of a wide range of sizes, were captured during all other surveys. Moderate numbers of mostly large brown trout were present in the first two surveys in 2006. However, after that the number declined in the catch and mostly smaller individuals were captured until spring 2008 when several larger brown trout were captured (Figure 79). In addition, one large adult congolli was captured at Gorge Weir, in spring 2007 (size = 263 mm).



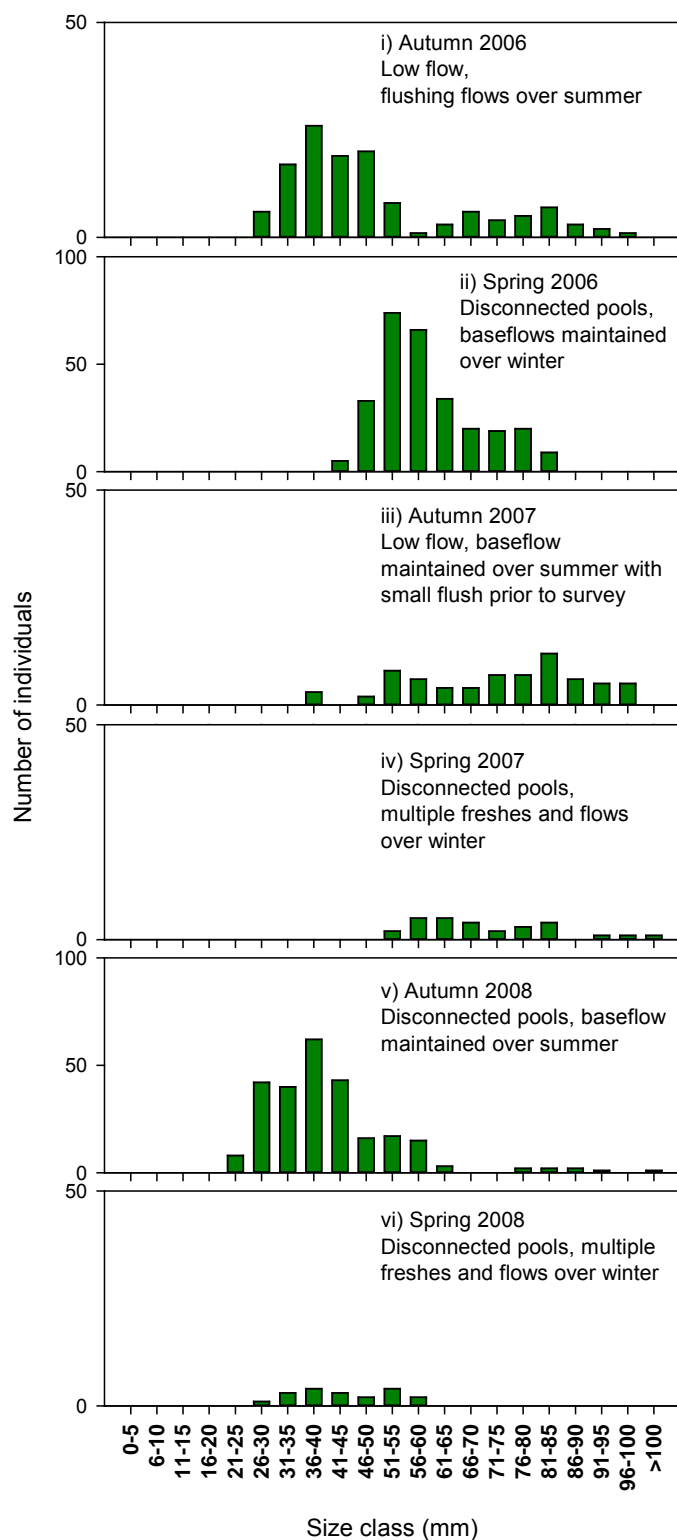


Figure 75. Lengths of flathead gudgeon (*P. grandiceps*) at Gorge Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



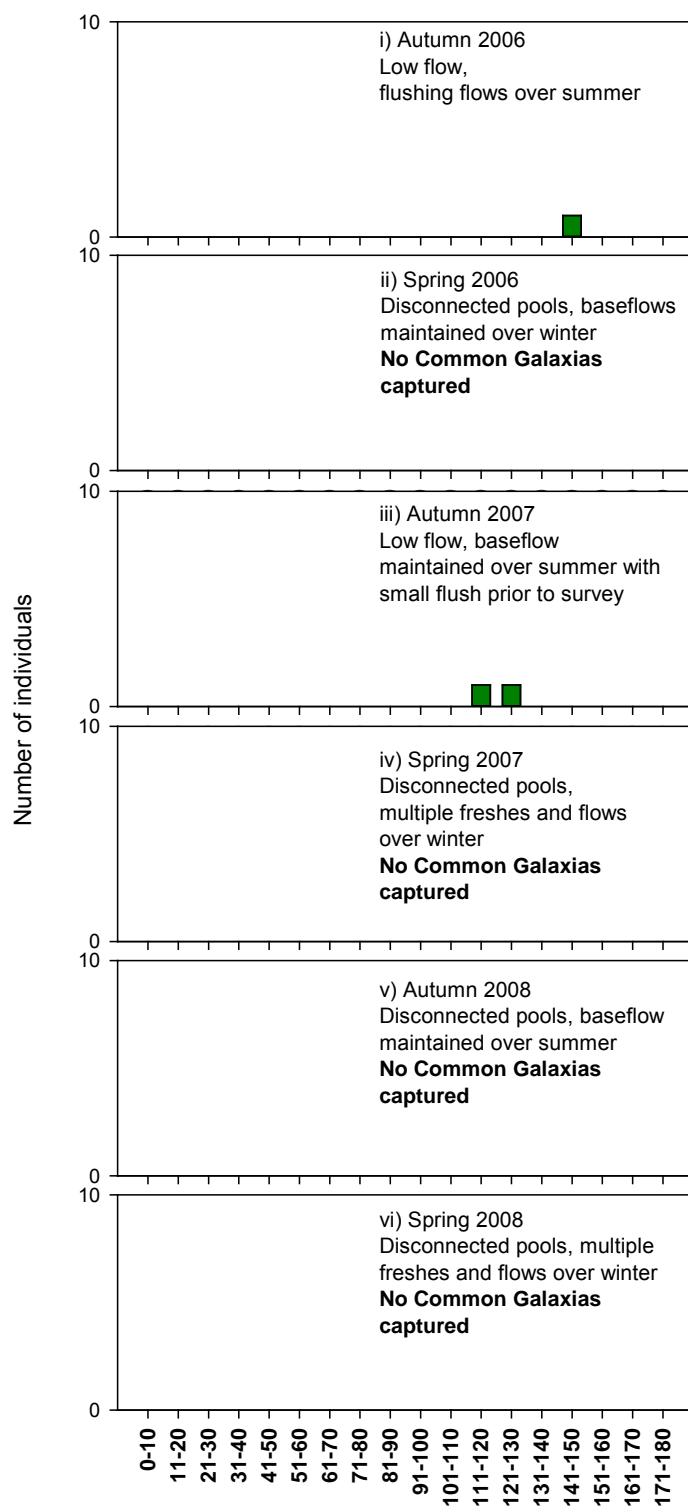


Figure 76. Lengths of common galaxias (*G. maculatus*) at Gorge Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



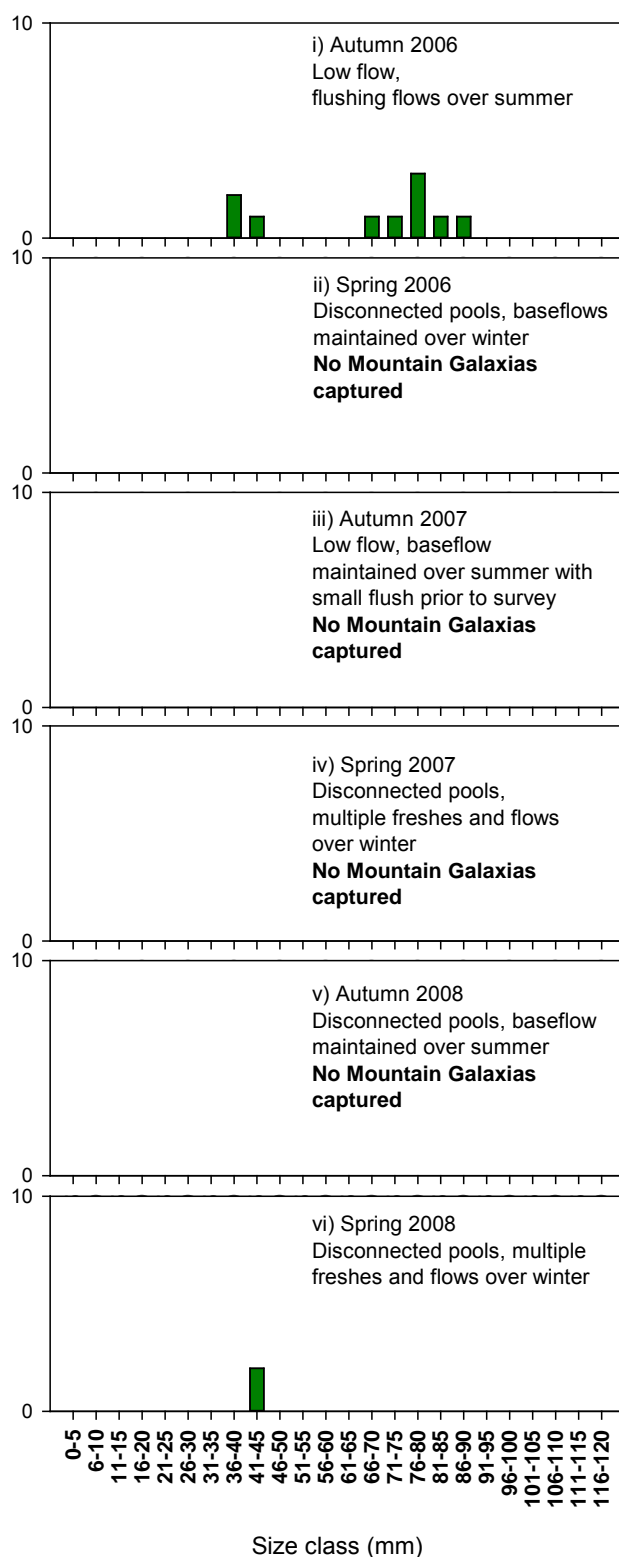


Figure 77. Lengths of mountain galaxias (*G. olidus*) at Gorge Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



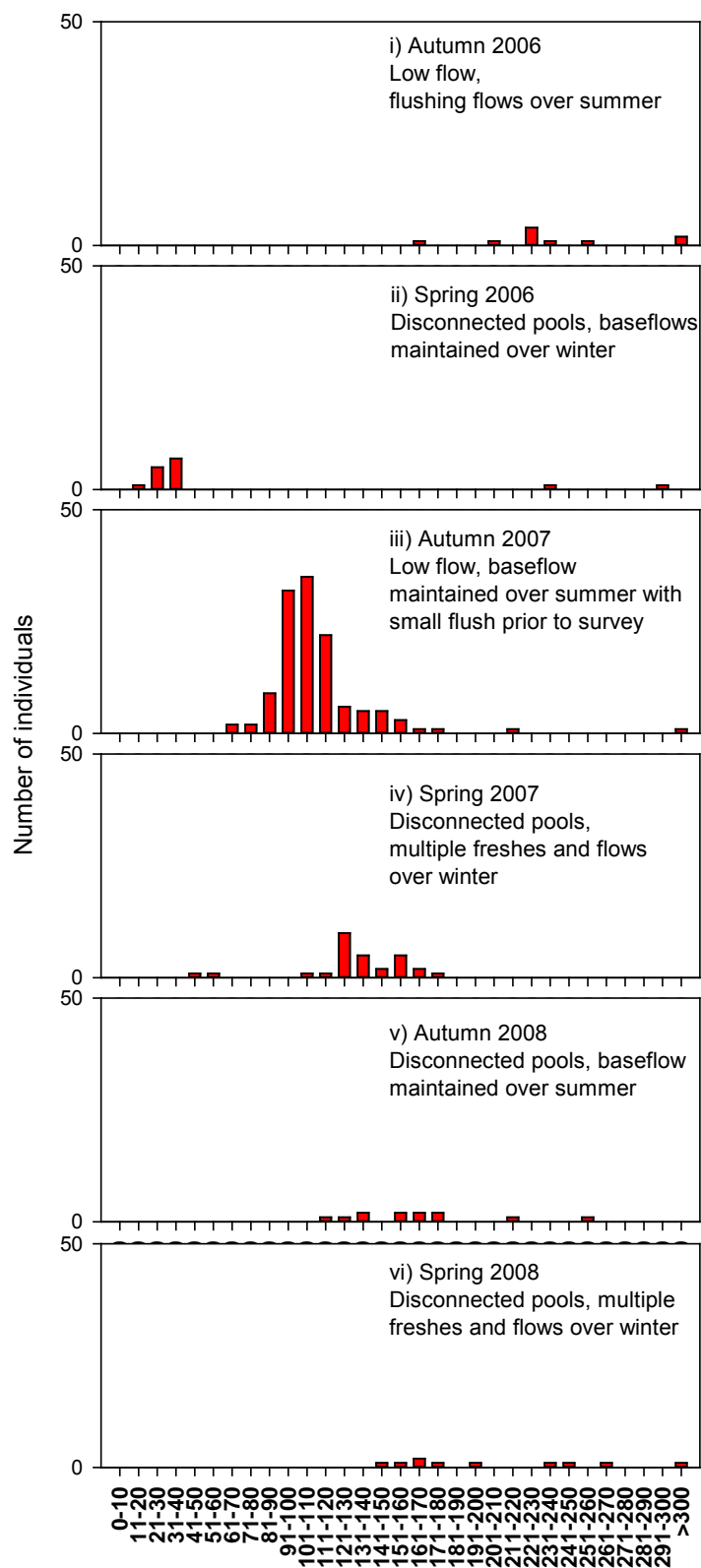


Figure 78. Lengths of redfin perch (*P. fluviatilis*) at Gorge Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



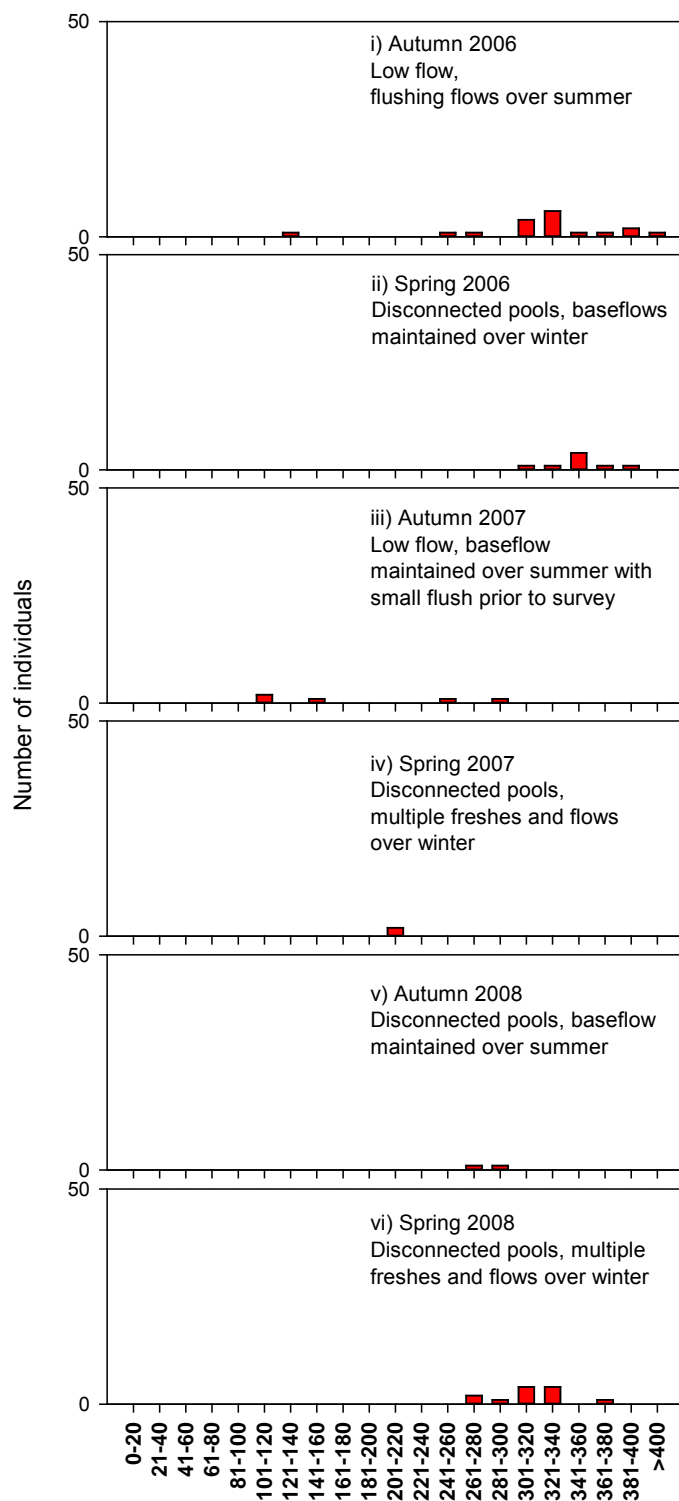


Figure 79. Lengths of brown trout (*Salmo trutta*) at Gorge Weir (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.2.4. Silke's Road

3.2.4.1. Site assessment

All three sites were located within a 1km stretch of the river which was narrow but reasonably deep (~2m) throughout the site. The substrates were predominantly rocky although pool 3 was dominated by silt (Table 37). Riparian vegetation varied with Pools 1 and 2 having very sparse overstorey and Pool 3 overhung by a few large redgums.

Table 37. Habitat characteristics of the three monitoring pools at Silke's Road in the River Torrens.

Silke's Road	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	<1-10+	10	1	2.0
Pool 2	<1-10+	5	0	2.0
Pool 3	<1-5	75	0	2.0

Pool 1 (Figure 80) was reasonable steep banked and completely surrounded by dense *Phragmites* and cumbungi beds. Whilst salinity was relatively high compared to other sites all water quality parameters and water depth were benign and reasonable consistent across sampling seasons (Table 38).

Estimates of macrophyte cover varied between 10% and 25% and were largely based on emergent cumbungi and *Phragmites* beds. Flow conditions were usually low during sampling with no flow recorded in both 2008 surveys. Antecedent flow conditions were predominantly low or very low flows with the exception of flushes preceding the autumn 2006 survey.



Figure 80. Silke's Road Pool 1 in a) spring 2006 and b) autumn 2008.



Table 38. Water quality parameters recorded in Silke's Road Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1733	8	12.8	2.0	25	Low flow	Flushes
2006	spring	5	1719	8	20.4	2.0	10	Low flow	Very low flow
2007	autumn	7	1366	7	16.5	2.0	20	Low flow	Very low /flushes
2007	spring	6	1535	5	21.6	2.0	25	Low flow	Low flow/flushes
2008	autumn	6	1500	8	16.9	1.8	10	No flow	Baseflows
2008	spring	4.6	3380	7.7	16.5	1.8	20	No flow	Low flow/flushes

Pool 2 (Figure 81) was very long and narrow and whilst as deep as pools 1 and 2 the maximum width was only ~ 2 m. Salinity in this pool was relatively high (Table 39) but not to levels that are likely to impact on fishes. All other water quality parameters were constantly benign. Water depth varied slightly across seasons whilst flow conditions were low during 2006 and 2006 and not flowing during 2008. Antecedent flows were variable with low flows, flushes and very low flows occurring across seasons. Macrophyte cover was largely emergent *Phragmites* and cumbungi and varied little across seasons.

**Figure 81. Silke's Road Pool 2 in a) spring 2006 and b) autumn 2008.****Table 39. Water quality parameters recorded in Silke's Road Pool 2 during each survey.**

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	9	1753	8	12.8	2.0	30	Low flow	Flushes
2006	spring	5	1778	8	20.5	2.0	30	Low flow	Very low flow
2007	autumn	8	1391	7	15.9	2.0	30	Low flow	Very low/flushes
2007	spring	8	1667	5	21.9	2.0	30	Low flow	Low flow/flushes
2008	autumn	7	2400	7	16.4	2.0	10	No flow	Baseflows
2008	spring	5.95	3720	7.26	18.1	1.5	30	No flow	Low flow/flushes



Pool 3 (Figure 82) was located below the footbridge linking the two sections of Silke's Rd. It had relatively stable water quality conditions across the survey, although dissolved oxygen was somewhat low in spring 2008 as was pH in spring 2007. Salinity was consistently high but not at levels likely to impact on biota (Table 40). Both water depth and temperature varied only slightly across seasons, whilst macrophyte cover varied more dramatically, based on the expansion of large beds of curly pondweed during spring in 2006 and 2008 and consistently low levels of emergent *Phragmites* at each end of the pool. Maximum depth became slightly lower during the drought in 2007 but was relatively stable across other seasons. Antecedent flows were variable with low flows, flushes and very low flows occurring across seasons.



Figure 82. Silke's Road Pool 3 in a) spring 2006 and b) autumn 2008.

Table 40. Water quality parameters recorded in Silke's Road Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	11	1780	8	12.7	2.0	10	Low flow	Flushes
2006	spring	7	1750	8	21.7	2.0	60	Low flow	Very low flow
2007	autumn	7	1428	8	15.1	2.0	5	Low flow	Very low/flushes
2007	spring	7	1707	5	20.7	1.8	5	Low flow	Low flow/flushes
2008	autumn	6	2100	8	16.1	1.5	5	No flow	Baseflows
2008	spring	4.6	2550	7.4	19.3	2.0	90	No flow	Low flow/flushes

3.2.4.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.



3.2.4.3. Hydrology

The water level was low at Silke's Road during each of the first three surveys, conducted in autumn 2006, spring 2006, and autumn 2007. During the last three surveys in spring 2007, autumn 2008 and spring 2008, the pools at Silke's Road were disconnected during surveys. The gauge data from Gorge Weir was used to determine the hydrology at Silke's Road between surveys. A detailed description of the hydrology is provided in the results for Gorge Weir.

3.2.4.4. Fish community

There were six native and four introduced fish species captured at Silke's Road over the six survey seasons (Figure 83). Flathead gudgeon were the most commonly captured taxa during autumn and spring 2006, high numbers continued to be collected; although they were less common than gambusia during the autumn 2008 survey. Small numbers of carp gudgeon were captured during all survey seasons. Very small numbers of galaxiids were captured throughout. Mountain galaxias were captured during the first three surveys and the spring 2008 survey, but not spring 2007 and autumn 2008.

One climbing galaxias was captured, in autumn 2006, and four common galaxias were captured in spring 2007. One freshwater catfish was also captured in spring 2007. Small numbers of goldfish were captured during the last four surveys. Two carp and one brown trout were captured in spring 2007.

The fish community at Silke's Road changed from being dominated by flathead gudgeon in 2006 to being dominated by gambusia in 2007 and autumn 2008. This shift occurred in association with the site becoming progressive drier each subsequent survey. The highest numbers of gambusia were captured in autumn, when water temperature was lower (but after a period of warm temperatures).



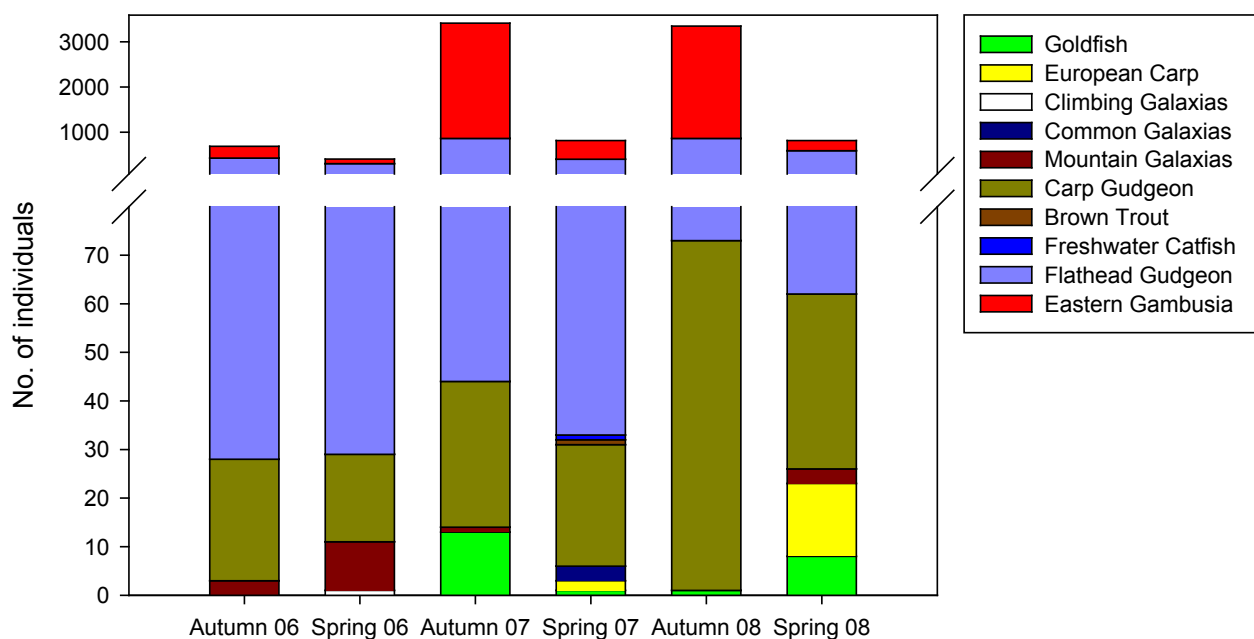


Figure 83. Abundances of each taxa present in the fish communities at Silke's Road (Torrens River) over six survey seasons.

3.2.4.5. Fish population structure

The numbers of flathead gudgeon captured at Silke's Road has been relatively high during all survey seasons and the size distribution was very consistent (Figure 84). Most of these fish were medium sized individuals, but both juveniles and large fish are also regularly captured.

There were a small number of medium sized carp gudgeon captured at Silke's Road (Figure 85). This population appears reasonably stable, but higher numbers were captured during autumn 2008.

Small numbers of mountain galaxias were captured but only during each of the first three survey seasons (Figure 86). In addition, three adult common galaxias were captured in spring 2007. One large adult climbing galaxias was captured during spring 2006 (size = 46 mm).

The gambusia population at Silke's Road appears to be relatively stable, with relatively high numbers of small to medium sized individuals captured throughout the surveys (Figure 87). Goldfish were not captured during 2006 (Figure 88). Several smaller individuals were captured in autumn 2007. One individual was captured during both spring 2007 and autumn 2008, but then several larger individuals were captured spring 2008.



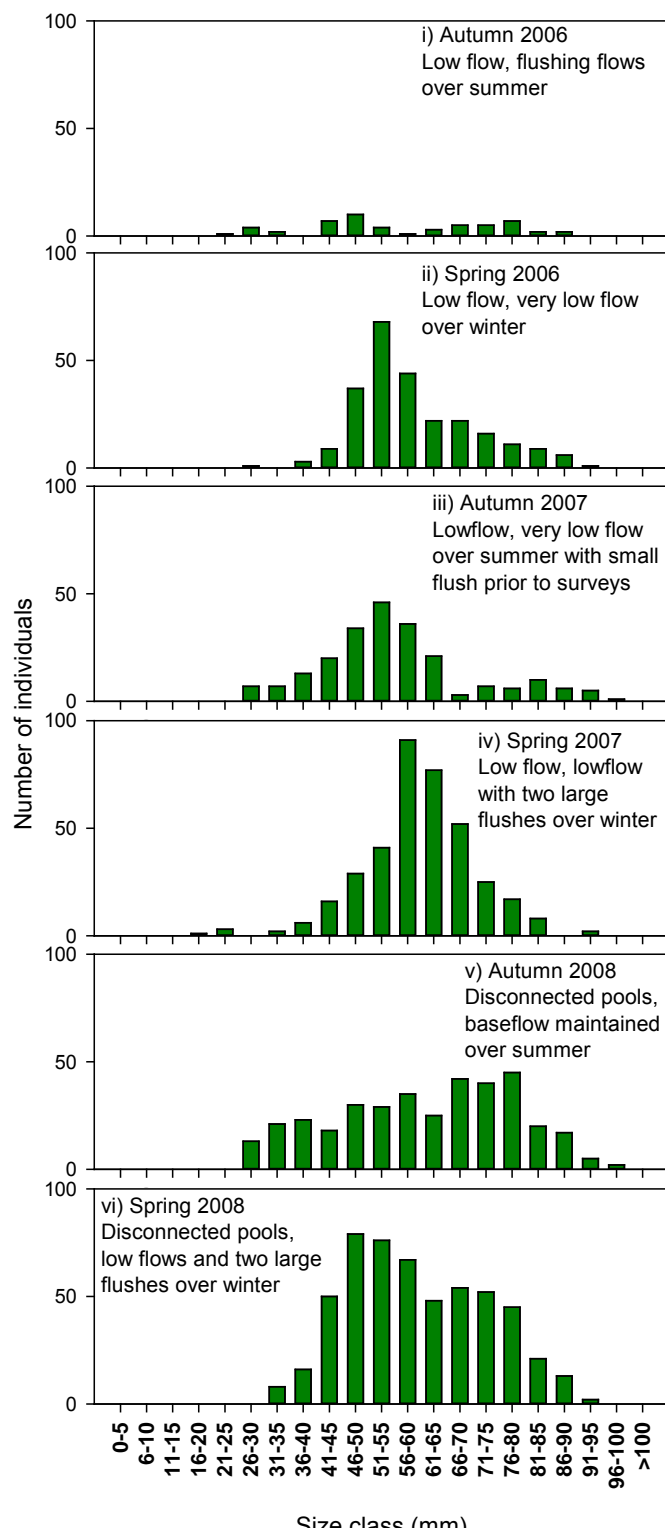


Figure 84. Lengths of flathead gudgeon (*P. grandiceps*) at Silke's Road (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



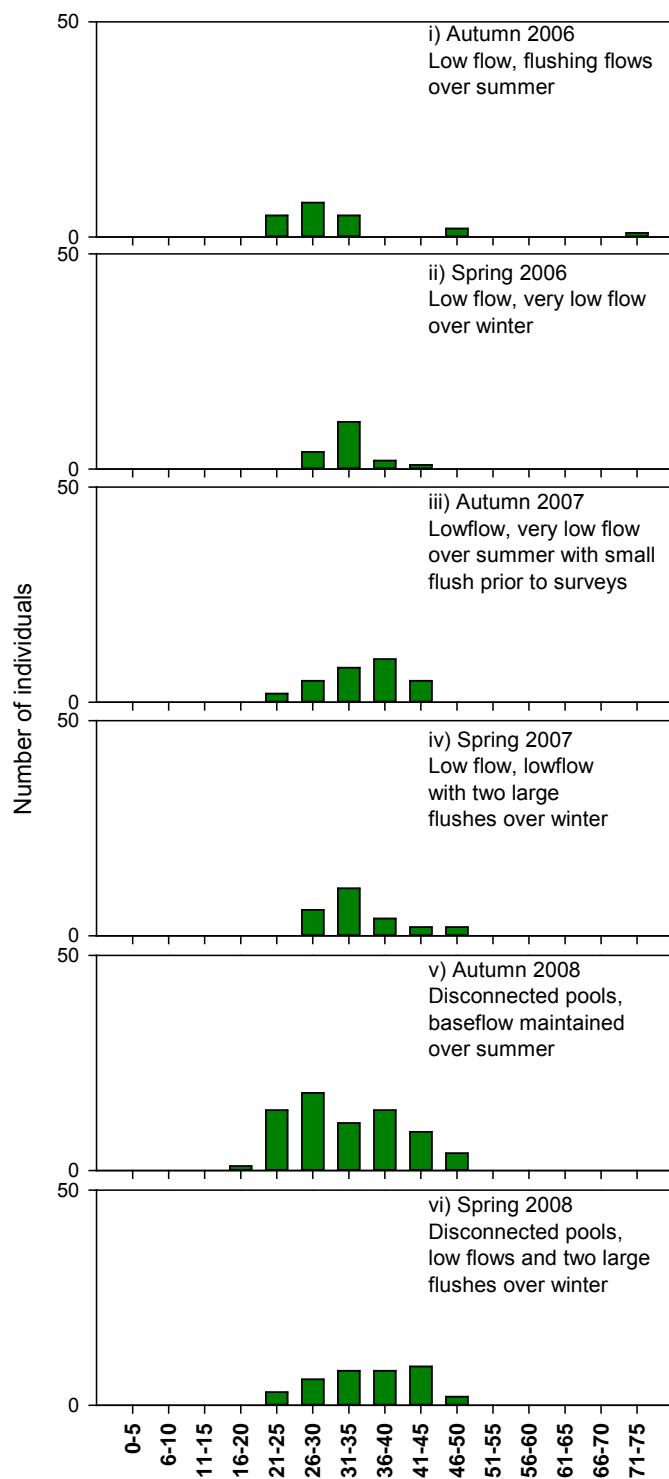


Figure 85. Lengths of carp gudgeon (*Hypseleotris* spp.) at Silke's Road (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



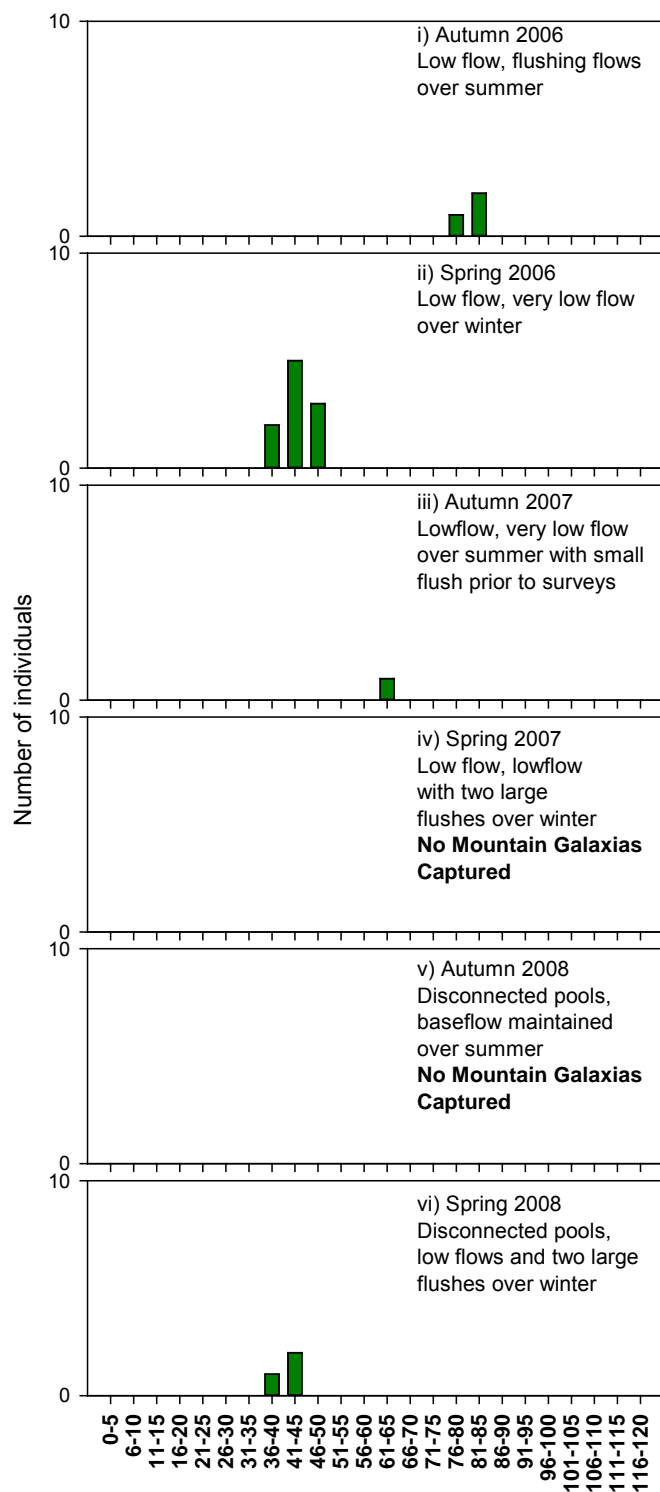


Figure 86. Lengths of mountain galaxias (*G. olidus*) at Silke's Road (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



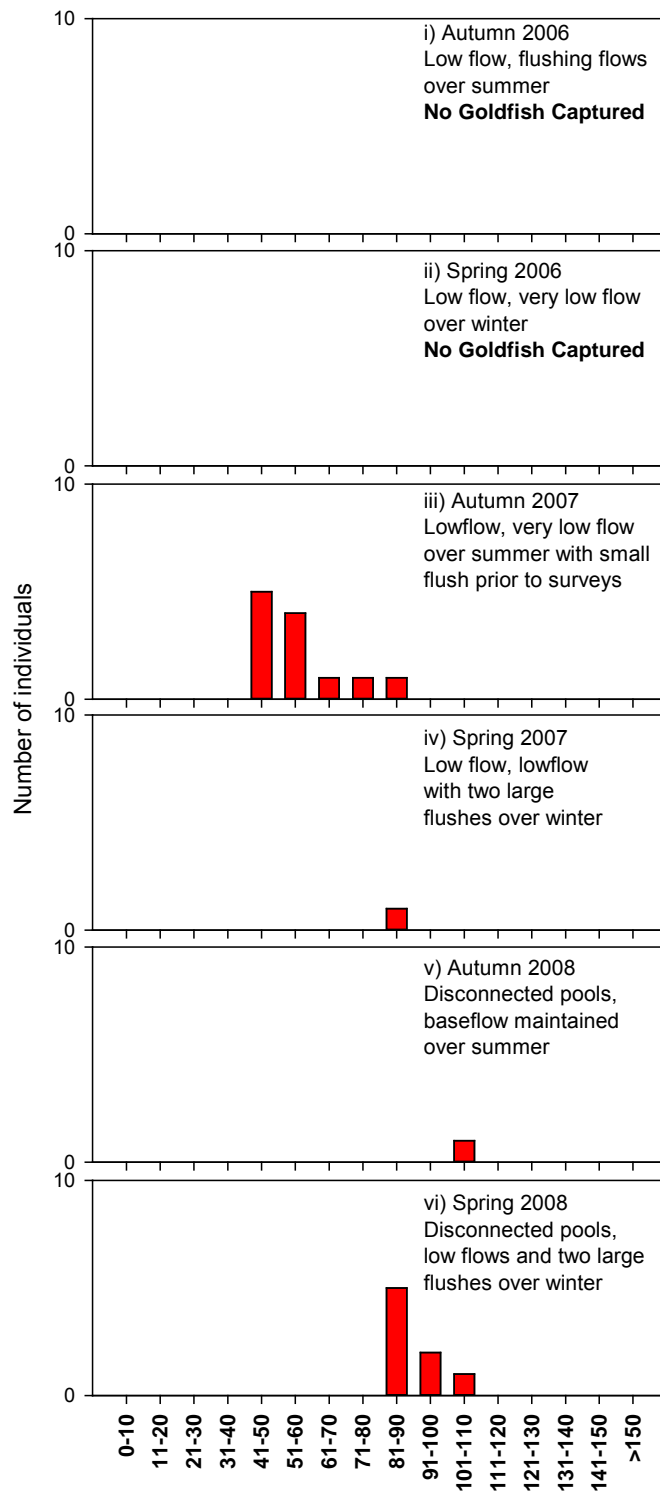


Figure 87. Lengths of goldfish (*C. auratus*) at Silke's Road (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



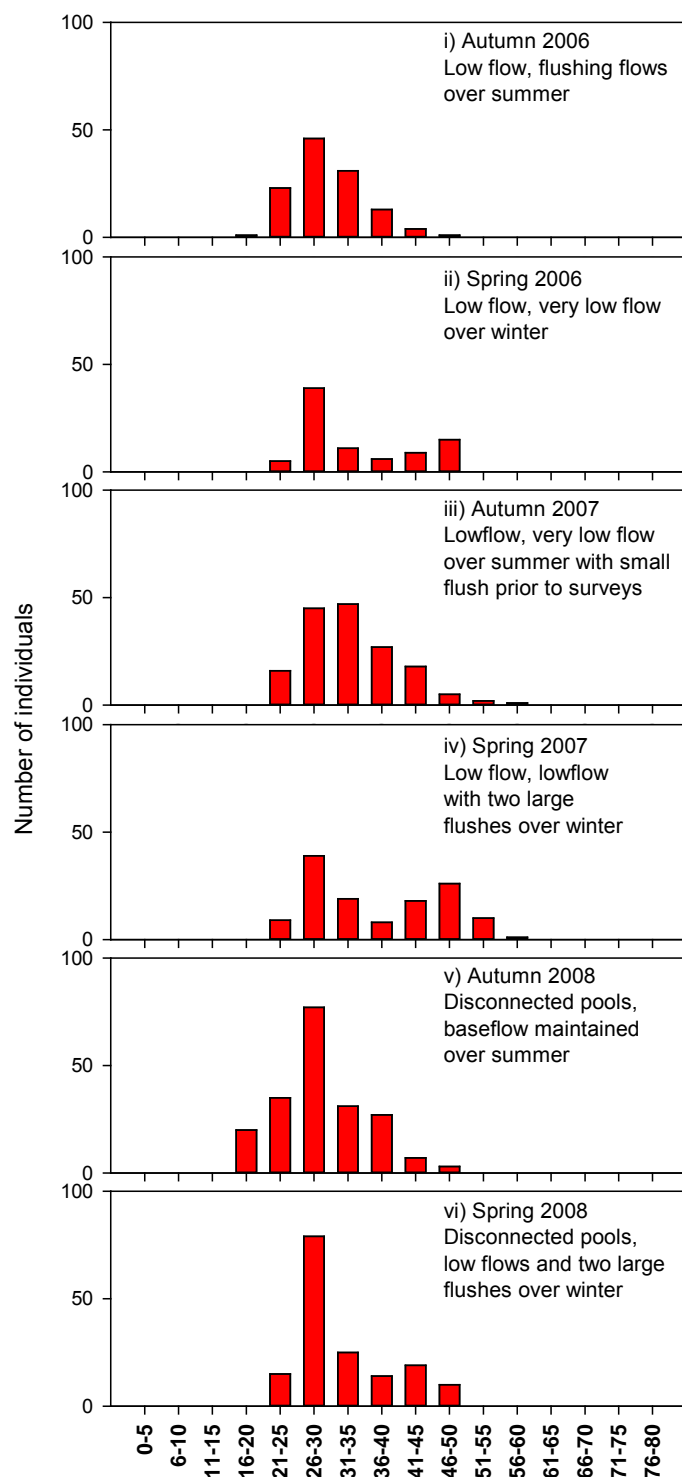


Figure 88. Lengths of gambusia (*G. holbrooki*) at Silke's Road (Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.2.5. Breakout Creek

3.2.5.1. Site assessment

The three pools vary greatly in substrate and depth whilst all had virtually no riparian cover and few if any snags (Table 41). Electrofishing surveys were carried out within any shallow reaches available, which varied with hydrology. These electrofishing reaches were most frequently up- and down- stream of Pool 2.

Table 41. Habitat characteristics of the three monitoring pools at Breakout Creek in the River Torrens.

Breakout Creek	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	<1	0	2	2.0
Pool 2	<1	0	0	1.3
Pool 3	Sand	0	0	3.5

Pool 1 (Figure 89) is located upstream of the Henley Beach Rd Bridge in the large pool created through relatively recent restoration work and maintained by a small rock weir at the downstream end of the site which has good facility for fish passage. The site has a high level of public access with wooden jetties and walking paths. Macrophyte cover varied across seasons with small beds of *Phragmites* and cumbungi dispersed around the site, and large beds of curly pondweed expanding and contracting seasonally (Table 42).

Water depth, temperature and pH did not vary significantly across seasons, whilst conductivity ranged between 540 and ~2000 μ S. Dissolved oxygen peaked dramatically at 16ppm in autumn 2006 but remained stable across other seasons. The site was predominantly isolated during most sampling trips, with low flows and flushing flows present during autumn 2006 and 2007 respectively. Antecedent flow conditions for this site changed between very low flows to baseflows and flushes across the study period.



Figure 89. Breakout Creek Pool 1 in a) spring 2006 and b) autumn 2008.



Table 42. Water quality parameters recorded in Breakout Creek Pool 1 during each survey.

Pool 1	season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	16	540	9	14.6	2.0	10	Low flow	Baseflows + flushes
2006	spring	8	1932	8	27.0	2.0	10	No flow	Baseflows + flush
2007	autumn	7	1963	7	20.0	2.0	25	Flush	Very low flows
2007	spring	6	780	8	26.8	1.5	10	No flow	Baseflows + flushes
2008	autumn	7	1600	7	17.1	2.0	10	No flow	Very low flow
2008	spring	7.4	1251	8.1	19.8	2.0	30	No flow	Very low flow

Pool 2 (Figure 90) was situated downstream of Henley Beach Rd and has been dramatically re-engineered following the spring 2008 sampling trip, and therefore providing excellent ‘before’ data for assessing the impacts of the development at this site. The survey in autumn 2006 was actually carried out farther downstream below Tapley’s Hill Rd but was moved following loss of wetted habitat following that season. The site was sampled above and below a small concrete weir which divided the pool. Above the weir sediments were predominantly silty with large beds of macrophytes predominantly introduced *Elodea canadensis*. Below the weir the pool was predominantly rocky with some littoral silt beds covered with *Elodea*. The pool possessed large cumbungi beds both above and below the weir that expanded and contracted seasonally covering between 0% and 70% of the pool, predominantly increasing in spring (Table 43).

Oxygen, pH and salinity fluctuated slightly throughout the study, whilst temperature fluctuated seasonally. Water depth remained constant throughout the study, whilst flow conditions were mainly zero flow with low flow in autumn 2006 and flushing flows in autumn 2007. Antecedent flow conditions for this site changed between very low flows to baseflows and flushes across the study period.

**Figure 90. Breakout Creek Pool 2 in a) spring 2006 and b) autumn 2008.**

Table 43. Water quality parameters recorded in Breakout Creek Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	12	538	8	12.4	0.3	0	Low flow	Base/flushes
2006	spring	8	1932	8	28.0	1.0	30	No flow	Base/flush
2007	autumn	8	700	8	15.0	1.3	10	Flush	Very low flows
2007	spring	5	804	10	29.7	1.0	10	No flow	Base/flushes
2008	autumn	8	1400	7	18.1	1.0	10	No flow	Very low flow
2008	spring					1.0	70	No flow	Very low flow

Pool 3 (Figure 91) was situated at Breakout Creek, with the main pool located below the weir within the estuarine section of the Torrens. This pool is estuarine in nature, and as such should not be compared directly to other pools, but rather used as an indication of connectivity between marine and freshwater sections of this reach. Nets were also set in the freshwater section above the weir wall when inundated and a net was always set above the fishway to ensure that fish moving into freshwater habitats were captured. The conditions in this pool (downstream of the weir) fluctuated between marine and brackish (Table 44), with freshwater flows generally stratifying the pool with saline conditions remaining at depth and freshening at the surface. Dissolved oxygen fluctuated across seasons becoming severely hypoxic during spring 2006 and autumn 2008 during zero flow events under high salinities.

Whilst there were no macrophytes at the site, decaying marine algae was often abundant over sandy substrates. Due to tidal influence, maximum depth and temperature did not vary dramatically over the survey period, although water temperature became relatively high in spring 2006 when the pool became anoxic. No flow condition prevailed during most surveys with low flow in autumn 2006 and flushes in autumn 2007 the exception. Flushes and baseflow in 2006 and in spring 2007 were the only flows recorded prior to sampling events.

**Figure 91. Breakout Creek Pool 3 in a) spring 2006 and b) autumn 2008.**

Table 44. Water quality parameters recorded in Breakout Creek Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	5170	8	11.5	2.0	0	Low flow	Base/flushes
2006	spring	0	55100	7	22.5	2.0	0	No flow	Base/flush
2007	autumn	8	7000	8	17.1	3.5	0	Flush	Very low flows
2007	spring	6	56100	8	19.3	2.0	0	No flow	Base/flushes
2008	autumn	2	60700	7	18.9	2.0	0	No flow	Very low flow
2008	spring	4.6	4920	7.8	18.5	2.0	0	No flow	Very low flow

3.2.5.2. Water Quality

Salinity at freshwater sites was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

Below the weir wall, however, estuarine and marine conditions prevailed and would likely exclude the long term survival of freshwater fish species. Fresh water sitting atop saline water during flows led to the capture of many freshwater fish below the weir, and the constructed fishway has been observed to facilitate the movement of these freshwater fish back up into more inhabitable reaches (McNeil *et al.* 2010e).

3.2.5.3. Hydrology

During sampling in autumn 2006 the water level at Breakout Creek was low and in the spring survey period the survey pools were disconnected at this site. During autumn 2007 the water level was moderate at the time of the surveys, but pools were again disconnected during the surveys of spring 2007 and also when the site was surveyed in autumn 2008.

Gauge data is available since 1978 for Breakout Creek (collected at Holbrook's Road: site number A5040529). Throughout the summer of 2005/06 a high baseflow was maintained, and there were a number of freshes and flushes, at this site (Figure 92). This hydrological pattern, of high baseflows and multiple flushing flows of various magnitudes, continued to the autumn 2006 surveys, conducted on May 25.

Baseflows above 5 ML/day were maintained, and there were a number of freshes and small flushes from this time until October 2006. Baseflows were lower in October and early November than they had been in previous months, averaging under 2 ML/day. However, there was a large flushing flow of 340 ML two and a half weeks prior to the spring 2006 surveys. These surveys were conducted on the 29 November, three days into a period where there was no readable flow recorded at the gauging station. This lack of any recordable flow continued until late December.



From January to late April of 2007 there were multiple freshes, but also long periods when no flow was recorded. Autumn 2007 surveys were conducted on April 30, just two days after a very large flushing flow (>800 ML in one day) had been recorded. From this time until early-November the baseflow was high and there were regular pulsed freshes and flushes, with one very high flushing flow of over 1600 ML in one day in early July.

Flows steadily declined over the week prior to spring 2007 surveys, conducted on November 14, when the flow was just above 3 ML/day. Flows were low over much of summer, but there was also a large flush in late December. There was no recordable flow at the site from early February until late March. From the beginning of April baseflow was maintained and there were a number of freshes up to the time of autumn 2008 surveys, conducted on April 23.

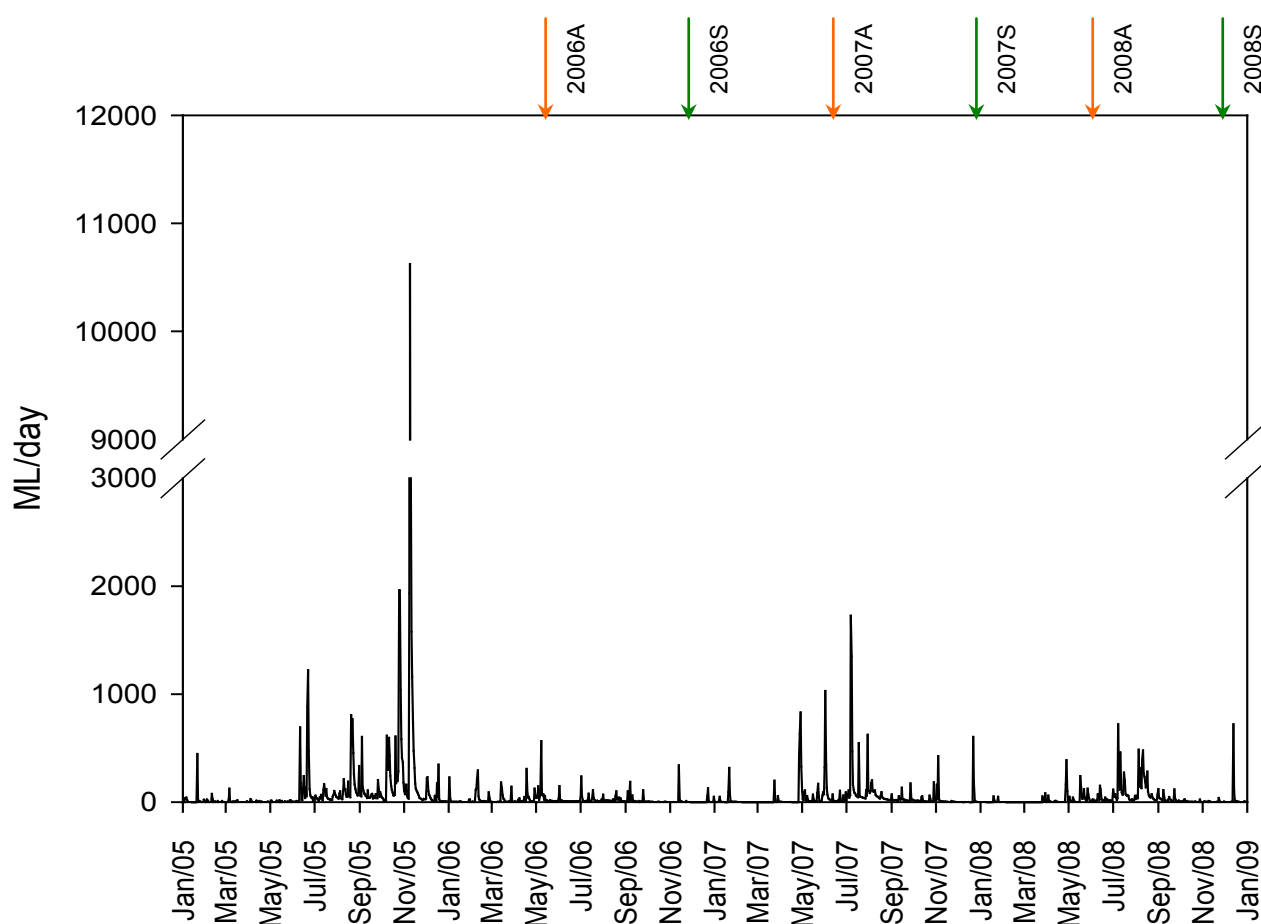


Figure 92. Hydrograph for flow in Breakout Creek (mouth of Torrens River). Flow data (ML/day) from Holbrook's Road (gauge number A5040529) is reported from January 1, 2006. The timing of each survey season is also shown above the figure.



3.2.5.4. Fish community

Breakout Creek had the highest diversity of fish amongst any of the sites surveyed in the WMLR, with a predominantly freshwater community above the fishway and an estuarine/marine community downstream of the fishway. Across all pools and survey seasons there were six native freshwater, fourteen native estuarine/marine and three introduced fish species recorded (Figure 93). Large numbers of carp gudgeon were captured in all seasons. Flathead gudgeon and Murray rainbowfish were also captured in relatively high numbers across all survey seasons.

There was an inverse relationship between the abundance of carp gudgeon and flathead gudgeon. Common galaxias were captured in each survey except for autumn 2008, but they were only captured in larger numbers during the spring 2008 survey (Figure a). The estuarine/marine taxa were mainly captured only in the most downstream pool and the numbers of captures of all these taxa were relatively low in all seasons (Figure b). Gambusia and European carp were the most commonly captured introduced taxa, and were caught in high numbers in alternating seasons: gambusia in autumn and carp in spring.



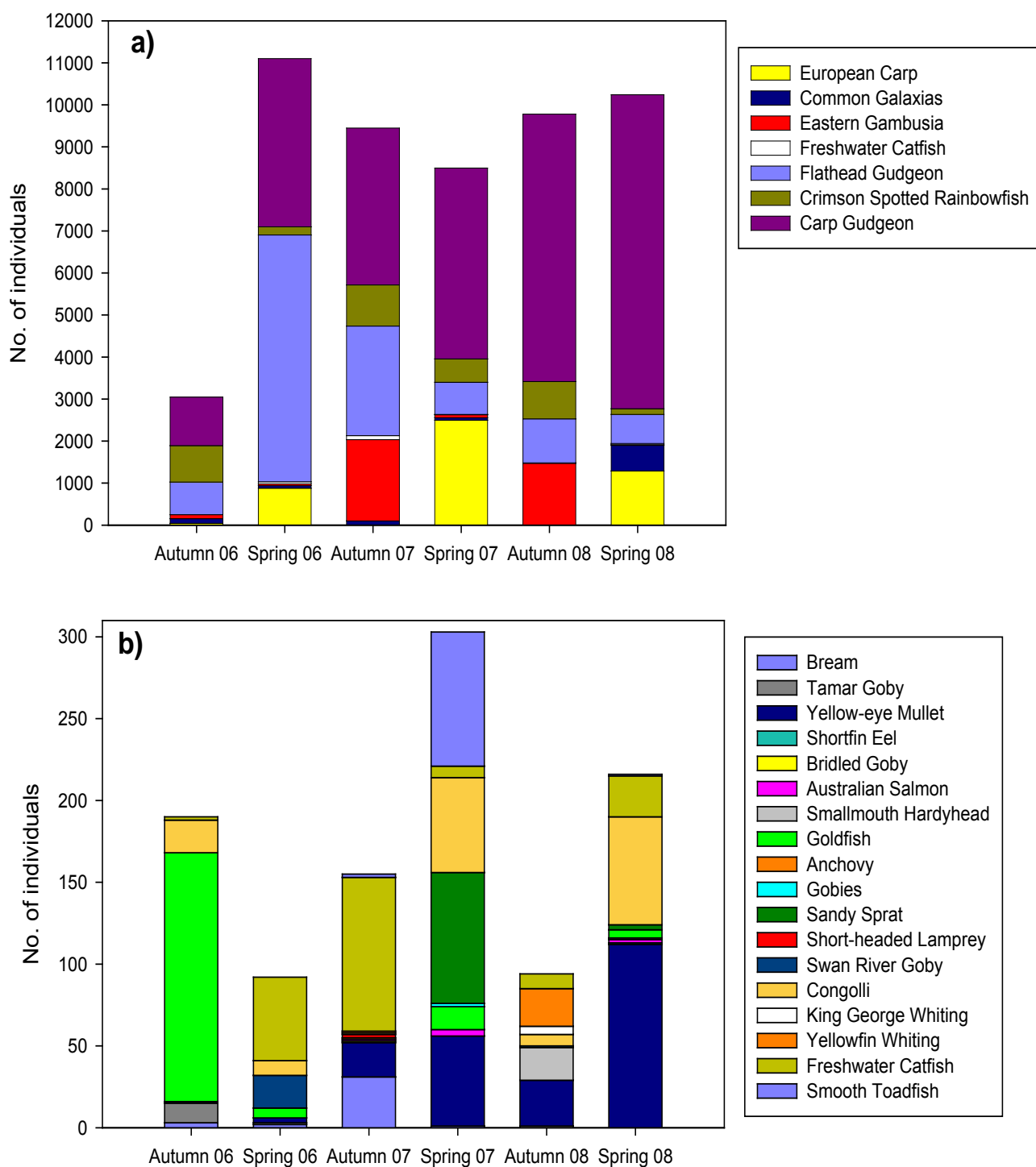


Figure 93. Abundances of each taxa present in the fish communities of each pool at Breakout Creek (mouth of Torrens River) over six survey seasons. a) Commonly captured species and b) uncommon species.



3.2.5.5. Fish population

There were relatively large numbers of common galaxias captured at Breakout Creek during all surveys conducted in 2006 and 2007. Larger individuals were present in autumn, and both large and small individuals in spring (Figure 94). Only two of these fish were captured during autumn 2008, but in spring 2008 large numbers had were again recorded. A small number of common galaxias were captured in 2007.

At Breakout Creek most congolli were captured in the pool downstream of the fishway, but they have also be captured above the fishway during most survey seasons (Figure 95). The number of congolli captures peaked in spring 2007. These were mainly small individuals and they were mostly below the weir. In spring 2008 there were again a large number of small congolli, but in that survey they were mostly above the fishway.

Flathead gudgeon were captured above the fishway in all seasons and there were also over 80 individuals of this taxon captured downstream of the fishway in autumn 2007 (Figure 96). Most of the individuals captured at this site were small to medium sized.

The population of Murray rainbowfish appears well established, with large numbers of medium to large fish captured during all of the present surveys (Figure 97). A pattern of smaller individuals in autumn and larger individuals in spring suggests strong recruitment over summer.

Freshwater catfish were captured above the fishway in all seasons, and there were also seven individuals of this taxon captured in the pool below the fishway in autumn 2007 (Figure 98). Across the middle three surveys, from spring 2008 to spring 2007, both small and large individuals of this species were captured. Only small individuals of this taxon were captured at this site in autumn 2006 and autumn 2008. In spring 2008 large and small freshwater catfish were captured again.

High numbers of, mainly small to medium sized, carp gudgeon were captured above the fishway during all of the survey seasons (Figure 99). These taxa were also captured in the pool below the fishway, in autumn 2006 (three individuals) and autumn 2007 (over 300 individuals). These fish displayed a uniform size distribution over the entire project.

Small numbers of both goldfish (Figure 100) and carp (Figure 101) were captured from the pools upstream of the fishway at Breakout Creek during the present surveys. Relatively large numbers of small carp were captured during all surveys conducted in spring, whereas only a small number of medium fish were captured during each of the autumn surveys. The largest numbers of goldfish were captured in autumn 2006, but none of this taxon was captured in either autumn 2007 or 2008. However, three small goldfish were captured in spring 2008.



Only small numbers of gambusia were captured in 2006, but there were large numbers of small to medium sized fish captured during both surveys in 2007 and in autumn 2008. The gambusia captured in spring 2008 were a similar size but had decreased significantly in number (Figure 102).

Most of the marine and estuarine species were captured infrequently and in low numbers therefore graphs are not provided here. Blue spot goby were only captured once (in spring 2007, in the middle survey pool, above the fishway). Tamar goby were captured in the pool downstream of the fishway at Breakout Creek in autumn 2006, spring 2006 and autumn 2008. Individual bridled goby were captured downstream of the fishway in autumn 2007 and spring 2008. Three small (29-43 mm) unidentified gobies were captured in spring 2007 and autumn 2008, but are likely to be misidentified blue spot or bridled gobies.

Two adult short-headed lamprey (430 mm and 380 mm) were captured in the pool downstream of the fishway at Breakout Creek in autumn 2007, but were not captured during any of the other surveys. This is the first record of this rare diadromous species in the catchment and may have been trapped below the weir from the previous spring due to low flows preventing upstream passage. Only a small number of medium and large black bream were captured from the pool downstream of the fishway, with the largest number in autumn 2007, whilst no individuals of were captured during autumn and spring 2008.

Jumping mullet were captured in the pool downstream of the fishway during all of the surveys. The highest numbers of captures occurred in spring 2006, when all captures were large individuals, and autumn 2007, which was predominantly small individuals, in spring 2008, one large and one small individual were captured. The captures of yellow-eyed mullet increased from only a few individuals in 2006 to relatively large numbers, of predominantly small individuals, in spring 2007; predominantly medium individuals in autumn 2008, and smaller individuals again in spring 2008. All of these fish were captured in the pool downstream of the fishway.



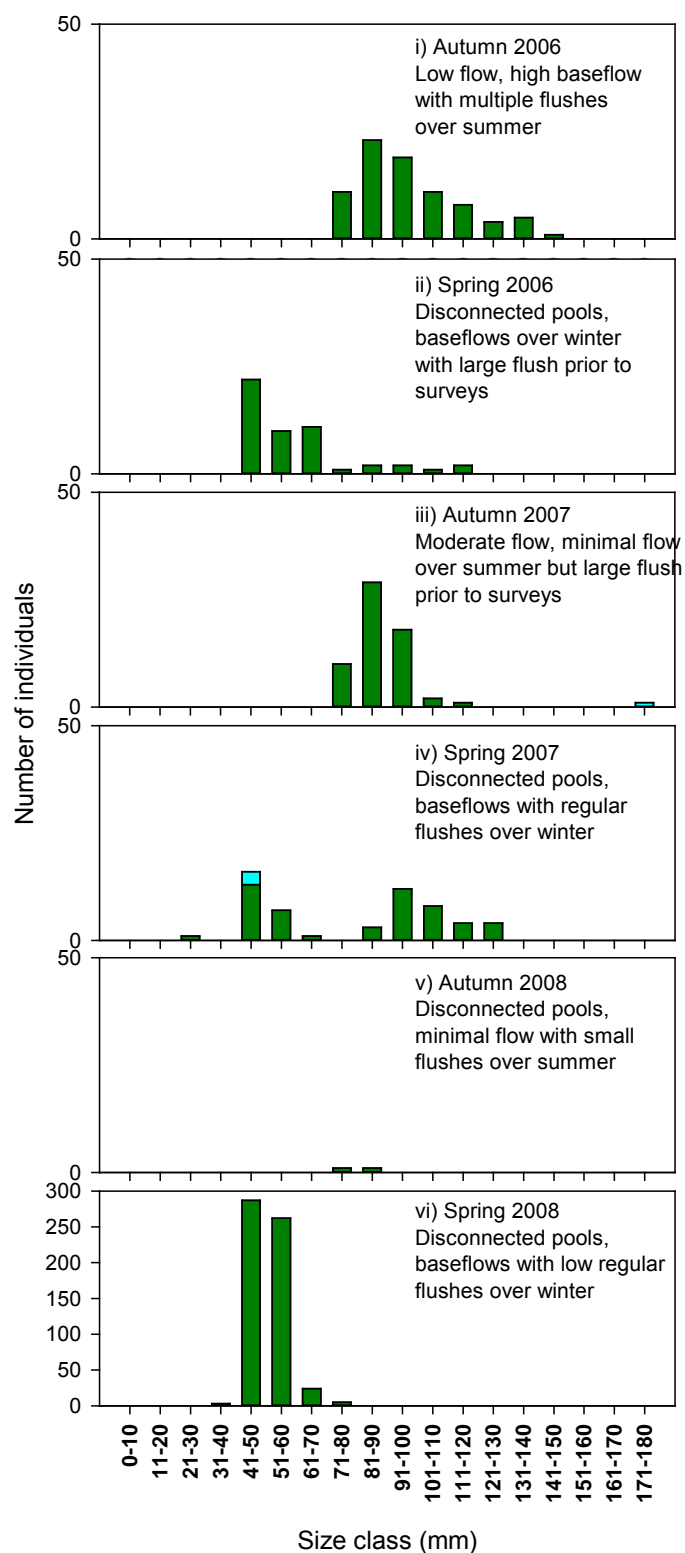


Figure 94. Lengths of common galaxias (*G. maculatus*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



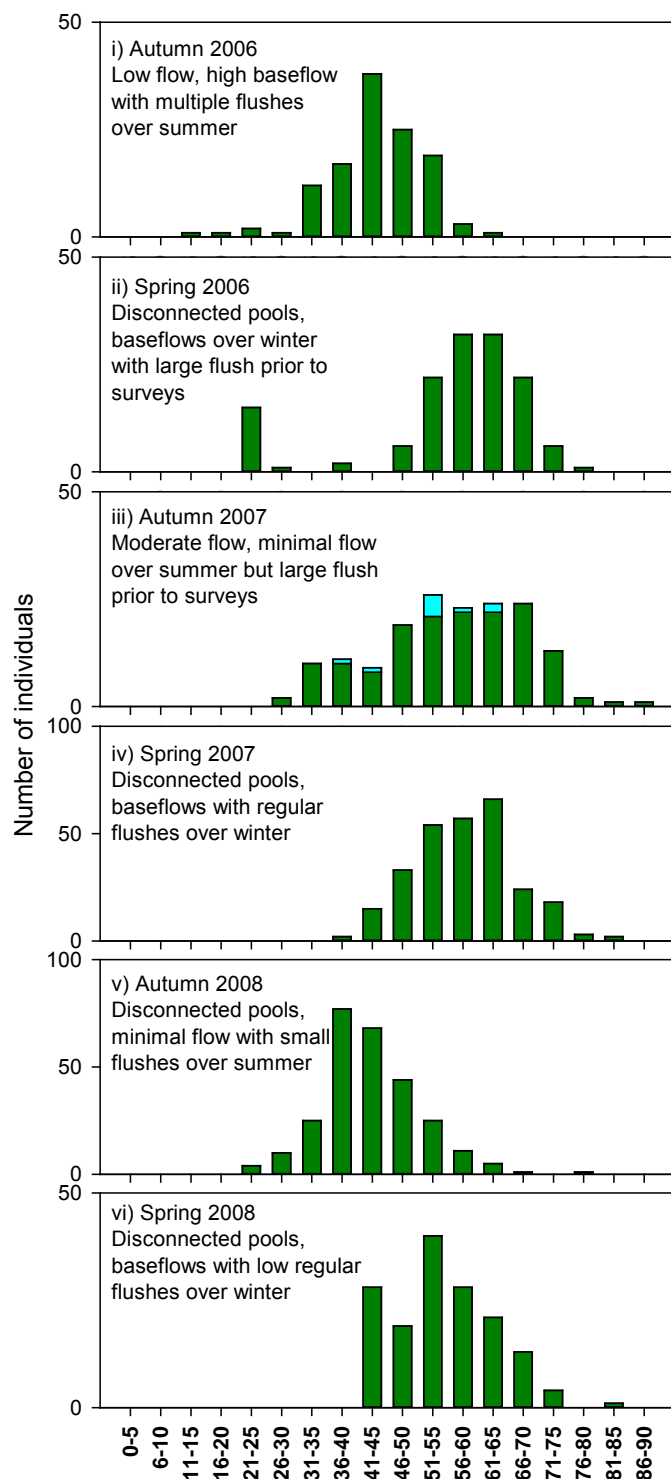


Figure 95. Lengths of Murray rainbowfish (*M. fluviatilis*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



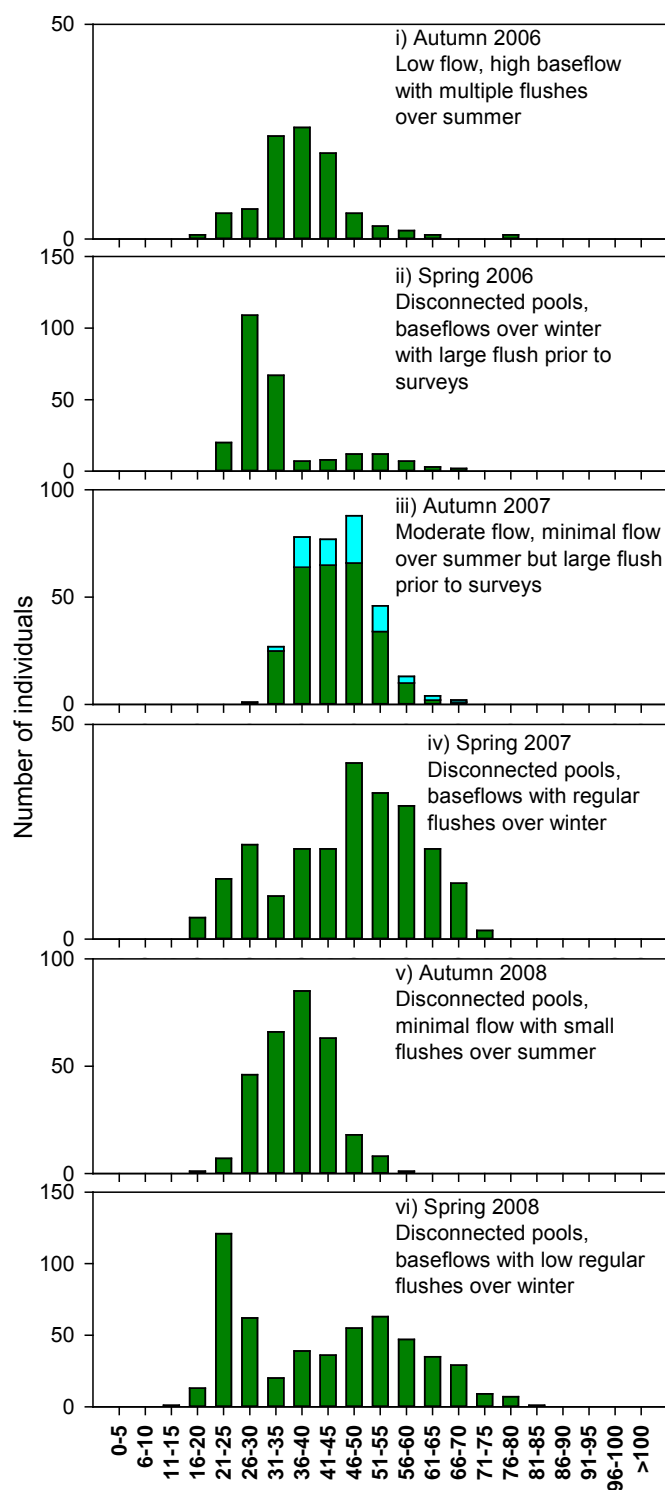


Figure 96. Lengths of flathead gudgeon (*P. grandiceps*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



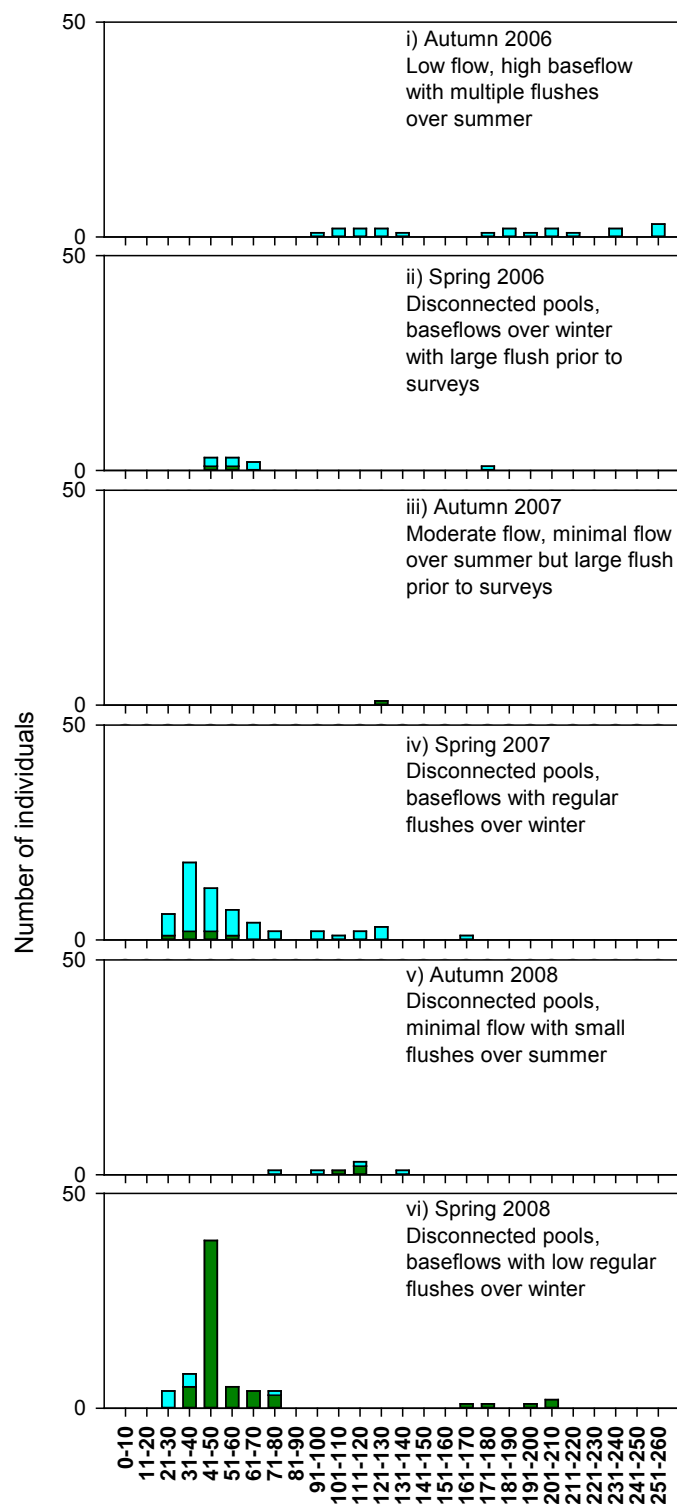


Figure 97. Lengths of congolli (*P. urvillii*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



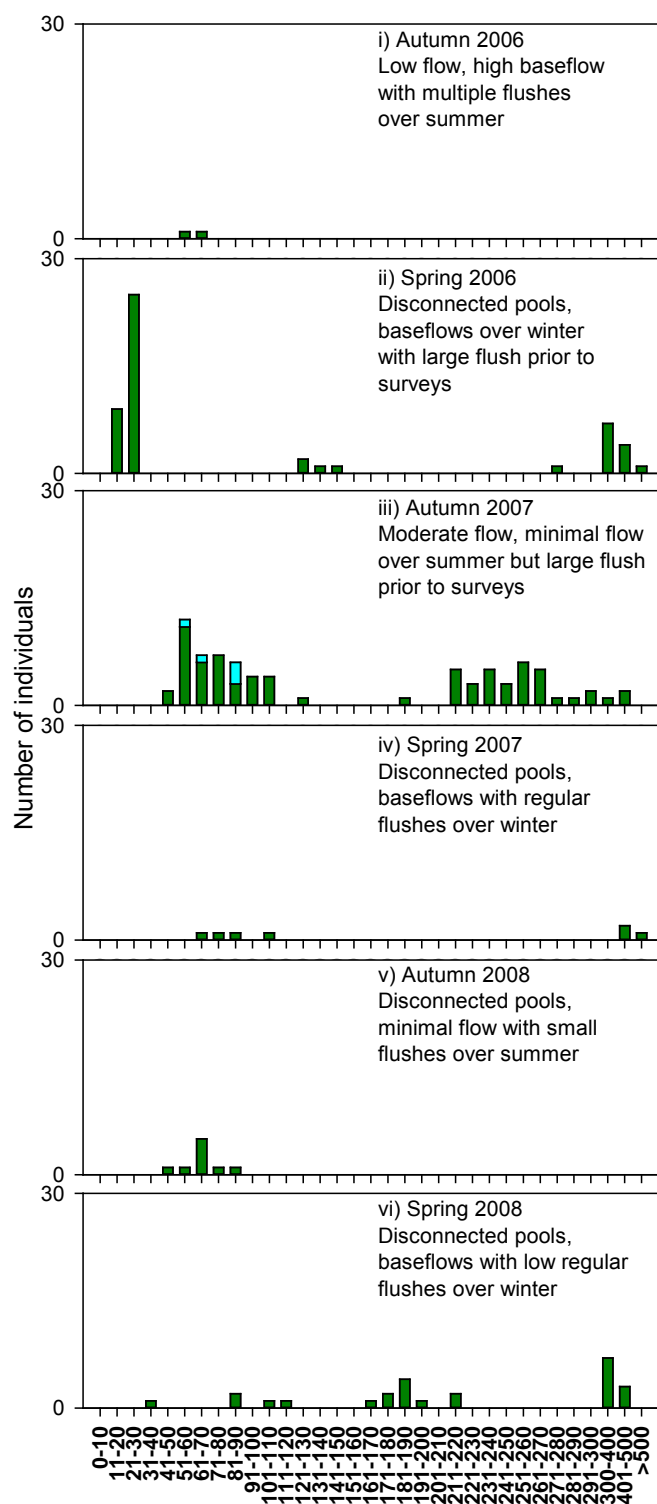


Figure 98. Lengths of freshwater catfish (*T. tandanus*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



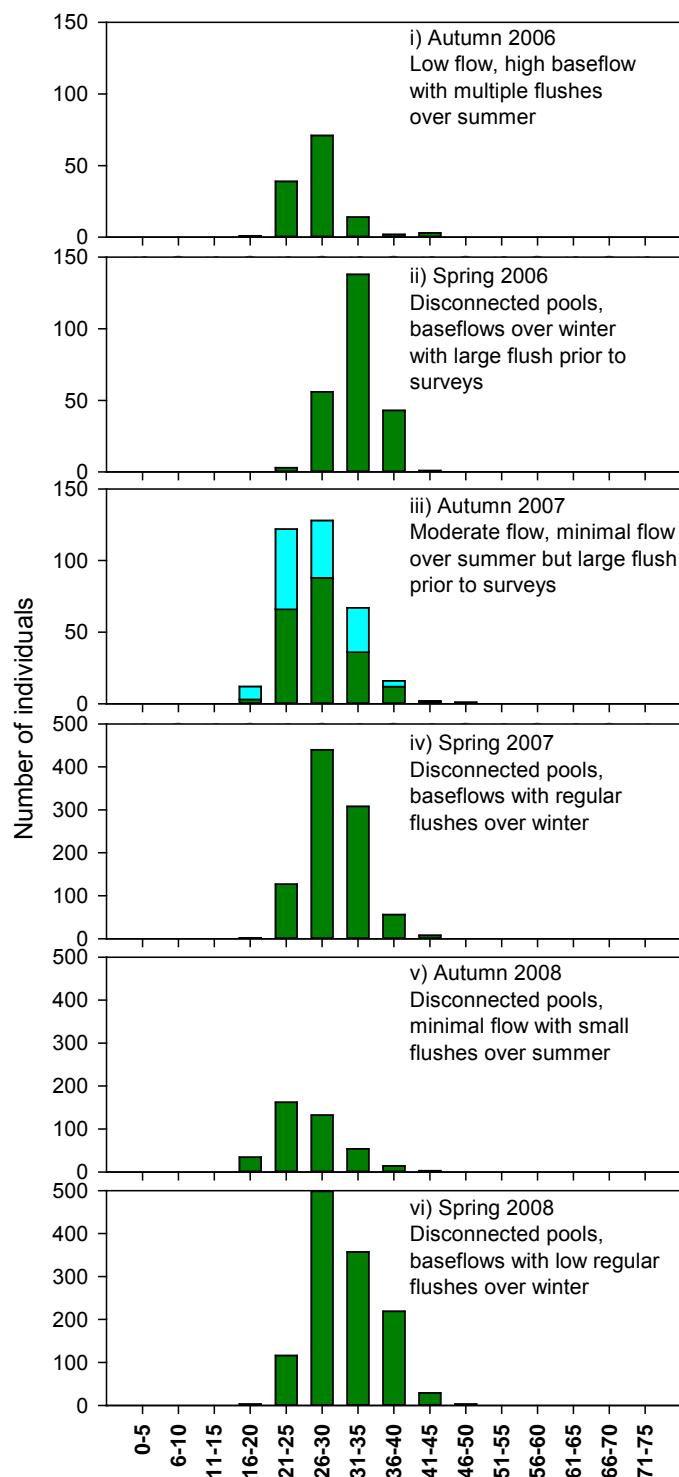


Figure 99. Lengths of carp gudgeon (*Hypseleotris* spp.) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



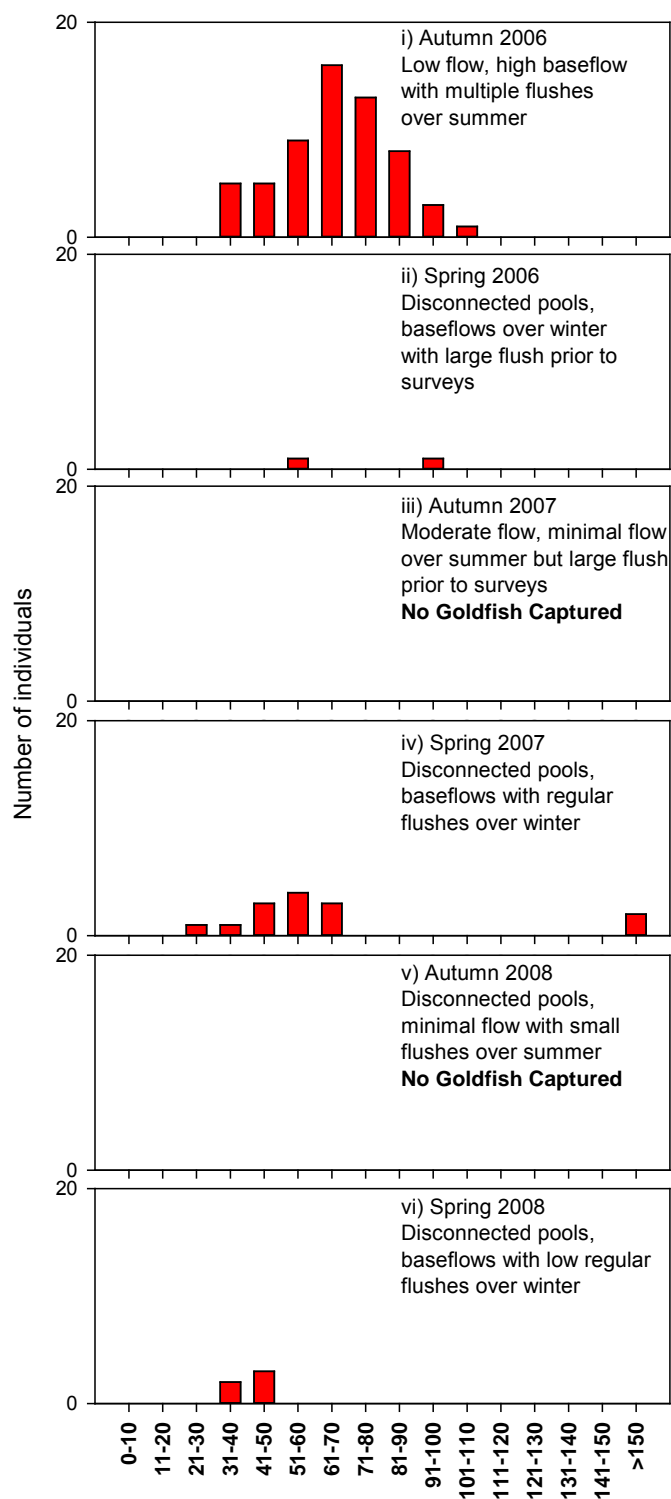


Figure 100. Lengths of goldfish (*C. auratus*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



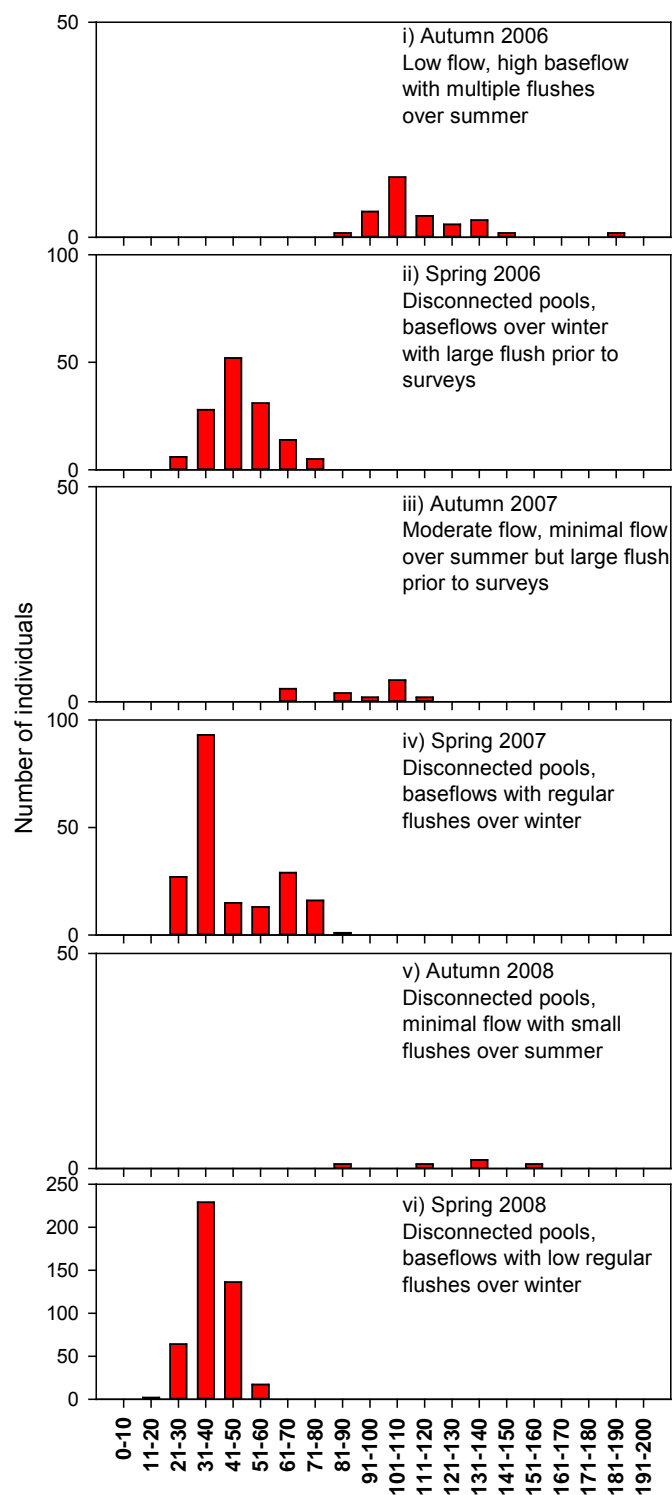


Figure 101. Lengths of carp (*C. carpio*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



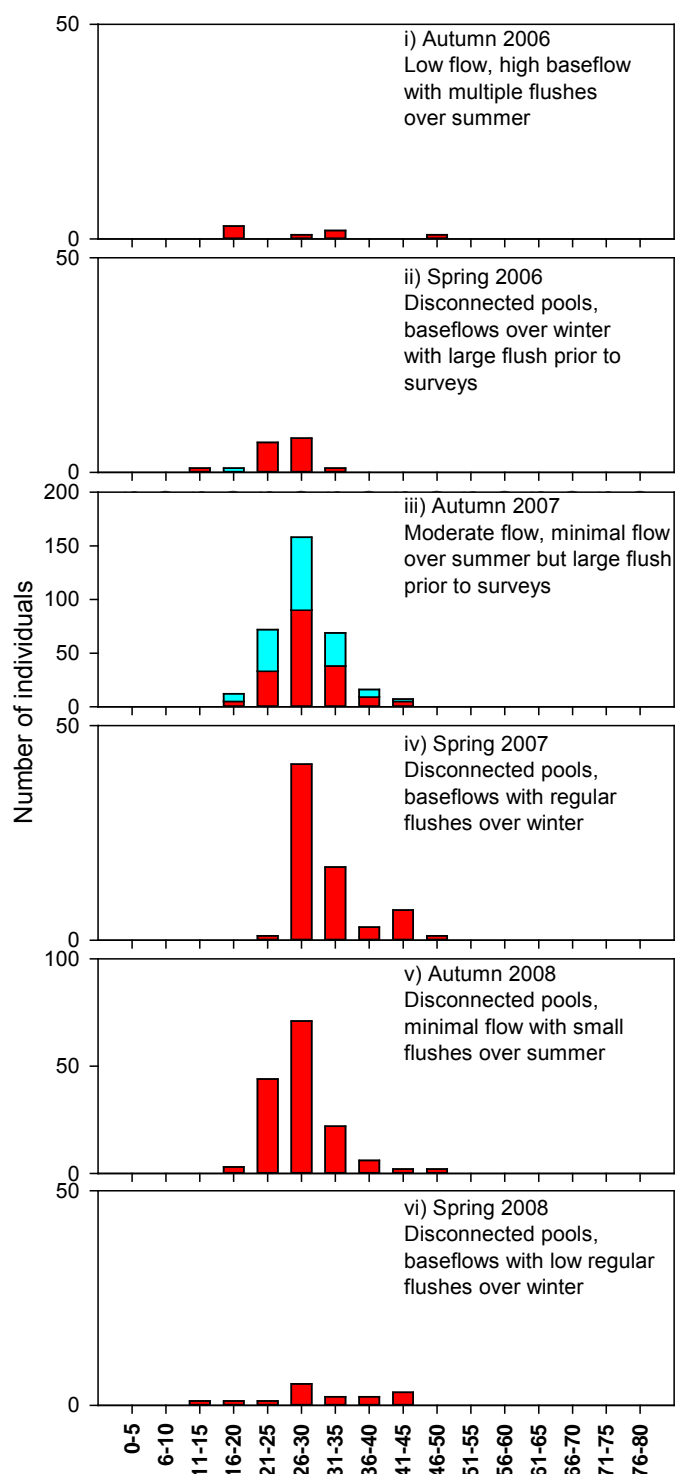


Figure 102. Lengths of gambusia (*G. holbrooki*) at Breakout Creek (mouth of Torrens River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.3. Onkaparinga River

The Onkaparinga River was second to the Torrens in species richness, with fourteen native species captured during the surveys, including seven native freshwater species. No known translocated species were captured, although the dwarf flathead gudgeon was possibly translocated from the Murray-Darling Basin through inter-basin water pipelines (McNeil and Hammer 2007). Golden perch, which were translocated into reservoirs in the Onkaparinga in the past (SKM 2003) were not recorded from the trial reach. The southern purple-spotted gudgeon was historically common in the Onkaparinga River (Scott 1961), but given the last confirmed records from this study reach were during the 1880s (Hammer *et al.* 2009) it is presumed extinct in the Onkaparinga.

Pouched and short-headed lampreys were not recorded from the Onkaparinga and its continued absence during this and other surveys (McNeil *et al.* 2009) suggest that these species may have become locally extinct from the catchment. Records of smelt from the lower Onkaparinga River (SKM 2003) are considered to be erroneous identifications. No other smelt have ever been recorded from the catchment during this or other surveys and several species slightly similar in appearance to smelt (juvenile common galaxias, glass goby and hardyhead) are present at the reported sites (see also Hammer and Walker 2004).

It is recommended that the presence of smelt in the WMLR hereby be considered erroneous and that the species should not be included in the fish fauna of the WMLR.

There were a large number of introduced species (five), however trout and common carp were not observed during these surveys, although they have been recorded within the reach during related separate surveys. Flathead gudgeon and dwarf flathead gudgeon were widespread in the catchment but their numbers declined during the survey period, particularly at upstream sites. Common galaxias were initially distributed throughout the target reach, but disappeared in the upper reaches throughout the survey. This contraction of diadromous fish into the very lower reaches of the river matched the distribution of congolli. It is considered that species with marine dependant life history phases were unable to recolonise the upper reaches, probably due to low flows. Furthermore, fish in lower reaches were subject to extreme environmental conditions in shrinking pools with most fish suffering from disease and malnutrition during the summer of 2008 (Figure 103).

Multivariate analyses of the fish community in the Onkaparinga confirmed the distinct fish assemblage at Old Noarlunga (Figure 104). This was largely due to the diadromous and estuarine species present there that due to low flows, didn't have access to upper reaches of the river. Accordingly, there was a weak relationship between higher conductivity and the Old Noarlunga



samples, and higher dissolved oxygen and pH with Brooks Road and Clarendon. Flow metrics did not have a significant relationship with fish assemblage. In other words, there were no flow metrics that were capable of explaining 10% of the variation in fish assemblage, but water quality parameters (conductivity, DO and pH) were.



Figure 103. Emaciated, diseased *G. maculatus* from the shallow Pool 1 at Old Noarlunga during the dry season of 2008 showing infections, encystations and rupturing emergent parasites.

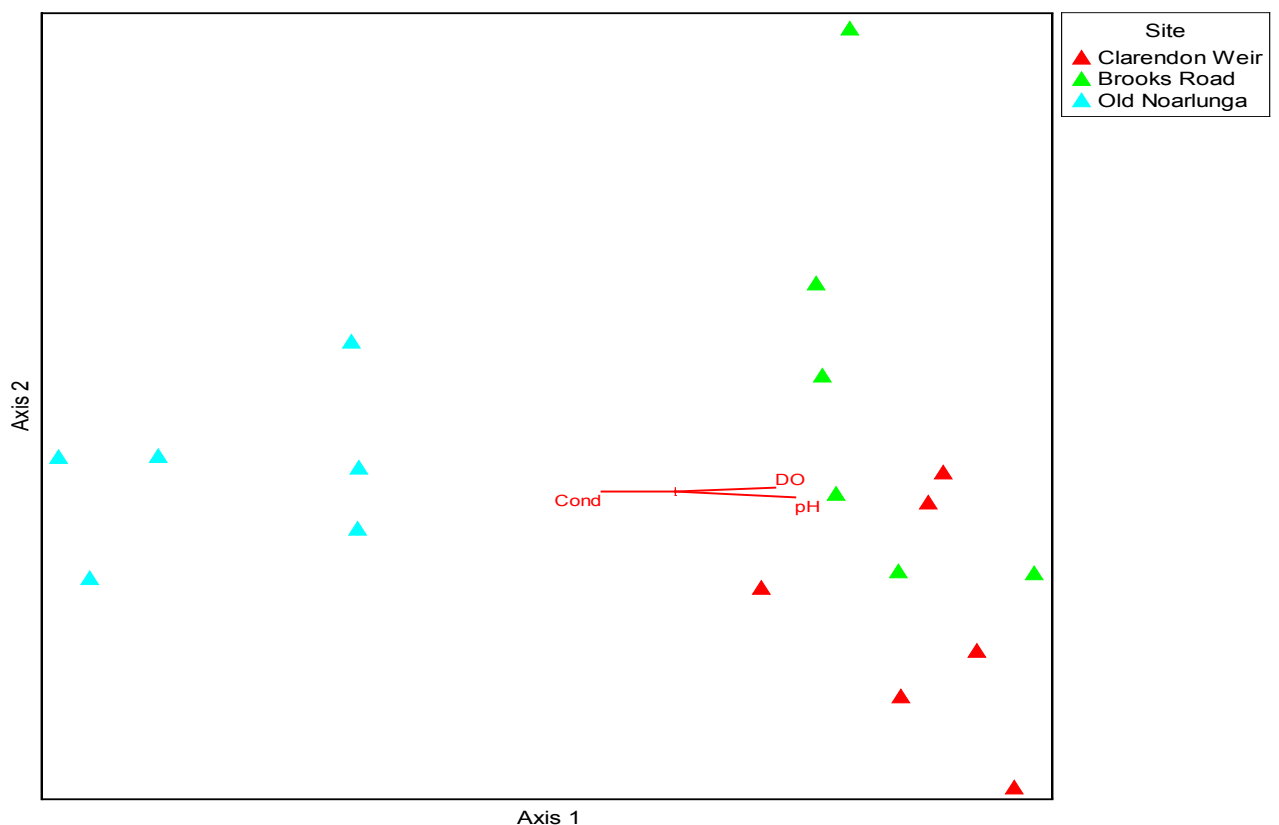


Figure 104. NMDS ordination of total fish community in the Onkaparinga River, overlain with correlated environmental vectors ($R^2 > 0.1$) and labelled by site.



Table 45. Taxa which were present (P), spawning (^s) and recruiting (^r) for each site and season. The columns of native freshwater fish taxa are shaded green, those of exotic taxa shaded red and those of marine/estuarine taxa shaded blue.

Site Name	Sampling Season	Common galaxias	Mountain galaxias	Climbing galaxias	Flathead gudgeon	Dwarf flathead gudgeon	Shortfinned eel	Gambusia	Redfin perch	Goldfish	Carp	Tench	Congolli	Bridled goby	Blue Spot goby	Tamar goby	Smallmouth hardyhead	Black bream	Jumping mullet	Yellow-eyed mullet
Clarendon Oval	2006A	P			P	P	P	P	P	P ^r	P ^r	P								
	2006S	P	P		P	P		P	P											
	2007A	P ^r			P	P		P	P		P ^r									
	2007S			P	P	P		P	P	P		P								
	2008A			P ^r	P	P		P	P											
	2008S		P		P	P		P	P	P	P	P								
Brooks Road	2006A	P ^s	P ^s		P	P		P ^s		P										
	2006S	P	P	P	P ^s	P ^s		P	P	P ^r										
	2007A	P ^s	P ^s		P ^s	P		P	P ^r											
	2007S	P	P		P	P		P												
	2008A	P ^r	P		P	P		P		P ^r										
	2008S		P		P	P		P												
Old Noarlunga	2006A	P ^s			P			P					P ^s		P ^r	P ^r		P	P	
	2006S	P			P	P		P ^r					P		P			P ^r		
	2007A	P ^s			P	P		P					P ^s	P	P	P		P	P	
	2007S	P ^s			P ^s	P ^s							P ^s			P		P	P	
	2008A	P ^s			P	P		P ^r					P ^s							
	2008S	P			P	P		P					P		P		P	P	P	P

3.3.1. Clarendon Oval

3.3.1.1. Site assessment

The Clarendon Site was situated at the Clarendon Oval reserve and consisted of three separate pools within a 300 m reach approximately 500 m downstream of the Clarendon Weir. Each of the pools was similar in size and depth with pool 2 being the smallest and shallowest (Table 46). The substrate in all pools was dominated by cobbles over 10 mm diameter with large littoral sections of emergent macrophytes, predominantly cumbungi and *Phragmites*.

The riparian zone was largely dominated by exotic deciduous trees with a few redgums whilst blackberry and fig trees dominated the understory. Pool 3 had a denser riparian overstorey than the others. Small patches of submerged macrophytes, predominantly water ribbon (*Triglochin procerum*) were present in all pools, fluctuating in cover seasonally. All pools were bordered by a rocky cliff on the right bank with modified parkland on the left bank. A long section of overgrown shallow riffle habitat separated Pool 1 and Pool 2, whilst Pool 2 and Pool 3 were separated by a short section of *Phragmites*.

All pools became isolated during each dry season and were reconnected each winter, no pools dried completely in any season. Electrofishing surveys were conducted where access was possible between pools and extended upstream to the footbridge causeway. The run/riffle section downstream of Pool 3 was electrofished when inundated.

Table 46. Habitat characteristics of the three monitoring pools at Clarendon Oval in the Onkaparinga River.

Clarendon Oval	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	5-10+	30	0	2.0
Pool 2	5-10+	21	1	1.8
Pool 3	5-10+	95	3-4	2.2

Pool 1 (Figure 105) was situated on a bend with high cliff on the right bank. Large rocks and cobbles dominated the substrate. The left bank was dominated by cumbungi with a riparian overstorey of wattle and redgum with some bottlebrush. The right bank consisted primarily of fig (*Ficus* spp.) and blackberry (*Rubus* spp.), with no overstorey. This was the least variable of the three Clarendon pools although the pool became reasonably shallow during 2007 and 2008 (Table 47).

Most water quality parameters remained fairly constant over the study period, whilst macrophyte cover varied between 5 % and 25 % seasonally. Green filamentous algal mats formed within this



pool during 2007. Except for the first season in autumn 2006, this pool was isolated and not flowing in either spring or autumn sampling periods.



Figure 105. Clarendon Oval Pool 1 in a) autumn 2007 and b) spring 2007.

Table 47. Water quality parameters recorded in Clarendon Oval Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1135	8	15.9	2.0	25	Low flow	Flushes
2006	spring	8	981	8	15.7	1.8	5	No flow	Flushes
2007	autumn	7	1736	8	15.3	1.8	20	No flow	Very low flows
2007	spring	10	1363	8	16.5	1.5	15	No flow	Very low flows
2008	autumn	11	1300	8	12.3	1.0	10	No flow	Very low flows
2008	spring	6.6	1138	7.4	18.2	1.6	20	No flow	Very low flows

Pool 2 (Figure 106) was almost completely surrounded by emergent *Phragmites* with small patches of cumbungi. The right bank was rocky cliff whilst neither bank possessed significant riparian overstorey except for a single bottlebrush and a small silver willow (*Salix* spp.) with some blackberry also present. Pool 2 always possessed a reasonable cover of macrophytes although estimates of cover varied seasonally between 5 % and 40 %, being higher in spring compared to autumn (Table 48). Macrophytes were dominated by water ribbon and large patches of curly pond weed (*Potamogeton crispus*) developing in some seasons. This pool became very shallow during autumn 2007 and 2008 but filled each winter.

Oxygen could be very high in this pool, particularly with higher water temperature and salinity rose to 2800 $\mu\text{S}/\text{cm}$ in autumn 2008, although these values are unlikely to have biological significance. Very low flow conditions existed during the first (autumn 2006) and final (spring 2008) sampling trips but this site was isolated and not flowing during all other times.





Figure 106. Clarendon Oval Pool 2 in a) autumn 2006 and b) autumn 2007.

Table 48. Water quality parameters recorded in Clarendon Oval Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. (μS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	6	1165	8	15.2	2.0	15	Low flow	Flushes
2006	spring	8	1038	8	15.8	1.8	20	No flow	Flushes
2007	autumn	14	1264	8	17.2	1.0	5	No flow	Very low flows
2007	spring	9	1152	8	16.2	1.8	40	No flow	Very low flows
2008	autumn	12	2800	8	12.8	1.0	10	No flow	Very low flows
2008	spring	13.3	1190	7.8	17.3	2.0	40	Low flow	Very low flows

Pool 3 was the farthest downstream and as with the others the right bank was dominated by a cliff with two bottlebrush overhanging the pool (Figure 107). The upstream end of Pool 3 was surrounded with cumbungi and *Phragmites*, however the left bank was dominated by tall exotic trees and a few redgums with little ground cover or understorey. The downstream end of the pool opened into a wide riffle/run section and connected to a larger corner pool downstream when full. A deep section below a rock ledge on the right bank made this the deepest of the three Clarendon pools.

Water quality parameters varied little over the study period; however the pool became shallower during autumn and very shallow in autumn 2008. Macrophyte cover increased each spring with curly pondweed dominating and small patches of ribbonweed (*Vallisneria australis*) (Table 49). Except for the first season in autumn 2006, this pool was isolated and not flowing in either spring or autumn sampling periods.



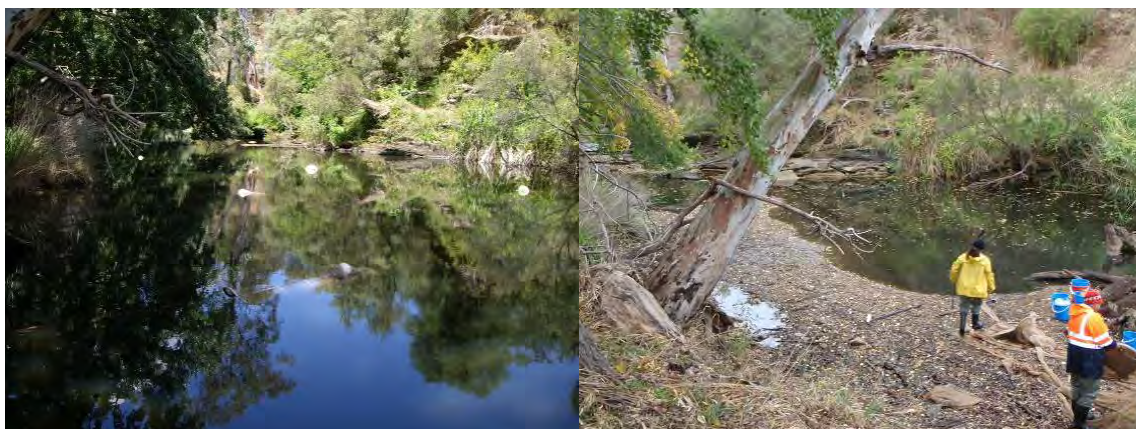


Figure 107. Clarendon Oval Pool 3 in a) spring 2007 and b) autumn 2008.

Table 49. Water quality parameters recorded in Clarendon Oval Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophyte (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	7	1050	7	15.1	2.2	10	Low flow	Flushes
2006	spring	6	957	8	16.0	2.0	25	No flow	Flushes
2007	autumn	10	1573	9	16.7	1.2	5	No flow	Very low flows
2007	spring	6	1131	8	15.5	2.0	10	No flow	Very low flows
2008	autumn	9	1800	8	12.6	0.8	0	No flow	Very low flows
2008	spring	6.8	1138	7.8	18.1	1.6	30	No Flow	Very low flows

3.3.1.2. Water Quality

Salinity was the only water quality parameter to be high enough to impact on aquatic biota. Whilst levels recorded here may be high enough to impact on particularly sensitive invertebrate species, all levels recorded are suitable for the maintenance of native fish.

3.3.1.3. Hydrology

The water level at Clarendon Oval was generally very low, however, survey pools were connected during autumn 2006, following this period these pools were disconnected for the duration of the project. Data from the Clarendon Oval gauge (flowing under the footbridge) indicates that there were periods of several months when no flows were maintained, and that water flow decreased from 2006 to 2007 (Figure 108). During the winter of 2006 there was sustained baseflow (average daily flow of 36 ML/day from the end of July to mid-October), which included five days of small flushing flows (over 65 ML/day) at the end of August. However, from mid-October until the spring 2006 surveys, conducted on November 16, there was no flow recorded at the gauge.

This lack of any recordable flow continued throughout summer and into autumn 2007, up until the surveys conducted on April 27. Over the winter of 2007 flow was much lower than the previous year, and very much lower than the environmental flow requirements recommended by the DWLBC (Van Laarhoven and van der Wielen 2009), averaging <1 ML/day except for a couple of small flushing flows of short duration. There was only one day when any of these pulsed flows



exceeded 40 ML/day during that winter. The average flow was very low (<0.5 ML/day) during the three months prior to the spring 2007 surveys, conducted on November 8, and there was no recordable flow for much of the time between these surveys and those conducted in autumn 2008, on April 30. No moderate or high flushing flows were recorded at Clarendon Oval over the past two years.

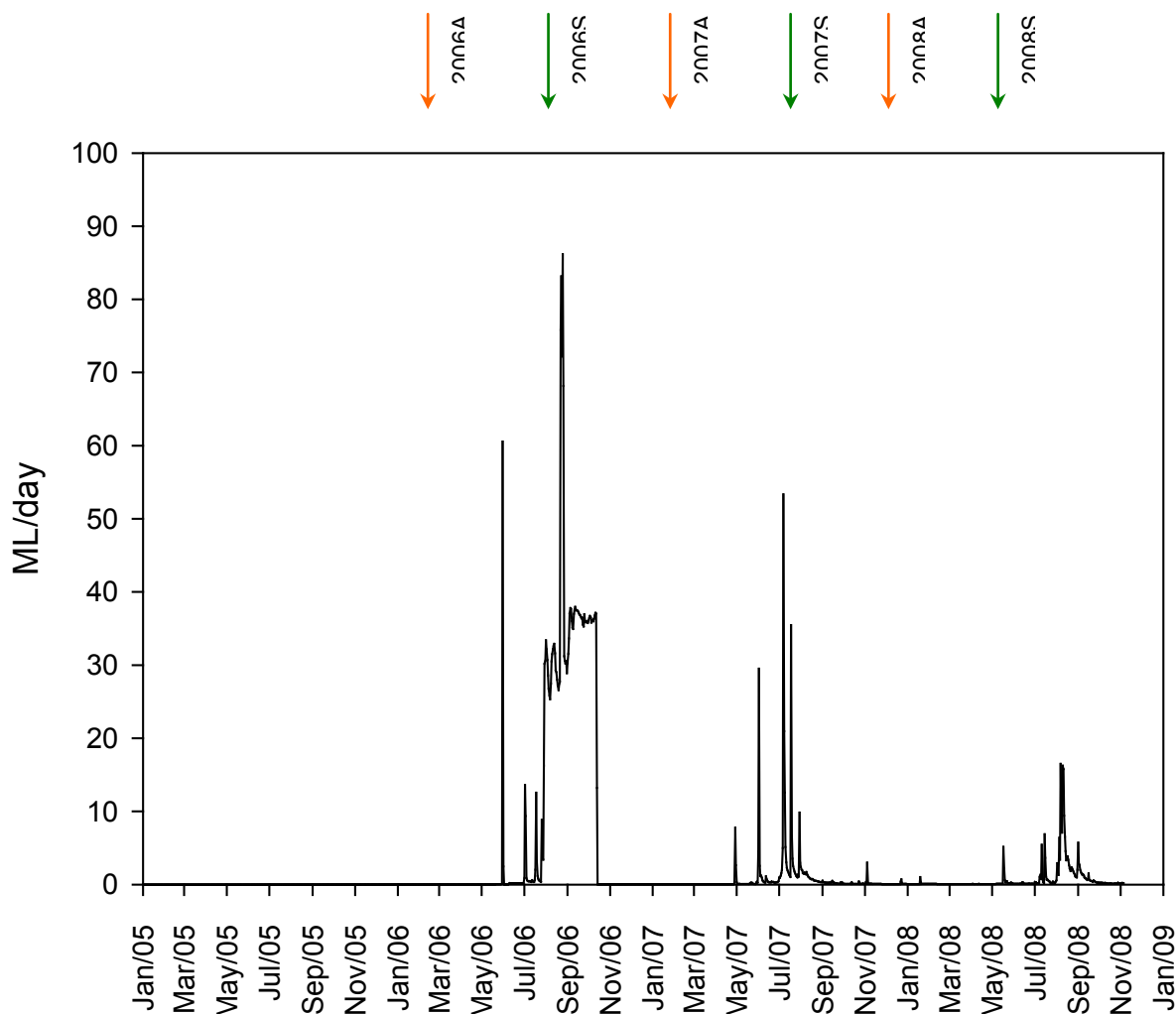


Figure 108. Hydrograph for flow in Onkaparinga River at Clarendon Oval. Flow data (ML/day) was collected downstream of Clarendon Oval (gauge number A5031004) from May 21, 2006 (indicated by blue arrow). The timing of each survey season is also shown above the figure.

3.3.1.4. Fish community

Six native and four introduced fish species were captured at Clarendon Oval over the five survey seasons (Figure 109). From autumn 2006 to autumn 2007 flathead gudgeon were the most common species captured; following this the community was dominated introduced species. Dwarf flathead gudgeon and galaxiids were captured in low numbers during each survey season. Common galaxias and mountain galaxias peaked in spring 2006, after the maintenance of winter baseflows. Neither of these galaxiids has been encountered during spring 2007 and autumn 2008,



and only one climbing galaxias was captured. A single native shortfinned eel was collected in autumn 2006, being the first record for the Onkaparinga Catchment.

Redfin perch and gambusia were the most common introduced species captured and in spring 2007 and autumn 2008, over 50% of the fish captured were one of these two species. Small numbers of introduced goldfish, carp and tench have also been captured, although typically as lone individuals in each season.

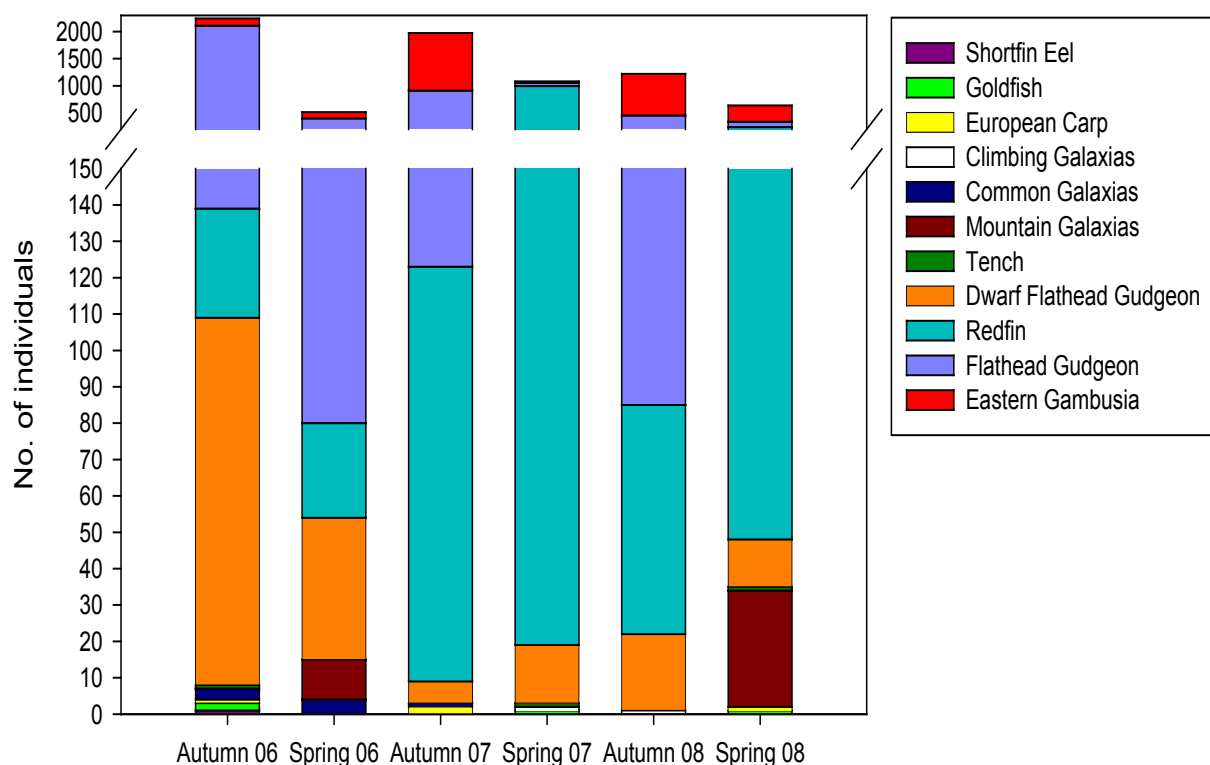


Figure 109. Abundances of each taxa present in the fish communities at Clarendon Oval (Onkaparinga River) over six survey seasons.

3.3.1.5. Fish population

The flathead gudgeon population at Clarendon Oval appears to be reasonably well established, with both small and large individuals captured throughout the survey (Figure 110). Although there was a decline in the number of captures from autumn 2006 to spring 2007, a large number of medium and large individuals were captured in autumn 2008. The largest numbers of dwarf flathead gudgeon captures occurred during in autumn 2006 (Figure 111). During all subsequent surveys small numbers of medium sized dwarf flathead gudgeon were captured. A small number of common galaxias were captured during both autumn and spring 2006 (Figure 112).



A small number of juvenile mountain galaxias were captured during spring 2006 (Figure 113). However, neither of these species was captured during any subsequent surveys. Two climbing galaxias were captured, one adult in autumn 2007 and one in spring 2007. The shortfinned eel was a large adult (~ 700 mm).

The gambusia population remained reasonably stable throughout the surveys (Figure 114). Large numbers of small to medium sized gambusia were captured in the three surveys from autumn 2006 to autumn 2007. Despite a decline in the number of captures in spring 2007, high numbers were again captured during autumn 2008.

The redfin perch population also appears to be well established, large numbers of small individuals and a number of large individuals were captured in each year (Figure 115). The largest numbers of juvenile recruits at this site were captured during the 2007 surveys and despite a decline in the number of medium to large sized fish (100mm+) over successive surveys there were still a large number of small recruits captured during the most recent survey, in autumn 2008.

One large individual tench was collected in spring of each year. A similar pattern was observed for goldfish, with individuals only occasionally captured, two medium sized fish in autumn 2006, and one large adult in spring of 2007 and 2008.



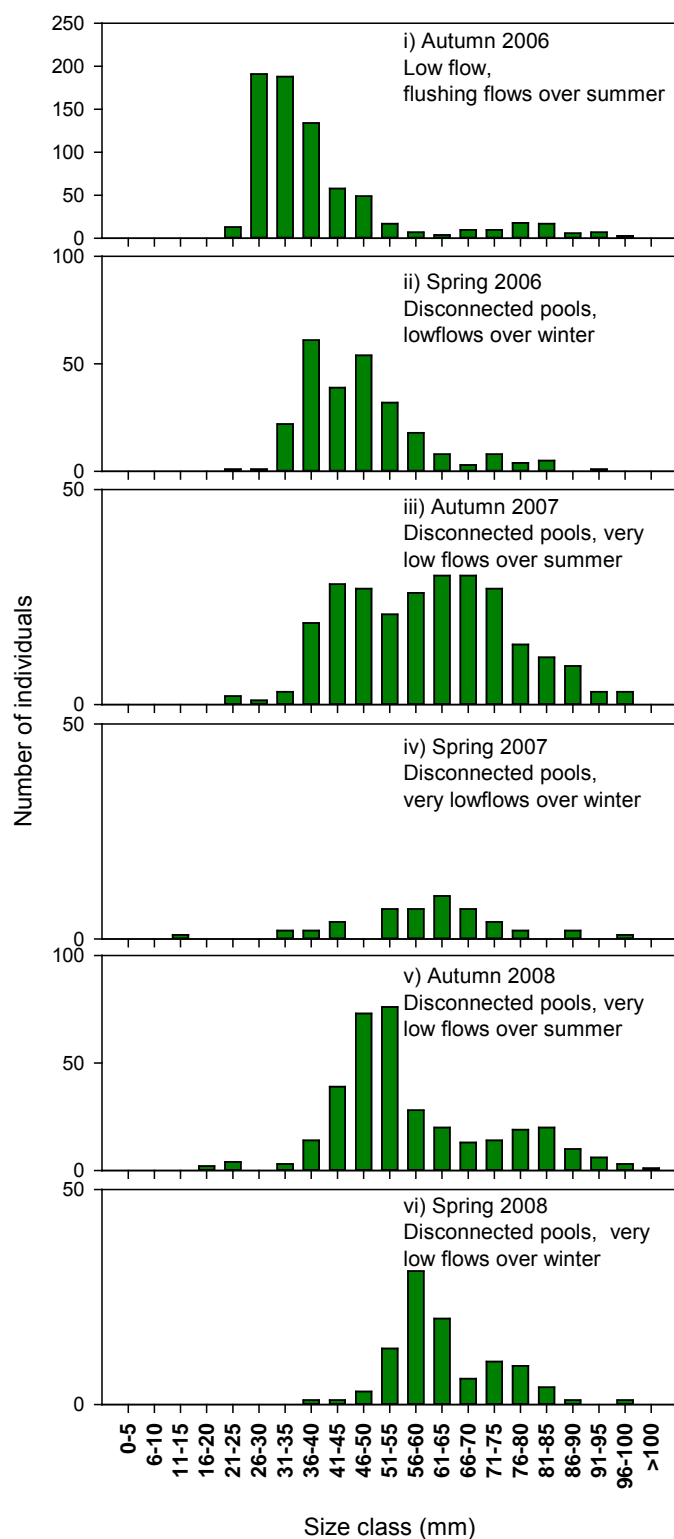


Figure 110. Lengths of flathead gudgeon (*P. grandiceps*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



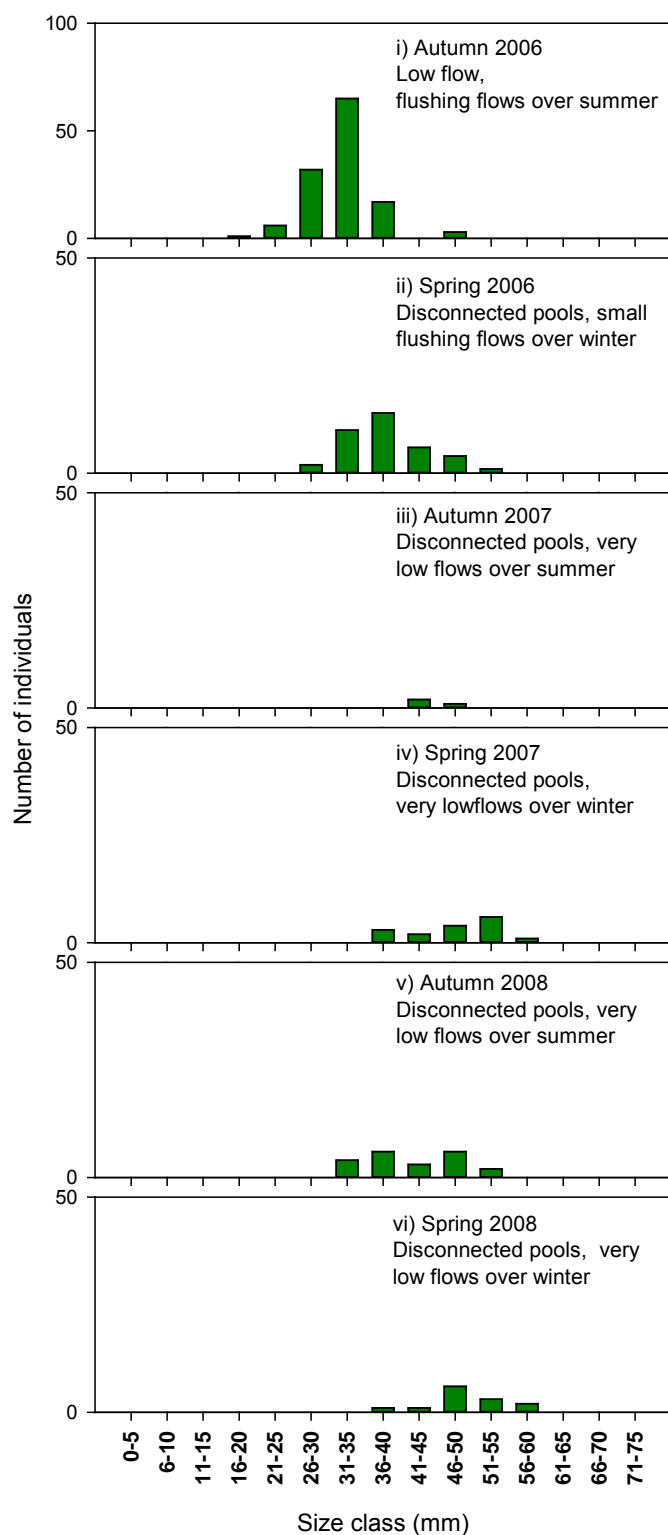


Figure 111. Lengths of dwarf flathead gudgeon (*P. macrostomus*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



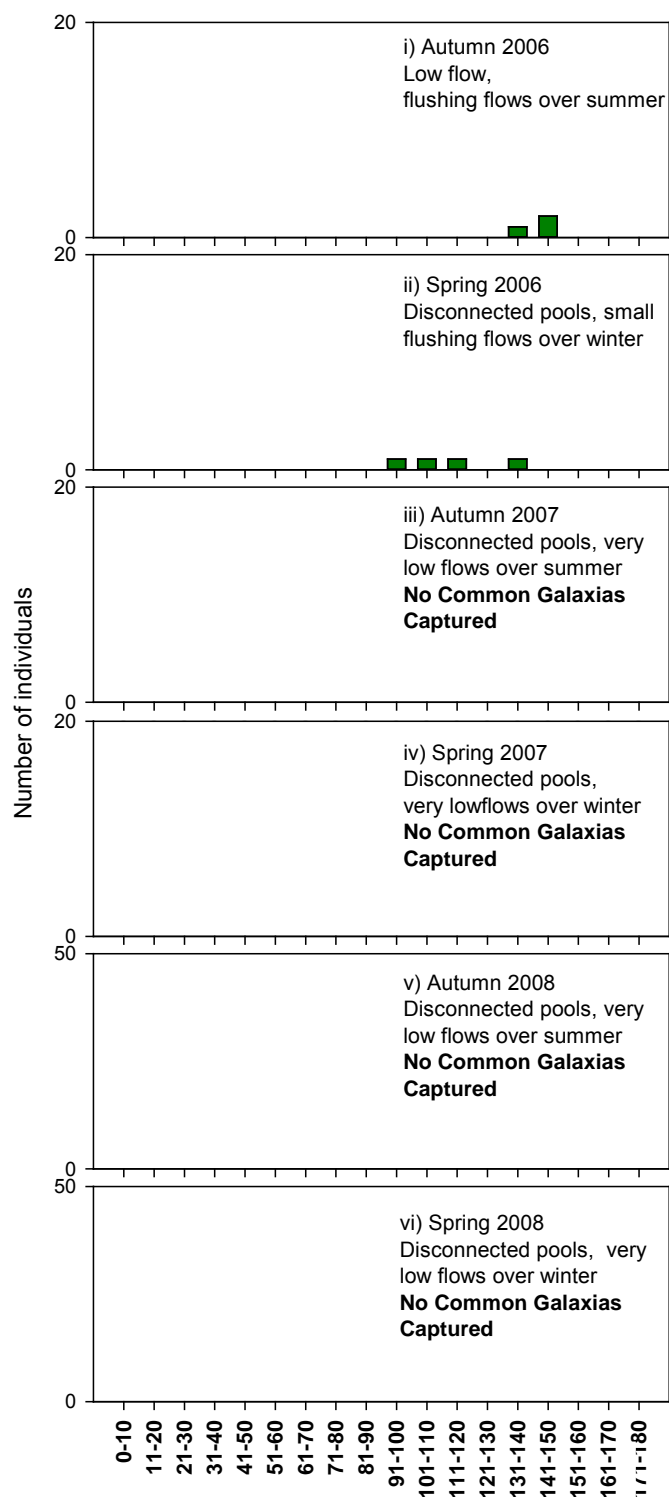


Figure 112. Lengths of common galaxias (*G. maculatus*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



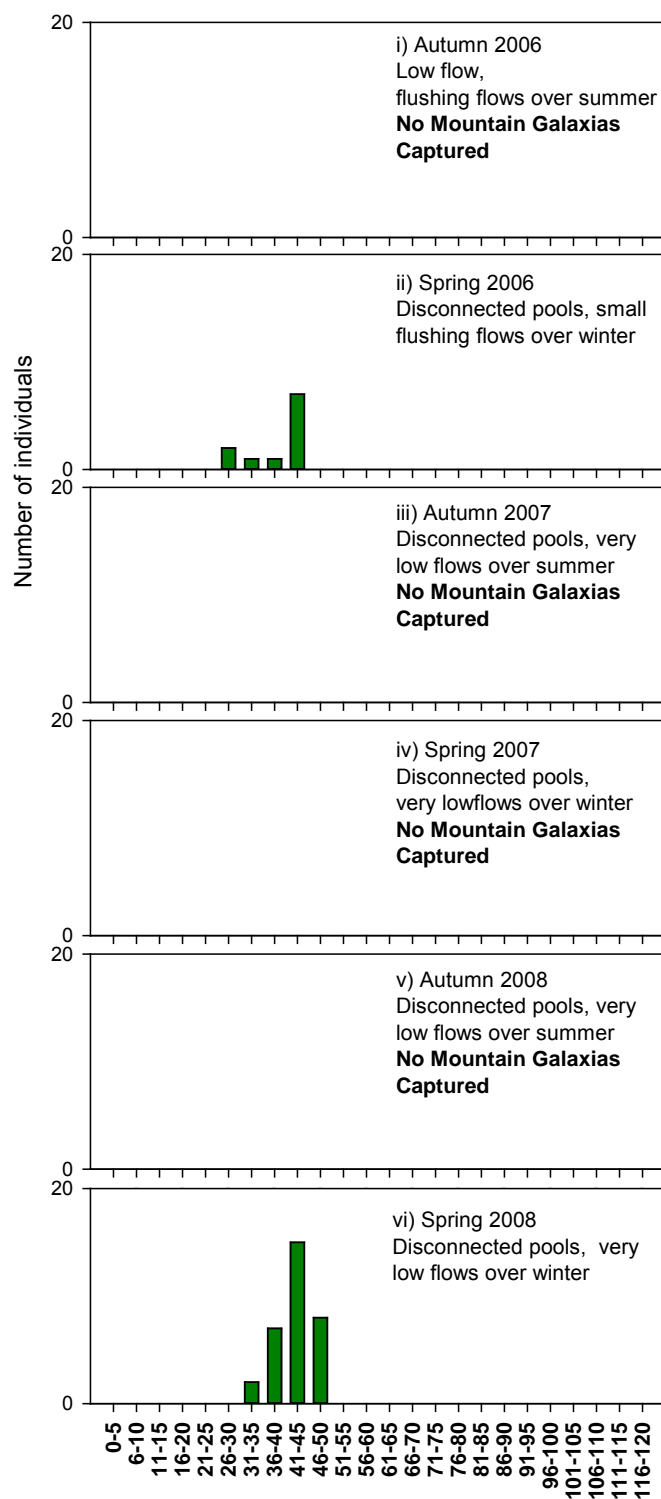


Figure 113. Lengths of mountain galaxias (*G. olidus*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



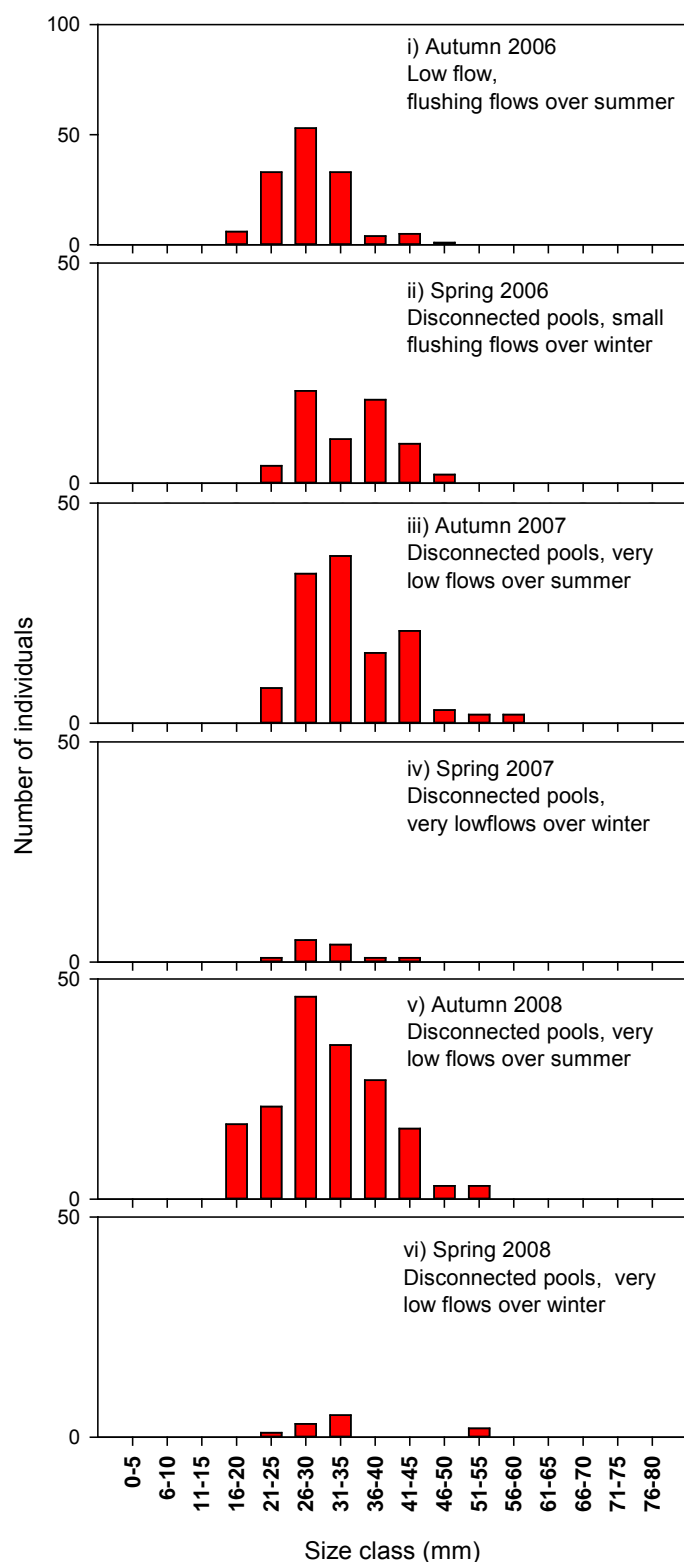


Figure 114. Lengths of gambusia (*G. holbrooki*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



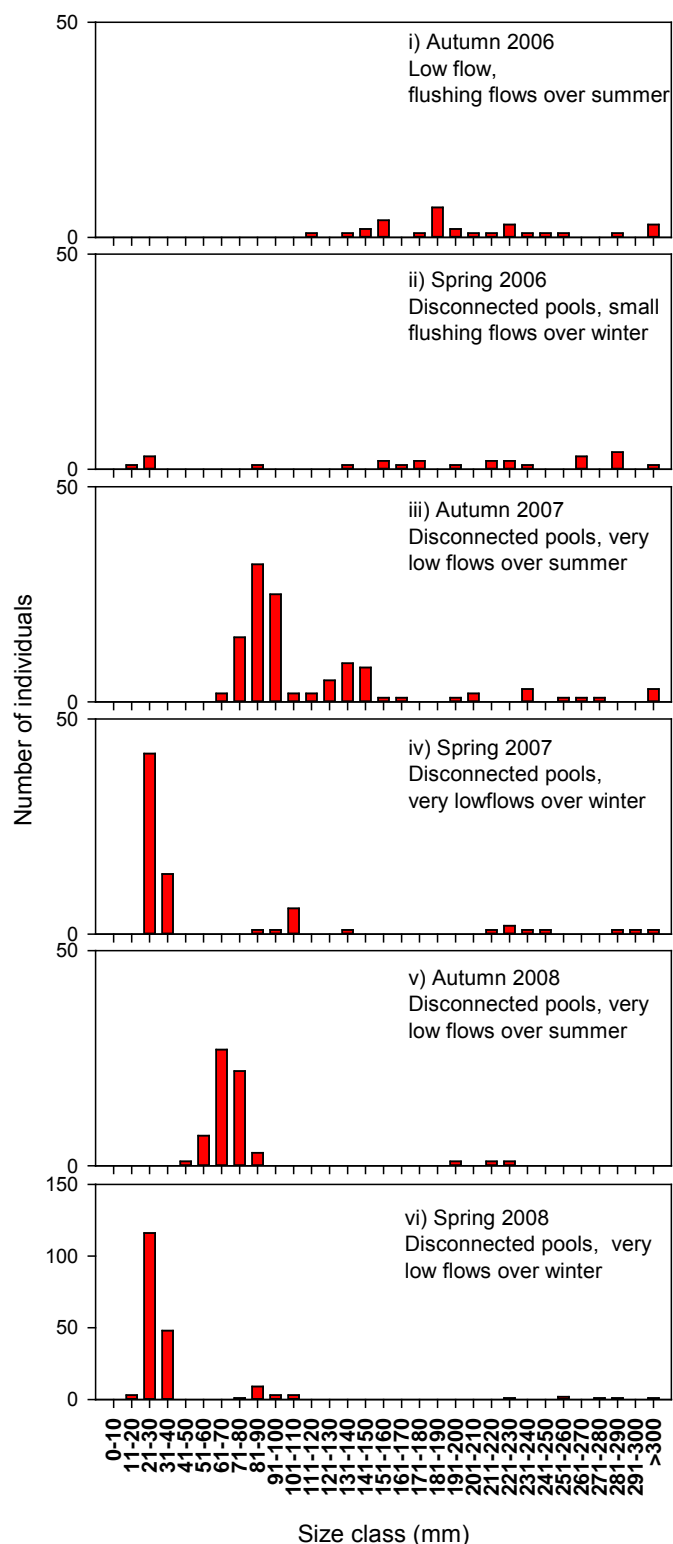


Figure 115. Lengths of redfin perch (*P. fluviatilis*) at Clarendon Oval (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.3.2. Brooks Road

3.3.2.1. Site assessment

The Brooks Rd Site is situated in the Onkaparinga Gorge several kilometres downstream of the Clarendon Weir. All sites were situated within a 300 m reach of the river. Pool 1 and pool 2 were connected when full, at opposite ends of a deep section of bedrock based river, with Pool 1 being somewhat shallower than Pools 2 and 3 (Table 50), whilst Pool 3 was separated from that section by ~ 30-40 m of riffle. The reach was dominated by solid bedrock with some large rocks present and steep gully on either bank. Riparian vegetation was not laterally extensive but consisted of large redgums and relatively high numbers of bottlebrush, ti-tree and wattle. The section was very rocky and dominated by the introduced foxtail grass (*Pennisetum villosum*) (Bald and Scholz 2007a), which formed a very dense understorey over 1m tall extending to the water's edge. This section was wholly within the Onkaparinga Gorge National Park although historical clearing was apparent and revegetation of the gorge has been recently undertaken. Electrofishing was conducted upstream and downstream of the site as well as between Pools 2 and 3. Upstream of Pool 1 is a small pool amongst dense vegetation which was electrofished when inundated. During dry periods throughout 2007 and 2008, electrofishing extended downstream to the junction of Kangarilla Creek as permanent water became scarce.

Table 50. Habitat characteristics of the three monitoring pools at Brooks Road in the Onkaparinga River.

Brooks Road	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	10+-Bedrock	80	0	1.2
Pool 2	Bedrock	50	1	2.5
Pool 3	Bedrock	50	0	2.0

Pools 1 and 2 are at separate ends of a large reach and are connected when full, but separate into separate pools during the dry season. Pool 1 was relatively shallow and possessed a higher degree of cobbled substrate in relation to bedrock compared to the other two pools (Figure). This pool is the one of the most ephemeral selected for the current study. In autumn 2007, this pool became incredibly shallow (Figure 116) and moderately saline and oxygen saturation was very low (Table 51) but still possessed fish; however by autumn 2008 it had dried completely, refilling in spring 2008. At other times, water quality parameters were reasonable stable and benign. The pool was surrounded on three sides with emergent cumbungi and *Phragmites* with a patchy overstorey of redgum, bottlebrush and some wattles. Submerged macrophytes were rare but were present in spring of each year. Except for the first season in autumn 2006, this pool was isolated and not flowing in either spring or autumn sampling periods.





Figure 116. Brooks Road Pool 1 in a) spring 2006 and b) autumn 2007.

Table 51. Water quality parameters recorded in Brooks Road Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	10	1267	8	15.7	1.2	0	Low flow	Flushes
2006	spring	7	834	7	18.8	1.0	15	No flow	Flushes
2007	autumn	4	3280	8	17.2	0.3	0	No flow	Very low flow
2007	spring	10	1421	8	19.6	0.5	5	No flow	Very low flow
2008	autumn	Not taken				0.0	0	No flow	Very low flow
2008	spring	9.1	1268	8.03	25	2.0	5	No flow	Very low flow

Pool 2 (Figure 117) was deeper and more permanent than Pool 1 and possessed a principally bedrock substrate, with little macrophyte cover and stable water quality, with exception of increased salinity in autumn 2007 (Table 52). During 2007 and 2008 the pool became very shallow and broke into three or four isolated pools of various sizes, but was full again in spring 2008. Macrophytes, predominantly ribbon weed, were rare but present each spring.

Riparian vegetation consisted of redgums, bottlebrush, wattle and *Leptospermum lanigerum* as well as an understorey of foxtail grass but lateral extent was confined to the banks. When full more complex littoral habitats were inundated including partial submersion of riparian vegetation. Except for the first season in autumn 2006 when very low flows were present, this pool was isolated and not flowing in either spring or autumn sampling periods. A few simple snags were present at this site with some areas of leaf litter particularly at the downstream end.





Figure 117. Brooks Road Pool 2 in a) spring 2006 and b) autumn 2007.

Table 52. Water quality parameters recorded in Brooks Road Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. (μS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	9	1187	8	15.8	2.5	0	Low flow	Flushes
2006	spring	6	833	8	16.9	2.3	5	No flow	Flushes
2007	autumn	8	1552	8	16.9	1.0	0	No flow	Very low flow
2007	spring	9	1434	8	20.5	0.8	5	No flow	Very low flow
2008	autumn	7	2700	7	14.2	0.8	0	No flow	Very low flow
2008	spring	9.1	1282	9.14	24.4	2.0	5	No flow	Very low flow

Pool 3 (Figure 118) was downstream of Pool 2 separated by a well shaded riffle section. Whilst a single pool when full, this pool dried into two separate pools both of which were sampled. Pool 2 had a largely bedrock substrate and whilst relatively deep, dried significantly throughout 2007 and 2008. At its shallowest, this pool became somewhat saline and in autumn 2007 became hypoxic (Table 53), approaching levels that may impact on fish (McNeil and Closs 2007). Macrophytes, largely ribbon weed, were rare but present each spring and in autumn 2006 following flushing flows.

Riparian vegetation consisted of a few large overhanging redgums and smaller bottlebrush. Areas of *Phragmites* were present, largely along the right bank, whilst foxtail covered rocky riparian areas around the rest of the pool. Except for the first season in autumn 2006 when very low flows were present, this pool was isolated and not flowing in either spring or autumn sampling periods.





Figure 118. Brooks Road Pool 3 in a) spring 2006 and b) autumn 2007.

Table 53. Water quality parameters recorded in Brooks Road Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	1193	8	16.1	2.0	5	Low flow	Flushes
2006	spring	5	852	8	15.6	1.8	10	No flow	Flushes
2007	autumn	2	4500	8	16.7	0.3	0	No flow	Very low flow
2007	spring	8	1625	7	27.9	0.5	5	No flow	Very low flow
2008	autumn	8	2800	8	13.8	0.4	0	No flow	Very low flow
2008	spring	5.99	877	7.02	21.6	1.1	5	No flow	Very low flow

3.3.2.2. Water Quality

Hypoxic conditions during 2007 reached levels low enough to present a challenge to the survival of some species of freshwater fish (McNeil and Closs 2007) however, there is no tolerance data for WMLR species. Obligate freshwater species such as *G. olidus* may be more sensitive to hypoxia and could feasibly be impacted by these levels. Salinity levels recorded here may be high enough to impact on particularly sensitive invertebrate species, but all levels recorded are suitable for the maintenance of native fish.

3.3.2.3. Hydrology

Whilst the present surveys were conducted at Brooks Road the water level was similar to that at Clarendon Oval, with low water level connecting pools during the initial survey in autumn 2006, but pools disconnected during all subsequent surveys.

The Brooks Road site is downstream from, and has a similar hydrology to Clarendon Oval. A detailed description of the hydrology occurring at Clarendon Oval during the present surveys is provided above.



3.3.2.4. Fish community

There were five native and three introduced fish taxa captured at Brooks Road over the five survey seasons (Figure 119). Amongst the natives, flathead gudgeon were present in relatively high abundances in all seasons. Dwarf flathead gudgeon were initially more abundant than flathead but their numbers have steadily declined from survey to survey.

A large number of mountain galaxias were captured in spring 2006, but far lower numbers of this taxon were captured in spring 2007 and each of the autumn surveys. Records of extremely hypoxic conditions at this site in 2007 may be associated with the decline in abundance of mountain galaxias given their association with flowing well oxygenated water. However, the species is known to tolerate extreme conditions in drying stream pools (Closs and Lake 2006) and tolerance threshold data would need to be collected for this species before a strong connection can be made.

Relatively small numbers of common galaxias were captured in all survey seasons. As for Clarendon Oval, the number of captures of these galaxiids peaked in spring 2006, at over 100 individuals, but only one individual has been captured during each of the last two surveys, conducted in spring 2007 and autumn 2008. During the present surveys, only one individual climbing galaxiid has been captured at Brooks Road in spring 2006. *Gambusia* was the most common introduced fish present in pools during all surveys at this site, with particularly high numbers of these fish captured in all autumns. Both redfin perch and goldfish were present in very low numbers across survey seasons.

3.3.2.5. Fish population

There were large numbers of flathead gudgeon captured at Brooks Road over 2006 and 2007 (Figure 120). These were predominantly small individuals, but medium and large gudgeon were also captured in each season. During these two years juvenile recruits peaked in both autumns, but fewer small individuals were captured in autumn 2008. Most of the dwarf flathead gudgeon captured at Brooks Road were of medium size in all seasons (Figure 121). This species peaked in spring 2006, but have steadily declined over successive surveys.

Medium and large mountain galaxias were captured at Brooks Road during the initial surveys in autumn 2006 (Figure 122). In spring 2006 there was a large number of juveniles captured, but only a small number of medium sized individuals were captured in autumn 2006. In 2007 the number of juvenile mountain galaxias captured in spring was much lower than that for the previous year. Only three medium sized individuals were captured in autumn 2008.

Most of the common galaxias captured at Brooks Road were medium and large individuals (Figure 123). There was a large number of medium sized individuals captured in spring 2006, with reduced



but still relatively high numbers of individuals captured in autumn 2007. However, there has only been one individual common galaxias captured in each of the two subsequent surveys. One medium climbing galaxias (size = 44 mm) was collected in spring 2006.

There were large numbers of small gambusia captured during each of the five surveys (Figure 124). Although few larger individuals were captured from this population, the numbers of captures has remained relatively stable over survey seasons. Small numbers of large goldfish were captured, but this does not appear to be an established population (Figure 125). One goldfish was captured during autumn 2008, and more were captured in 2007.

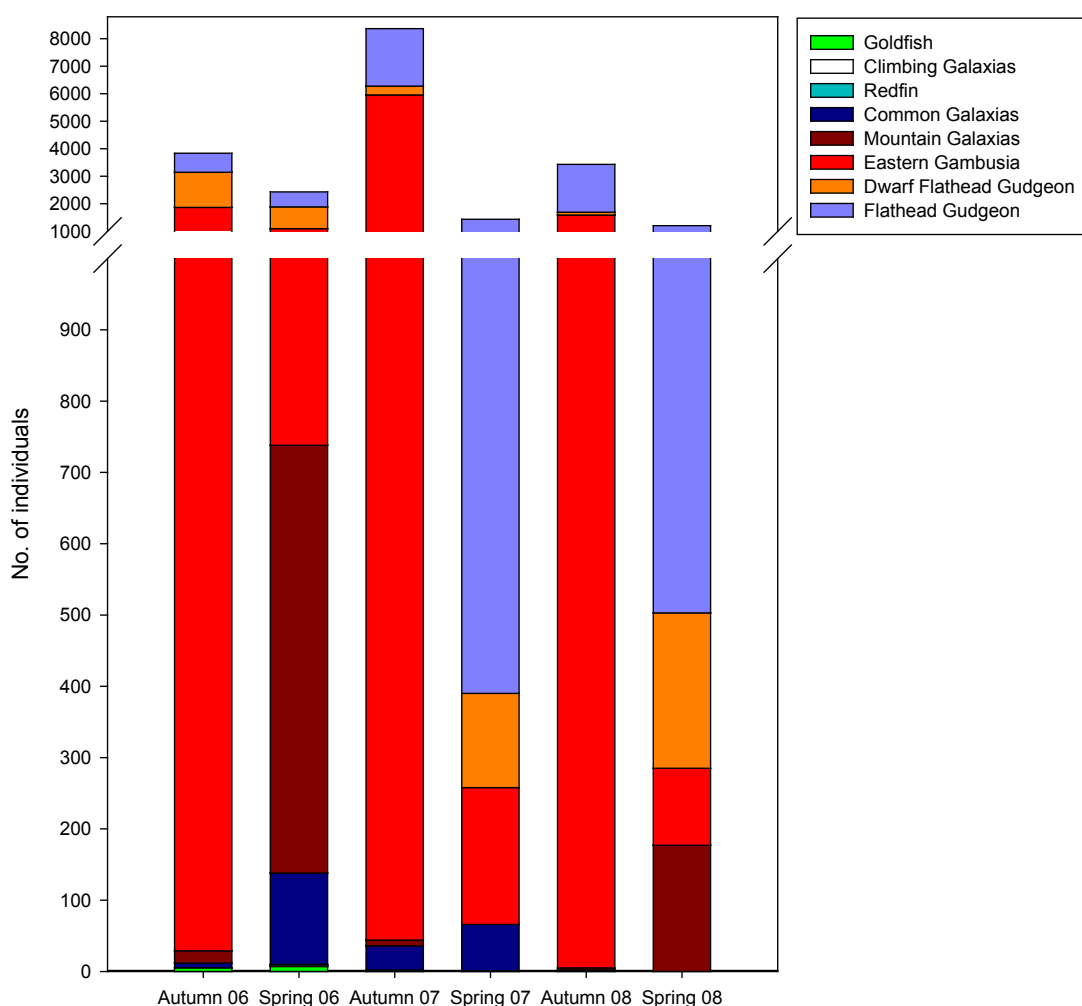


Figure 119. Abundances of each taxa present in the fish communities of each pool at Brooks Road (Onkaparinga River) over six survey seasons.



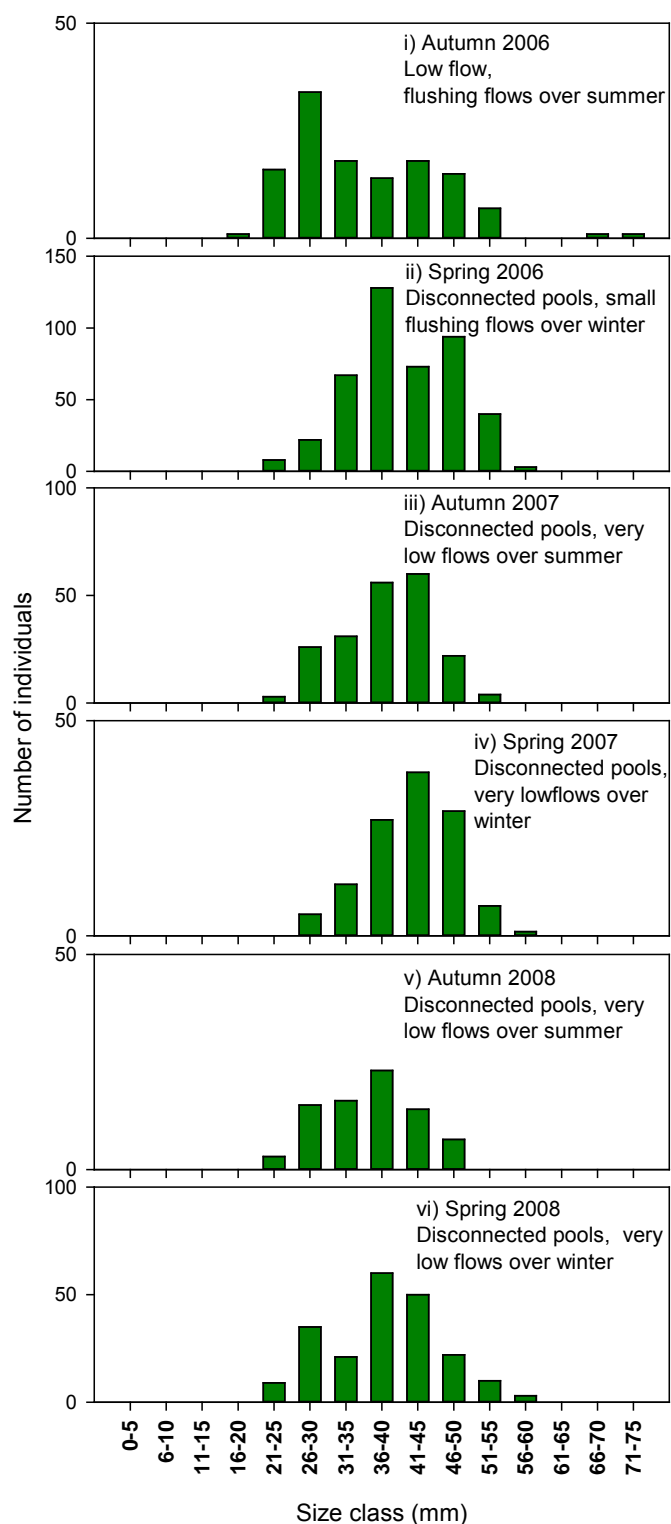


Figure 120. Lengths of dwarf flathead gudgeon (*P. macrostomus*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



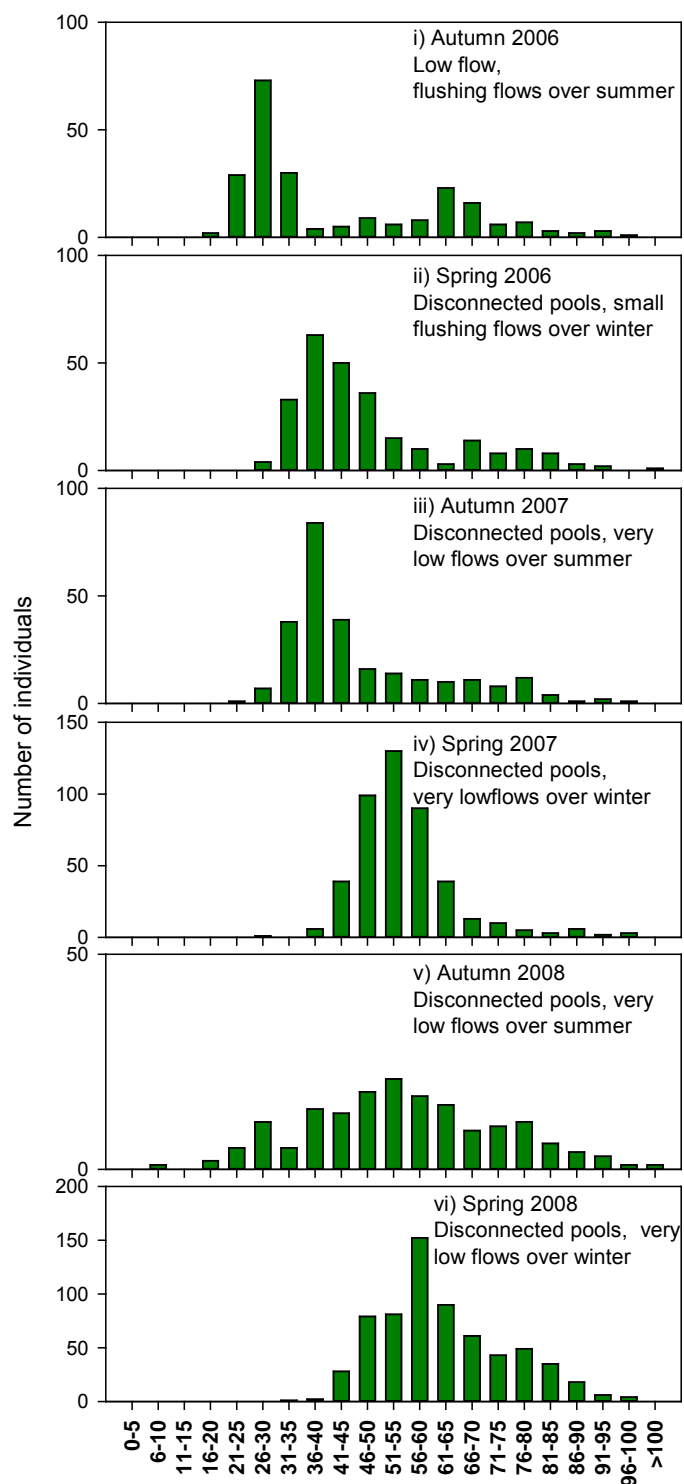


Figure 121. Lengths of flathead gudgeon (*P. grandiceps*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



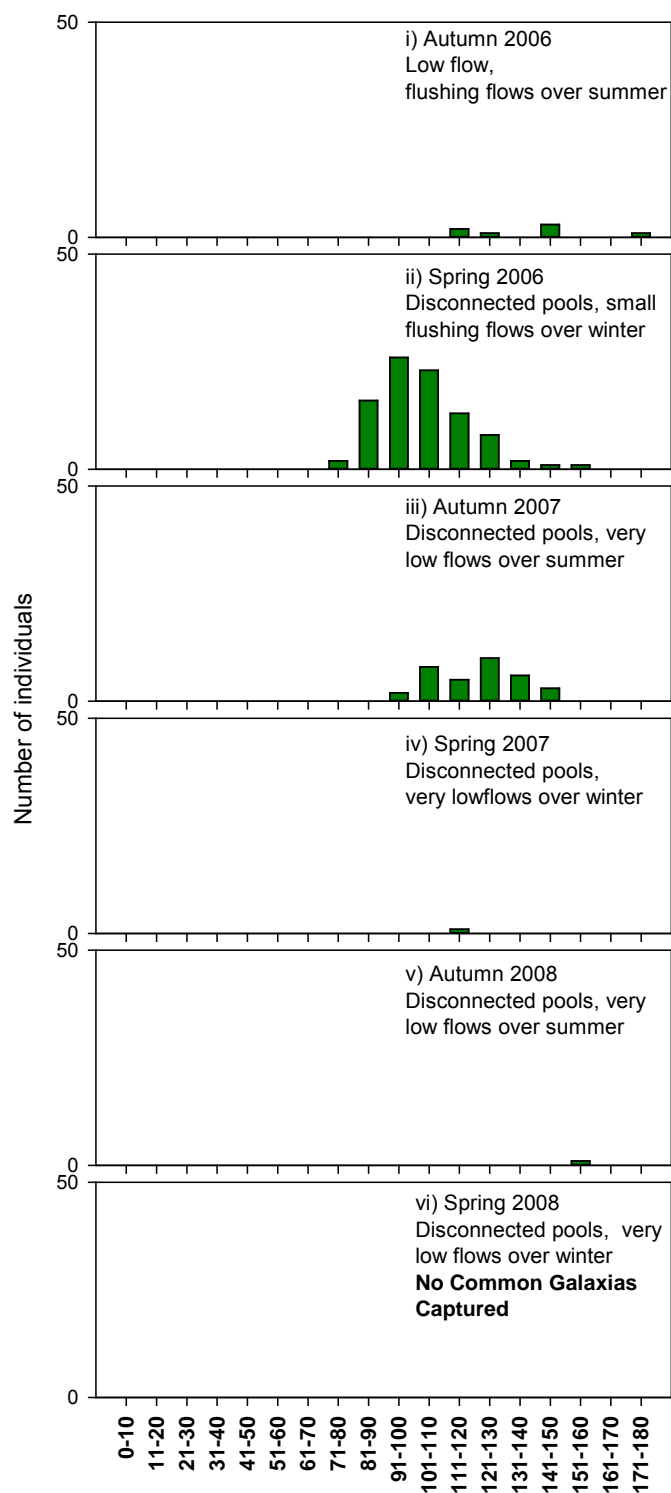


Figure 122. Lengths of common galaxias (*G. maculatus*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



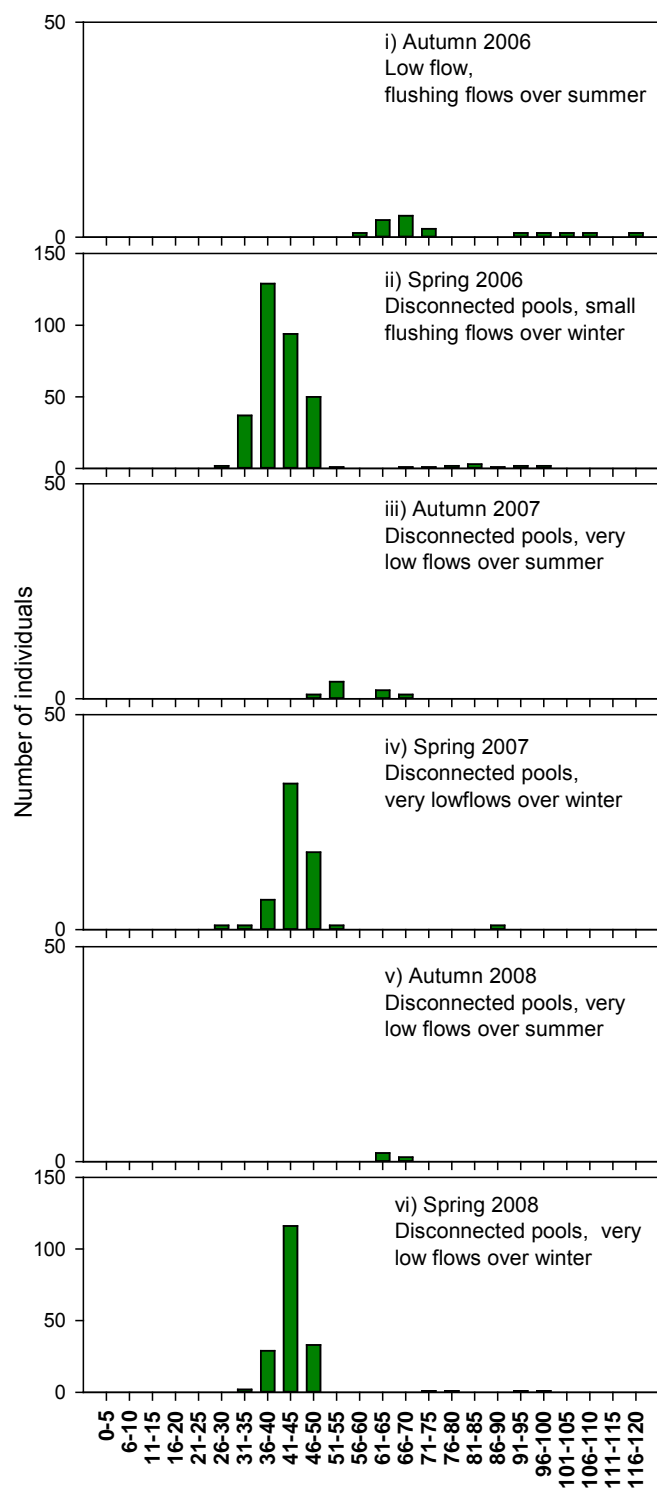


Figure 123. Lengths of mountain galaxias (*G. olidus*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



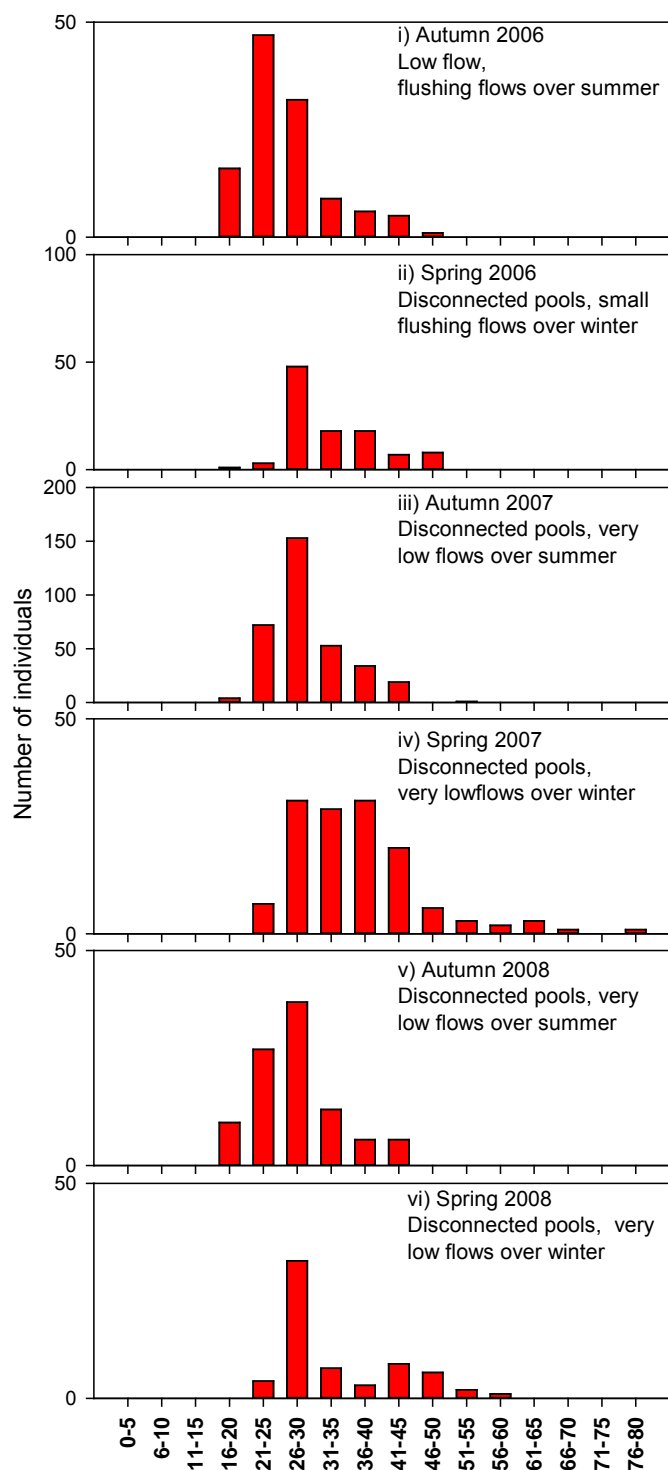


Figure 124. Lengths of gambusia (*G. holbrooki*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



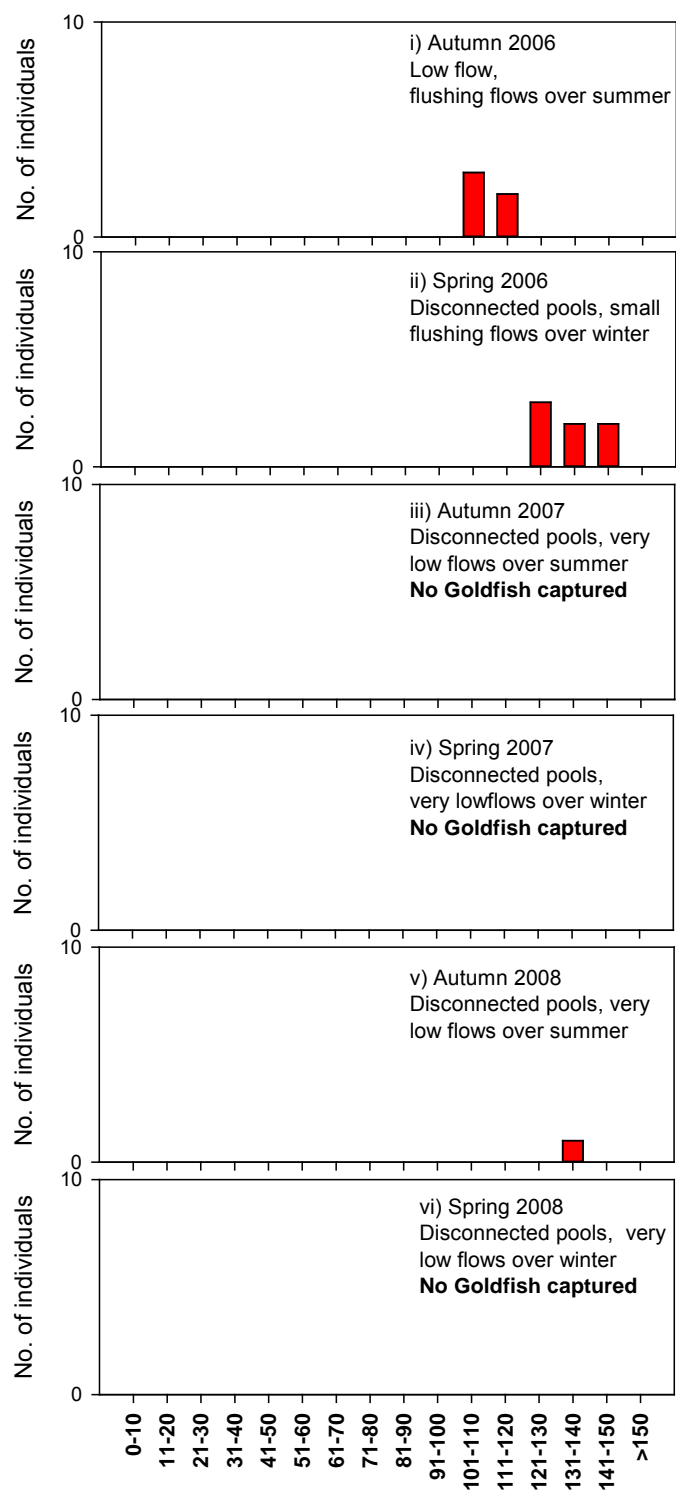


Figure 125. Lengths of goldfish (*C. auratus*) at Brooks Road (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



3.3.3. Old Noarlunga

3.3.3.1. Site assessment

The Old Noarlunga site encompasses the lower freshwater reaches of the river immediately above the normal upper influence of the tidal estuary. All pools are situated at the base of the Onkaparinga Gorge and encompassed by the National Park. The three pools were relatively deep, particularly Pools 2 and 3, with rocky substrate and bedrock sections (Table 54). These pools had a higher density of woody debris (snags) than other sites and riparian vegetation at all sites was dominated by native species primarily redgum and bottlebrush. All three pools were surrounded with dense emergent vegetation primarily *Phragmites* and cumbungi. With much of this reach dominated by deep pool sections, electrofishing was conducted amongst dense *Phragmites* between pools as well in shallower rifle/run sections upstream and downstream of Pool 1.

Table 54. Habitat characteristics of the three monitoring pools at Old Noarlunga in the Onkaparinga River.

Old Noarlunga	Substrate size (mm)	Riparian cover (%)	Snags	Absolute max. depth (m)
Pool 1	10+	45	7	2.5
Pool 2	5-10+	15	25	3.5
Pool 3	5-10+	25	20+	3.5

Pool 1 (Figure 126) was the shallowest of the Old Noarlunga pools (Table 55) at the hydrometric weir located at the point at which the water pipeline crosses the river. During dry periods the pool separated into three separate pools with the measurement weir the most downstream. The upstream pool was the most permanent and although it never dried completely became extremely shallow in autumn 2007 and 2008. This pool was moderately salty throughout the study period and became hypoxic during the intervening summer. Pool 1 was not flowing in spring 2006, autumn 2007 or spring 2008 sampling trips with low flow during other times.

Macrophytes were abundant at Pool 1 with large areas of emergent *Phragmites* and submerged beds of water ribbon and *Potamogeton crispus*, which increased in density each spring and becoming very dense in spring 2008 covering approximately 80 % of the pool. The pool was overhung with large redgums and some bottlebrush and was reasonably well shaded (Figure 125). Apart from flushes prior to sampling in autumn and spring 2006, antecedent hydrology consisted of very low flows prior to all other sampling trips.





Figure 126. Old Noarlunga Pool 1 in a) spring 2006 and b) autumn 2008.

Table 55. Water quality parameters recorded in Old Noarlunga Pool 1 during each survey.

Pool 1	Season	DO (ppm)	Cond. ($\mu\text{S}/\text{cm}$)	pH	Temp. ($^{\circ}\text{C}$)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	2580	8	12.5	2.5	40	Low flow	Flushes
2006	spring	5	1699	7	20.5	2.0	10	No flow	Flushes
2007	autumn	7	3360	8	16.1	0.5	10	No flow	Very low flows
2007	spring	3	2373	7	21.1	2.5	30	Low flow	Very low flows
2008	autumn	4	3270	7	12.9	0.3	15	No flow	Very low flows
2008	spring	2	2450	7	19.2	1.5	80	Low flow	Very low flows

Pool 2 is a deep permanent freshwater pool predominantly bedrock based with cobbled substrate towards the downstream end. The pool consists of a long deep channel approximately 2 m in depth and 50 m long which opens into a deep pool 3.5 m in depth and surrounded by emergent macrophytes (Figure 127). This large pool is dominated by a large redgum snag (whole tree) whilst other snags are abundant throughout the pool length. Riparian vegetation is fairly dense with large redgums and bottlebrush along both banks. Macrophytes mainly consisted of *Phragmites* which surrounded the pool and extended into the pool especially within the shallower downstream section.

Whilst dissolved oxygen and other water quality parameters remained relatively stable throughout the sampling period, acidic and low oxygen conditions were recorded in the final survey in spring 2008. Salinity fluctuated considerably, becoming somewhat saline in autumn 2007 and 2008 (Table 56).



Pool depth remained fairly consistent fluctuating within a metre over the course of the study. Low flow was detected during sampling in autumn 2006 and in spring 2007 and 2008 with no flow at other times. Apart from flushes in 2006, antecedent flow conditions were very low.



Figure 127. Old Noarlunga Pool 2 in a) spring 2006 and b) autumn 2008.

Table 56. Water quality parameters recorded in Old Noarlunga Pool 2 during each survey.

Pool 2	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	9	2630	8	13.9	3.5	20	Low flow	Flushes
2006	spring	7	1968	8	21.6	3.0	20	No flow	Flushes
2007	autumn	9	11600	8	15.6	2.5	20	No flow	Very low flows
2007	spring	6	2490	7	20.0	3.0	20	Low flow	Very low flows
2008	autumn	8	8600	8	14.8	2.0	20	No flow	Very low flows
2008	spring	4	2590	6	20.9	2.0	20	Low flow	Very low flows

Pool 3 (Figure 128) is a large and deep pool surrounded by *Phragmites* with sparse redgum and bottlebrush the riparian zone. This was the most environmentally variable pool within the study with significant changes in salinity. Whilst the pool was fresh at the beginning of the study and throughout 2006, salt water intrusion due to very large tidal and storm swells lead to marine conditions in the pool (Table 57). Small freshwater flushes during winter 2007 and 2008 freshened surface waters temporarily, returning to marine conditions in autumn 2008.

More detailed salinity mapping, not presented here revealed that salinity was strongly stratified in this pool and that marine conditions were permanent below 0.5 m following the autumn 2007 tidal inflow.



As a result Pool 3 underwent a shift from freshwater to marine habitat during autumn 2007. A dissolved oxygen reading of 22 ppm in 2007 may reflect a boom in productivity following this saltwater intrusion, whilst the following autumn experienced severe hypoxia with oxygen levels declining to levels not sufficient for fish respiration (McNeil and Closs 2007). As with other pools at this site, zero flow was observed during spring 2006, autumn 2007 and autumn 2008 with low flow at other sampling times, whilst antecedent flow conditions were very low in all years except for autumn and spring 2006.



Figure 128. Old Noarlunga Pool 3 in a) spring 2006 and b) autumn 2008 and c) flowing during winter surveys (from McNeil and Fredberg 2010).

Table 57. Water quality parameters recorded in Old Noarlunga Pool 3 during each survey.

Pool 3	Season	DO (ppm)	Cond. (µS/cm)	pH	Temp. (°C)	Max. depth (m)	Macrophytes (% cover)	Hydrology	Antecedent Hydrology
2006	autumn	8	2830	8	12.9	3.5	10	Low flow	Flushes
2006	spring	8	1850	8	21.9	3.0	10	No flow	Flushes
2007	autumn	22	50000	8	18.6	2.5	10	No flow	Very low flows
2007	spring	6	2930	8	20.8	3.5	10	Low flow	Very low flows
2008	autumn	1	62800	6	17.0	2.0	10	No flow	Very low flows
2008	spring	6	9060	6	23.5	2.0	10	Low flow	Very low flows

3.3.3.2. Water Quality

Extremes in dissolved oxygen and salinity levels highlight the highly variable and frequently harsh nature of this site, which fluctuates wildly between benign freshwater and marine conditions, a shift which is likely to cause large fish kills and result in changes to fish assemblage structure.

Water quality management at this site is critical and freshwater in-flows may be required to maintain freshwater habitats and prevent fish kills, particularly during large tidal and storm surges where saline waters are pushed up into normally fresh reaches.



3.3.3.3. Hydrology

The water level at Old Noarlunga has been low during all times that surveys have been conducted, with the survey pools disconnected on three of the five survey days, in spring 2006 and autumns of 2007 and 2008. The survey pools were connected by low flow in autumn 2006 and spring 2007.

Between the autumn 2006 and spring 2006 surveys the gauge data indicates that Old Noarlunga received multiple moderate flushing flows in the high flow period, including a flow of over 470 ML on July 18 and a sustained flow above 50 ML/day throughout most of August (Figure 129). However, there was no readable flow by mid-October. This lack of flow continued to the spring 2006 surveys, conducted on November 28, and then over summer until the autumn 2007 survey, conducted on May 16. Very low flows returned towards the end of May 2007, with a moderate flushing flow at the end of the low flow period in early June.

There were also two moderate flushing flows at the beginning of the high flow period. However, the flow was more typically low throughout July and the average flow was very low by mid-August. The average flow was less than 2 ML/day from September to the time of the spring 2007 surveys conducted on November 13. There was no readable flow from the end of November through the summer of 2007/08 and up to the time of the autumn 2008 surveys, conducted on May 1.

At Old Noarlunga, the structure of the fish community in the most downstream estuarine pool was distinct from the two freshwater pools at all times except during the spring 2006 surveys, prior to which there were sustained flushing flows. Within the two freshwater pools there was no consistent change in the structure of fish communities between seasons or among years, possibly indicating that none of the freshwater fish at this site are being favoured as conditions became progressively drier.



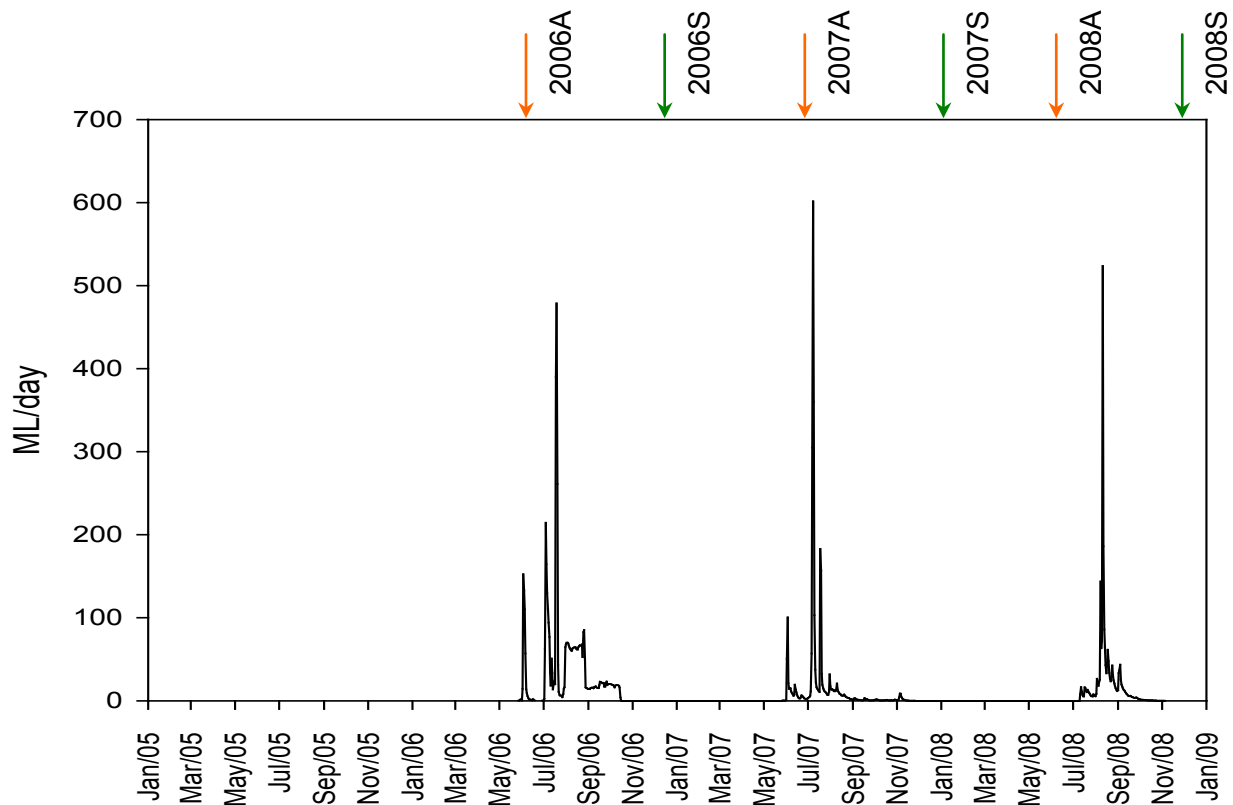


Figure 129. Hydrograph for the Onkaparinga River at Old Noarlunga. Flow data (ML/day) was collected upstream of Old Noarlunga (gauge number A5031005) from May 26, 2006 (indicated by blue arrow). The timing of each survey season is also shown above the figure.

3.3.3.4. Fish community

There were three native freshwater taxa and one introduced freshwater taxa, as well as six estuarine/marine taxa amongst the fish captured at Old Noarlunga over the six survey seasons (Figure 130). In all seasons the most common taxa encountered were common galaxias. Relatively high numbers of flathead gudgeon and congolli were also captured in all pools across all survey seasons. Small numbers of dwarf flathead gudgeon were captured in all pools and seasons.

Large numbers of gambusia were captured in the most upstream pool in autumn 2007 and in riffles during electrofishing surveys in autumn 2008, but these fish have never been captured in the two downstream survey pools. Conversely, the estuarine/marine taxa black bream, jumping mullet, tamar goby, bridled goby and blue spot goby have all only been caught in the pool farthest downstream and have always been relatively rare. Tamar goby (four individuals) and bridled goby (one individual) were only captured in autumn 2007.



3.3.3.5. Fish population

Only small numbers of dwarf flathead gudgeon were captured at Old Noarlunga during any of the present surveys (Figure 131). During spring of both 2006 and 2007 some of these fish were captured from the most downstream pool. High numbers of flathead gudgeon across a broad size range were captured at Old Noarlunga during all surveys (Figure 132). These fish have been captured from both the upstream freshwater pools and the downstream estuarine pool in all seasons, except during autumn 2008 when none were captured from the downstream pool.

The population of common galaxias appears well established, with high numbers captured during all surveys (Figure 133). The highest numbers of juveniles were captured during spring of 2006 and 2007, including a number of fish captured in the most downstream (estuarine) pool leading to an increase in adults moving up into the freshwater habitats at this site.

The population of congolli appears to be well established, with a wide range of sizes captured in all pools during each survey and regular progression of year classes throughout the survey (Figure 134). There were small numbers of medium gambusia captured at Old Noarlunga during both autumn and spring 2006 (Figure 135). The highest number of captures occurred in autumn 2007, but none were captured in spring 2007 and only a small number in autumn 2008.

The estuarine species were well represented at Old Noarlunga. The highest numbers of black bream were captured in the most downstream pool under low flow conditions during autumn 2006, but very few individuals were captured during any subsequent surveys (Figure 136). Only a small number of jumping mullet were captured during the present surveys, the peak occurred in autumn 2007. No jumping mullet were recorded in autumn 2008 (Figure 137).

Small numbers of blue spot goby were captured during 2006 and 2007, and none during autumn 2008 surveys (Figure 138). One medium sized bridled goby was captured in the most downstream pool during autumn 2007. Tamar goby catch peaked in the upstream pools during autumn 2006 (Figure 139). However, only four were captured in autumn 2007, and none of these fish have been captured at the site during either of the spring surveys or in autumn 2008.



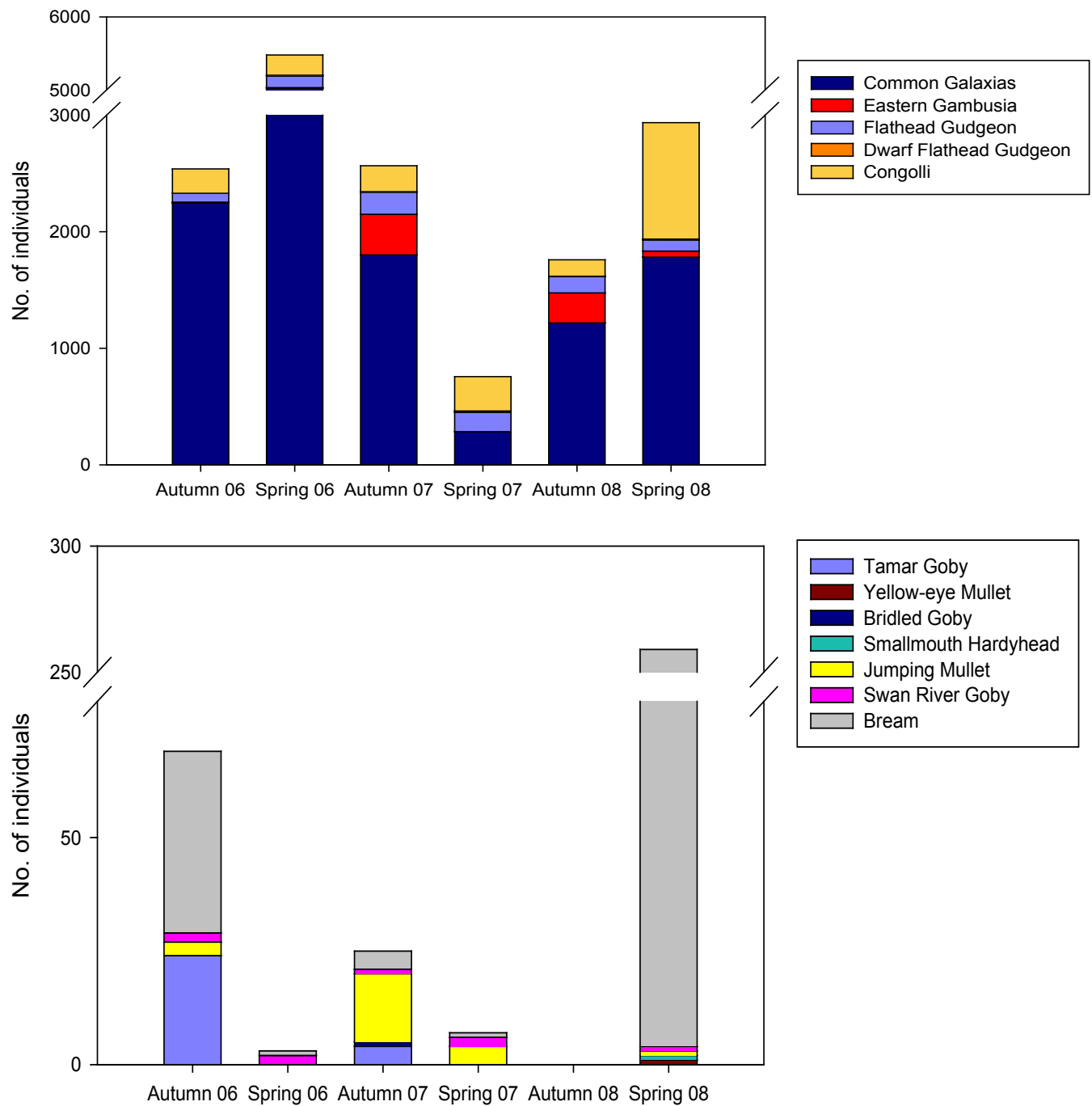


Figure 130. a) Abundances of freshwater taxa present in the fish communities of each pool at Old Noarlunga (Onkaparinga River) over six survey seasons, and b) Abundances of estuarine taxa present in the fish communities of each pool at Old Noarlunga (Onkaparinga River) over six survey seasons.



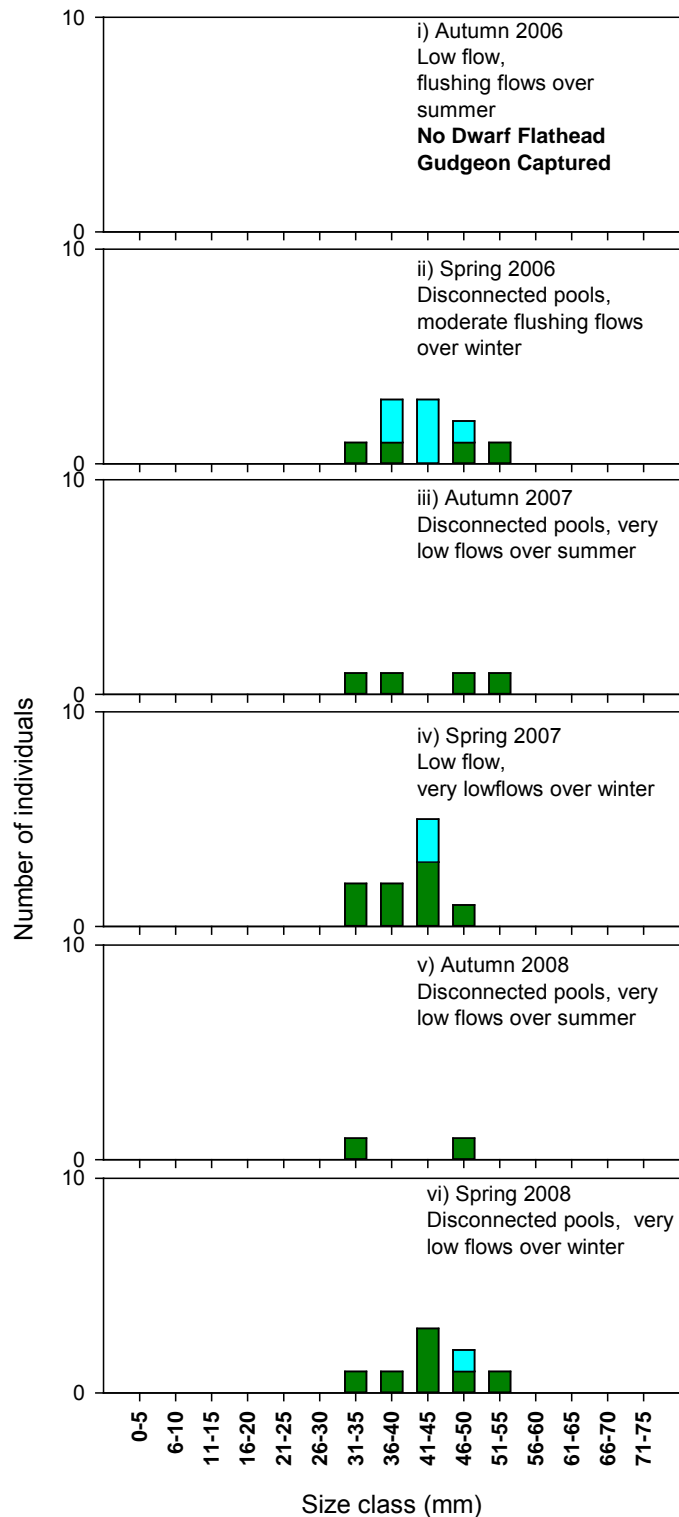


Figure 131. Lengths of dwarf flathead gudgeon (*P. macrostomus*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



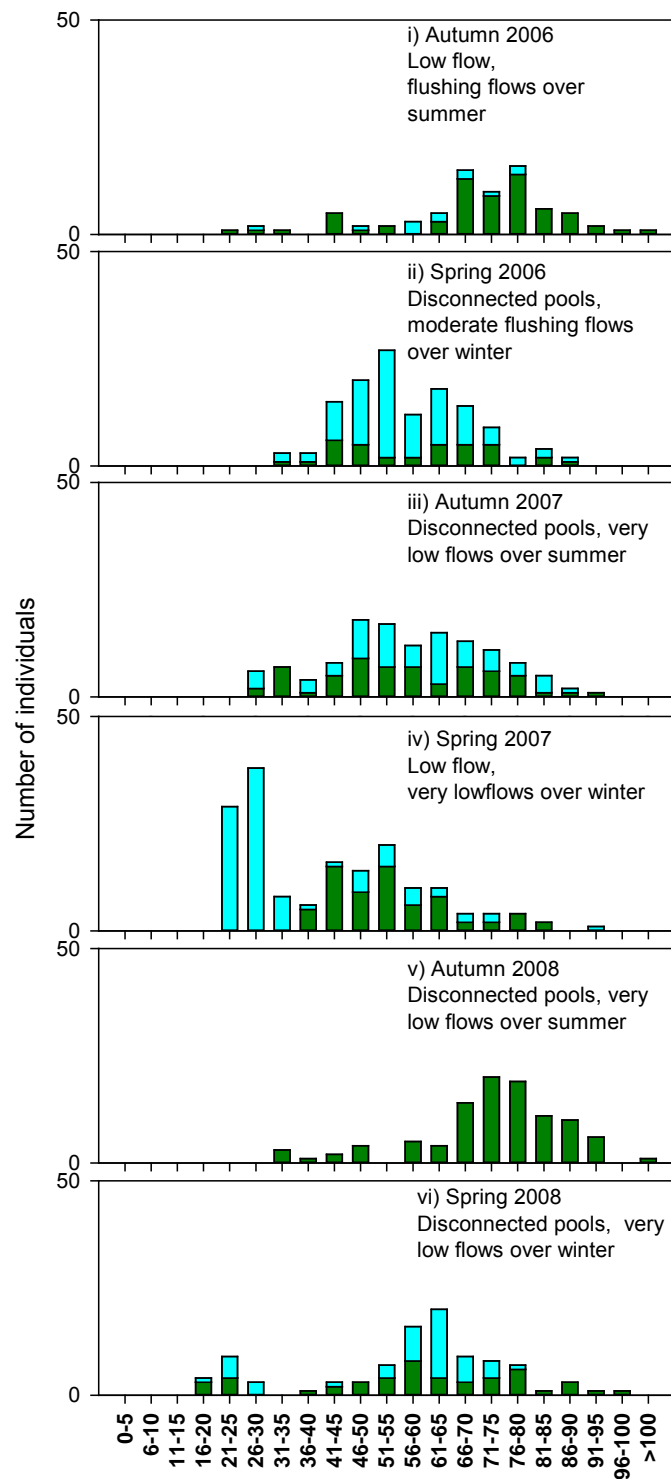


Figure 132. Lengths of flathead gudgeon (*P. grandiceps*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



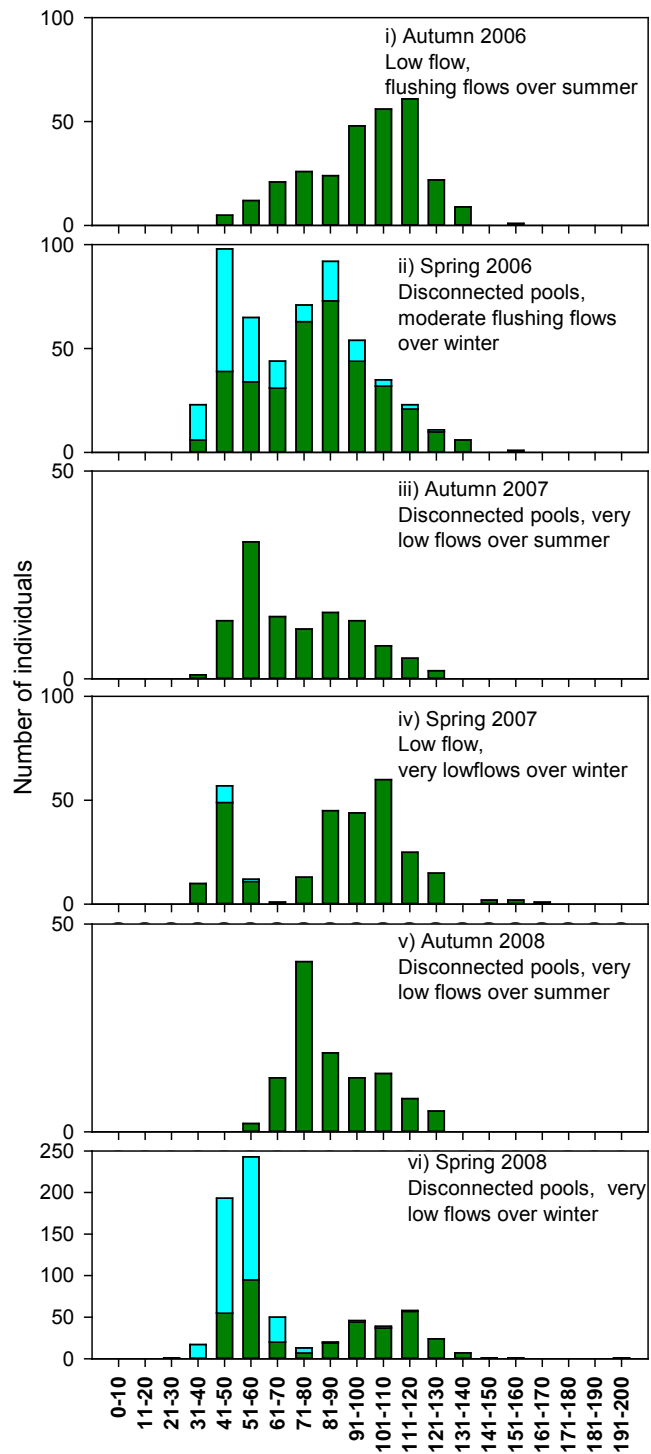


Figure 133. Lengths of common galaxias (*G. maculatus*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



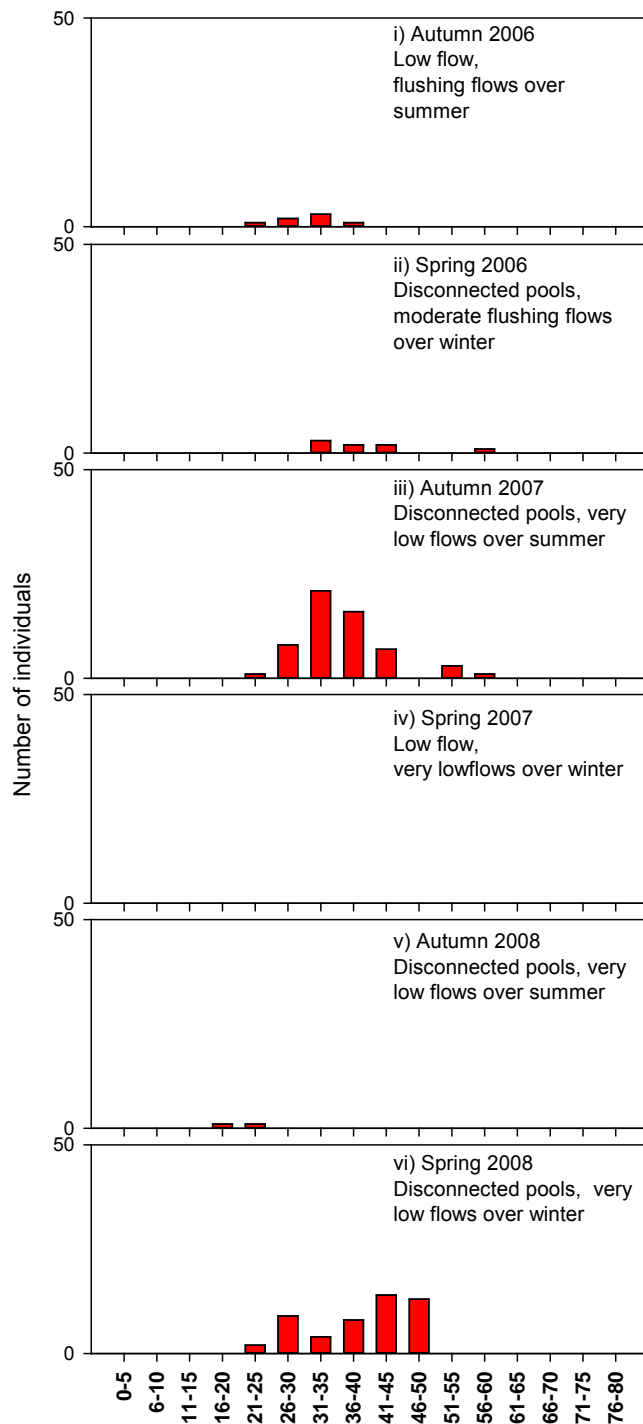


Figure 134. Lengths of gambusia (*G. holbrooki*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



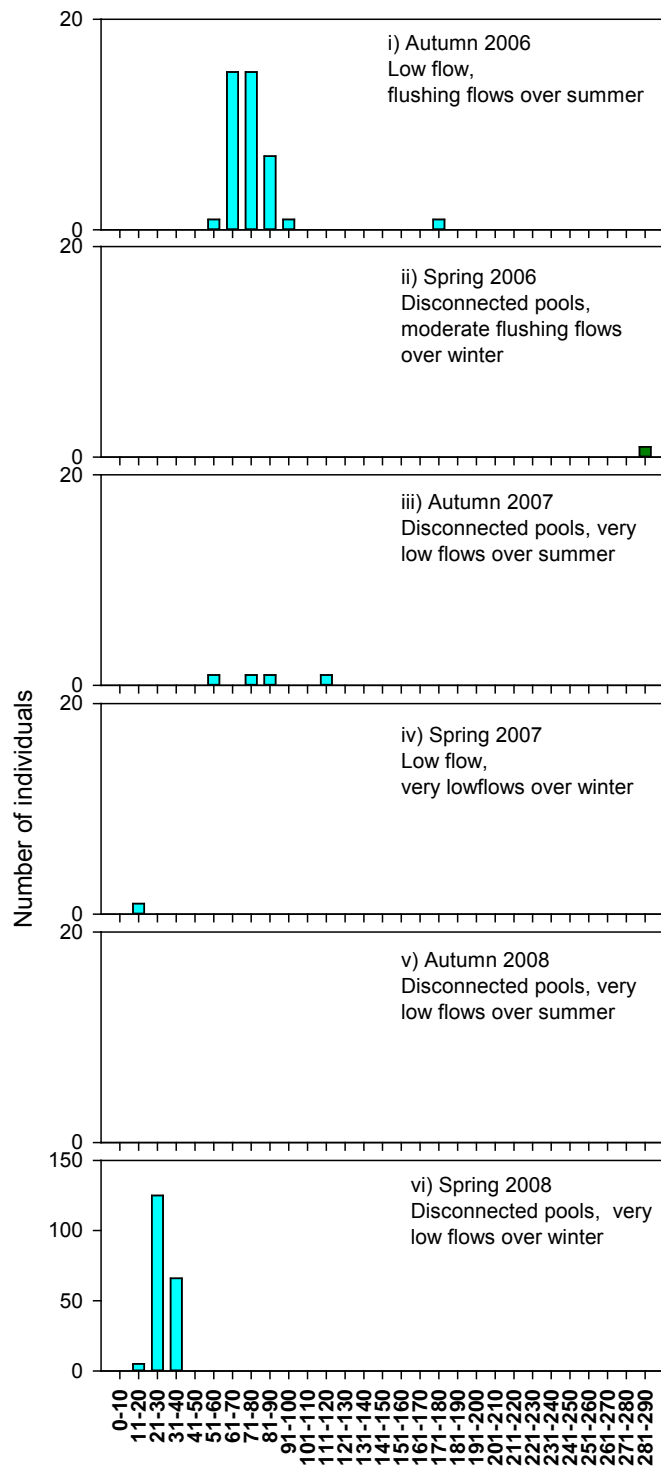


Figure 135. Lengths of black bream (*A. butcheri*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



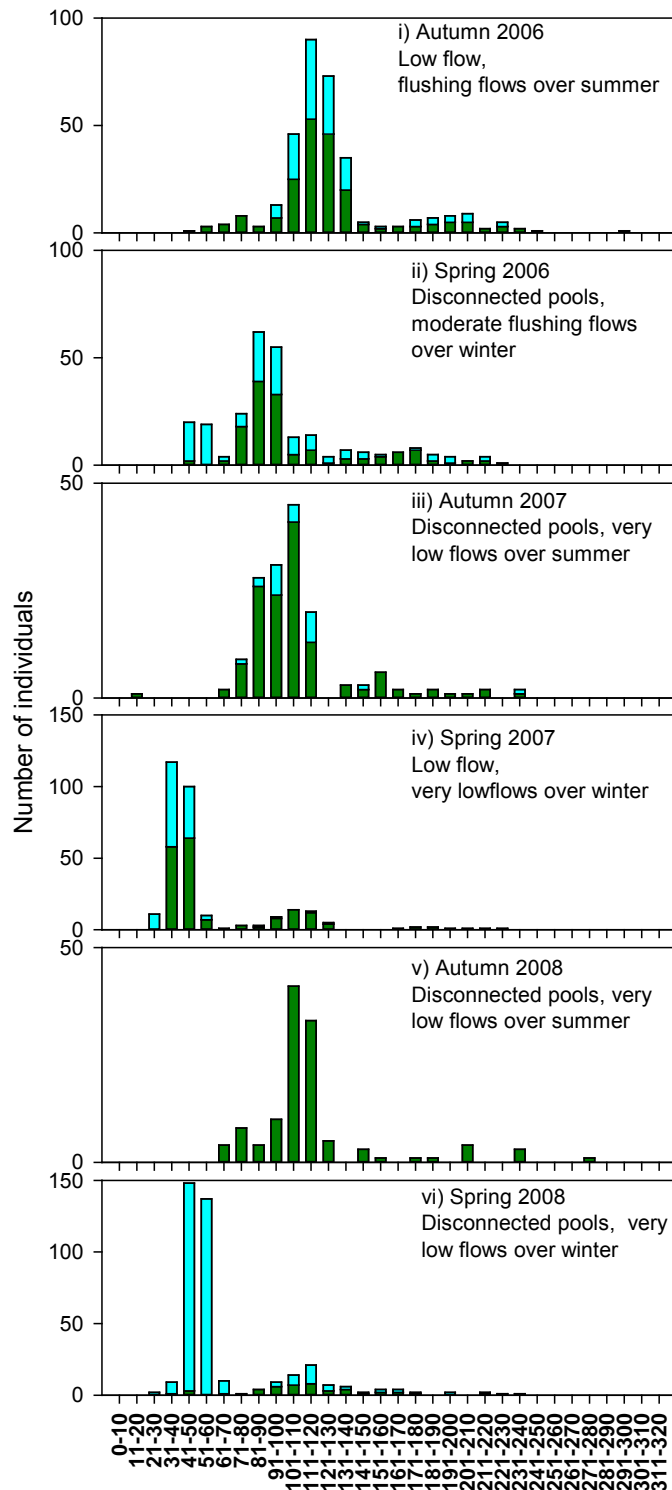


Figure 136. Lengths of congolli (*P. urvillii*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



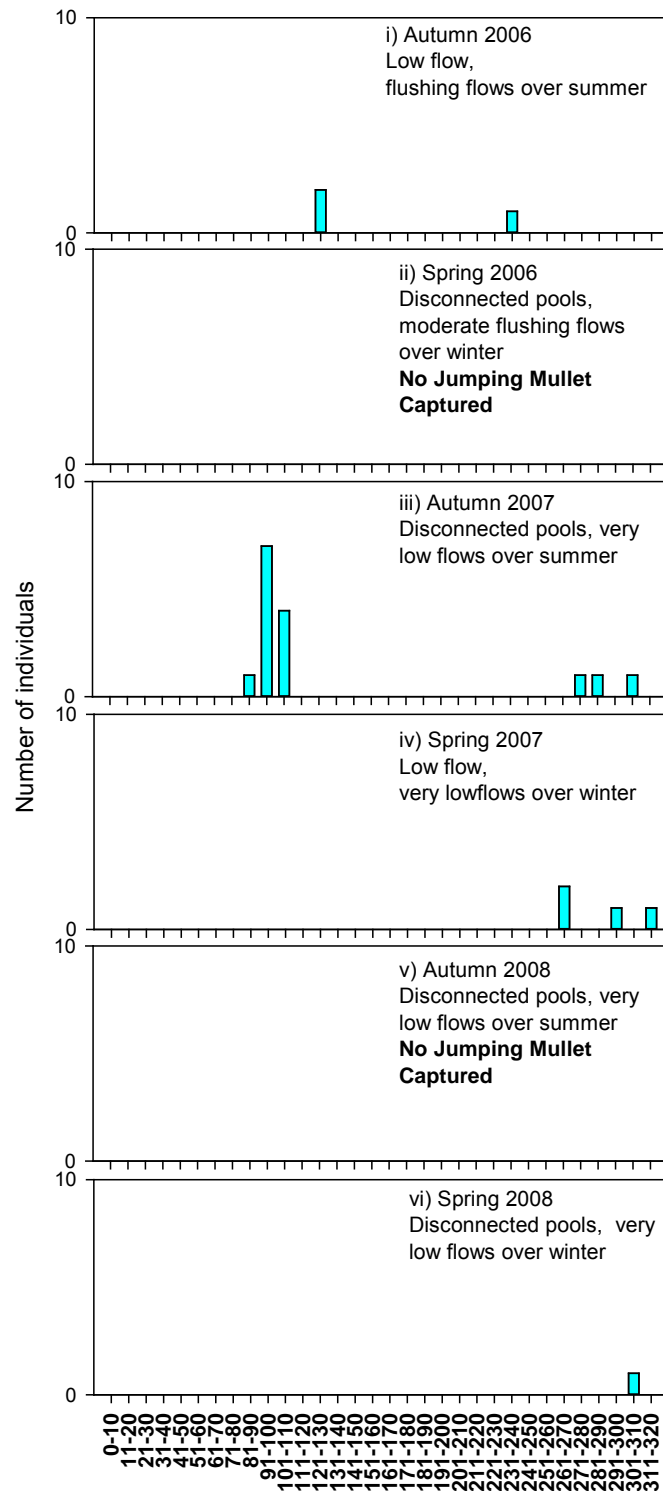


Figure 137. Lengths of jumping mullet (*L. argentea*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



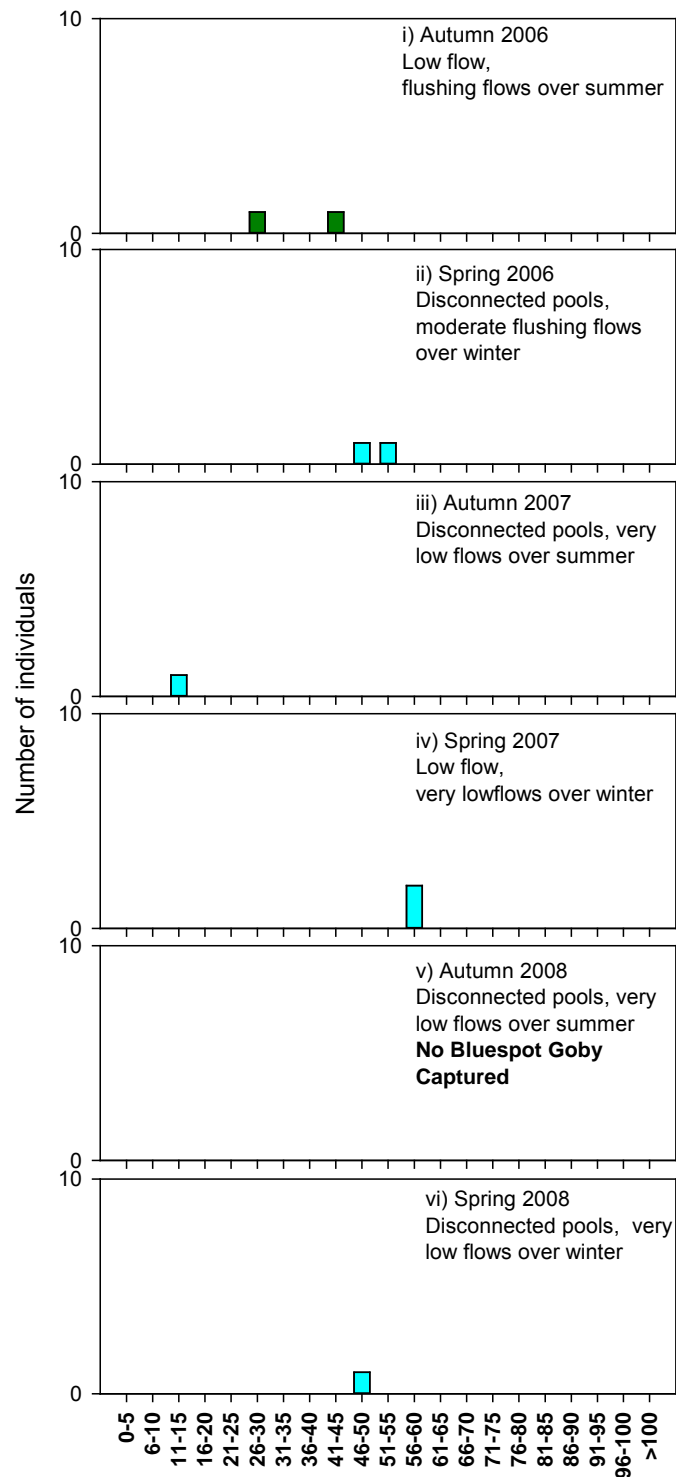


Figure 138. Lengths of blue spot goby (*P. olorum*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. Note, light blue bars indicate fish captured in estuarine waters. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



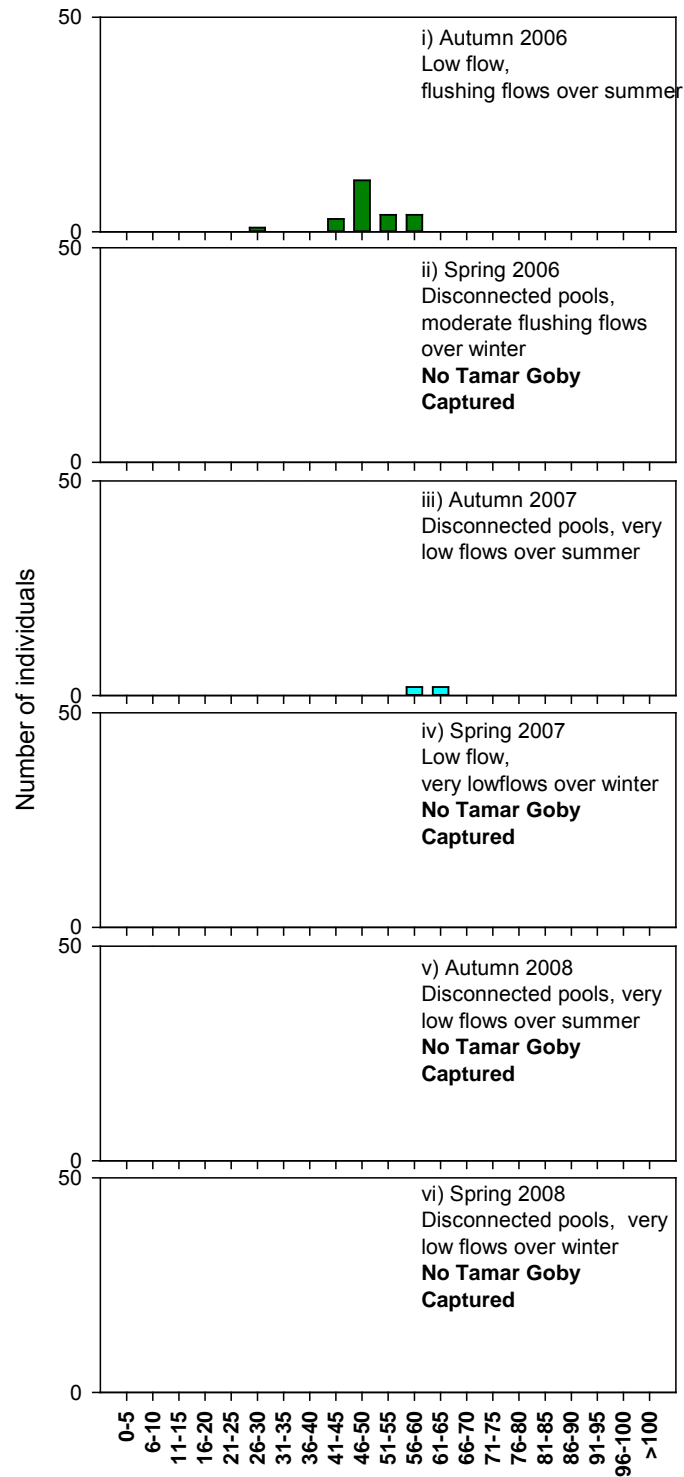


Figure 139. Lengths of Tamar goby (*A. tamarensis*) at Old Noarlunga (Onkaparinga River) over six survey seasons, from autumn 2006 to spring 2008. The flow at the time of the survey and major hydrological pattern since the last survey are shown for each season.



4. DISCUSSION

4.1. Baseline Assessment of Fish Populations in the WMLR

Sampling under the current survey caught all native and introduced fish species previously recorded as common in the WMLR with the exception of the southern purple-spotted gudgeon. This species was once considered locally common in the WMLR (Scott 1962) but appears to now be extinct from the region. The local extinction of this species over the past 50 years reflects the extreme degree of modification that anthropogenic development has had on the ecology of WMLR catchments and reiterates the urgency for implementing management changes that protect and revive the extant native fishes in the region. It is unclear why this species has suffered such a devastating loss to distribution and abundance over the past fifty years, although a combination of flow regime changes, loss of instream and riparian vegetation, destruction and drainage of wetlands, pollutants and the introduction of redfin perch have all been identified as likely contributors (Hammer *et al.* 2010, Lintermans 2007). This species would formally have been the largest piscivorous predator in the WMLR, and their replacement by trout and redfin perch over the period of their decline suggests they are likely contributors to extinction in the region.

A number of new species were identified that were previously not recorded from the WMLR and/or SA Gulf Drainage Division and are summarised in Table 58. Short-finned eel was discovered for the first time in the Onkaparinga and Torrens Rivers, although only single specimens were recorded from each. Bony herring, a widespread and common fish throughout inland Australia was recorded for the first time in the upper Torrens. Whilst the discovery of short-finned eel potentially reflects very rare far-western populations of this species (it could also be a Murray River or aquarium translocation), the appearance of bony herring can only suggest transfer into the drainage through human dispersal (either directly or via Murray water pipeline) or perhaps a very rare transfer via some vector such as pelicans or ducks that may carry such a fish across the MLR from the Murray River. In addition, a number of diadromous and euryhaline species not collected for extended periods were re-discovered during these surveys, particularly in the lower Torrens. Blue spot goby, congolli, short-headed lamprey and common galaxias (*Galaxias maculatus*) were all historically abundant (Scott 1962), but were not found in recent surveys of the lower Torrens (Rowntree and Hammer 2004, Gray *et al.* 2005, Hicks and McEvoy 2005). These discoveries are likely to be due to the relatively recent installation of the Torrens Fishway by the Torrens Catchment Water Management Board, which has improved



hydrological connectivity and fish passage between the Breakout Creek and Gulf St Vincent (McNeil *et al.* 2009).

4.1.1. Idealised pre-European fish communities

The assemblage structure of EWP reaches varied considerably across sites, although historically, it would be expected that all matching reaches would have possessed extremely similar fish fauna based on the similar size and structure of natural habitat and flow characteristics. A generalized pre-European fish community in the WMLR may have appeared something like this:

Coastal wetlands and estuary: Periodically populations of freshwater species especially congolli, common and climbing galaxias would move into these areas to spawn or to gather prior to migration back into freshwater habitats. Adult lampreys would aggregate *en masse* in late winter to spring before moving into freshwater reaches to spawn. Estuarine species including black bream, jumping and yellow-eyed mullet, mulloway, hardyhead and a range of gobies, all of which would move into and out of fresh and saline habitats at various times or for various life history stages.

Lowland river: Dominated by congolli, common galaxias, blue spot goby and purple spotted gudgeon (flathead gudgeon were considered rare prior to the 1960's - Scott 1961). Fish would have attained large sizes for their species and migrating fish from both up-and downstream would periodically move through these reaches. Most species would regularly move laterally into inundated floodplain habitats during winter/spring floods, and species such as purple spotted gudgeon may have remained in billabongs and wetlands. Lamprey may regularly spawn and young ammocoetes develop in silt or gravel areas with relatively low flow (Quintella *et al.* 2003). Eels may sporadically move in based on coastal currents and reside for many years representing the apex piscivore in the system. Climbing galaxias would be found in deeper pools with mountain galaxias extending downstream in localised riffle habitat, especially near tributary junctions.

High velocity gorge reaches: Dominated by climbing, mountain and common galaxias, these fish would have grown much bigger and had far greater population size and resilience than they do now, utilizing resources and habitats now overtaken by trout and redfin perch. Regular flushing flows would have been a regular occurrence used to access coastal spawning areas during autumn and winter and to facilitate recruitment migrations from the sea during spring.

Upper catchment: Climbing galaxias (diadromous fish that easily scale steep and high velocity reaches) and mountain galaxias would have dominated these reaches with larger adults living in the



Table 58. Summary of new, missing and exotic fish species as well as identification of recruitment patterns and key species for management attention across EWP Sites.

Site	New Species	Missing Species	Key Species for Management	Recruitment	Exotic Species
South Para	New species recorded above woodlands weir (congolli , common galaxias) were translocated to the site and not naturally established populations.	All native fishes except for the common flathead gudgeon failed to have viable populations in this reach.	Mountain galaxias were only found in a tributary creek and appear unable to colonise the main channel habitats probably due to redfin perch.	Recruitment of flathead gudgeon and introduced gambusia and redfin perch were observed.	This reach was dominated by redfin perch and gambusia . Goldfish and tench also present below woodlands weir.
Torrens (Upper)	Bony herring were identified for the first time in the SAG drainage below Gumeracha Weir. This discovery reiterates concerns about the potential for translocation of Murray-Darling species via cross catchment water transfers.	Purple-spotted gudgeon appear extinct. River blackfish populations not found.	Climbing galaxias moved into riffle areas during higher flows but were unable to remain in main channel pools during dry periods probably due to redfin perch and trout predation. <i>Galaxias olidus</i> persisted in low numbers in refuge pools but declined under low flows.	Seasonal recruitment was observed for most species, but declined over the drought period.	Redfin perch and trout and gambusia were common. Possible translocated species include bony herring and dwarf flathead gudgeon .
Torrens (Lower)	Short-finned eel were caught for the first time from the Torrens. Diadromous fishes re-established in breakout creek following the construction of the fishway. Congolli , blue-spot goby , common galaxias and shorthead lamprey identified from lower reaches after absence in recent surveys.	Purple-spotted gudgeon appear extinct. River blackfish populations not found. Pouched lamprey not identified during this study (although observed to be present in related surveys).	Diadromous species are critical for management in the Lower Torrens, especially common galaxias , congolli , lamprey , eels and blue spot goby . The lack of climbing galaxias and scarcity of lamprey and eels suggests that diadromous species are still suffering in this reach despite the construction of Breakout Creek fishway.	Seasonal recruitment was observed for most species, less decline over the drought period. Strong recruitment by freshwater catfish , flathead gudgeon , congolli and common carp . No recruitment recorded for eel.	Carp are abundant in lower reaches as were goldfish . Gambusia abundant throughout and trout particularly abundant upstream of the Adelaide Plains. Several translocated native species dominate the lower reaches, especially freshwater catfish , Murray rainbowfish and carp gudgeon , all introduced from the Murray-Darling Basin.
Onkaparinga	Short-finned eel caught in the Onkaparinga for the first time.	Purple-spotted gudgeon appear extinct. Lamprey species not recorded, climbing galaxias extremely rare.	Common galaxias in particular, was impacted during low flows and were not able to migrate into upstream parts of the reach. Climbing galaxias are conspicuously rare, supporting the failure of flows and/or connectivity to suitable adult habitats to facilitate viable populations of diadromous species in the lower Onkaparinga. Estuarine species also utilised freshwater habitats and are important species for management.	Seasonal recruitment was observed for most species, but declined over the drought period.	Tench , carp , goldfish and redfin perch all present in relatively low abundances. This reach has the lowest exotic fish impact of all sites.

main channel and smaller individuals in tributary streams. Freedom of movement between the main channel and tributaries would be common with regular connectivity during rain induced flow events.

Against this idealized model, the high degree of catchment modification appears to have lead to modified fish assemblages with greatly reduced abundances based on the current survey. In the South Para River EWP reach, only the hardy generalist flathead gudgeon remains of this fauna although it is known that diadromous species still attempt to recolonise during flows and upland fishes remain in low numbers in upper tributaries, landlocked by large reservoirs. The Torrens is highly segmented longitudinally, with different reaches exposed to extremely different flow regimes, habitat modifications, and abundant introduced and translocated predators and competitors. Although many of the native fishes survive in low abundance in some patches, connectivity and conditions are insufficient to maintain viable widespread populations throughout their theoretical historical ranges. In particular, abundance and distribution of galaxiid populations are spatially and temporally heterogeneous.

Diadromy was until recently almost non-existent in the Torrens and is still restricted to the reach downstream of the city weir. Landlocked populations are considered at a great disadvantage to diadromous populations with smaller size and parasitic infections impacting landlocked galaxiid populations (Pollard 1974, Chapman et 2006), and added risks associated with low genetic population size. The presence of predators in almost all large pools means that galaxiids are restricted to sub-optimal habitats such as tributaries and attain relatively small sizes (Smith and Hammer 2005). The populations of native fish in the Onkaparinga initially appeared most intact, with diadromous fishes extending the length of the reach with access to the sea and existing populations of mountain and climbing galaxias remaining despite the presence of exotic predators high in the reach. However, the lack of flows throughout the study period rapidly led to declines in diadromous fish distribution and abundance and caused a decline in the abundance of flathead gudgeon, dwarf flathead gudgeon and mountain galaxias.

Overall, highly resilient and abundant native fish populations, consistent with the idealized model of sustainable fish populations outlined above, were not present in any EWP Reach. The various impacts of threats such as barriers, introduced species and habitat and flow regime change will be further explored on a reach by reach basis in the following section.

Finally, this survey has provided important new information relating to the composition of the fish fauna in the WMLR, despite the restricted focus of sampling on the four EWP Reaches (summarised in Tables 58, 59 and 60). The data demonstrates the benefit of regular sampling to support management of freshwater fish populations and ecosystems, however, it should be recognized that



more spatially comprehensive surveys would provide additional benefit, by informing over a much broader range of habitat types that are likely to possess discrete fish assemblages and may harbor cryptic, as yet undiscovered or indeed 'presumed extinct' fish species. Regular, broad spatial surveys should be considered to support the development of accurate and realistic water resource and flow allocations for sustaining native fish biodiversity and ecological sustainability in the WMLR.

4.2. Physical Habitat at EWP Sites

Care was taken during the initial site selection for EWP trials to select reaches with similar, and relatively intact physical habitat characteristics. All sites possessed cobbled substrates with bedrock and some alluvial sediment. Siltation was principally an issue for sites in the Torrens river, with turbid Murray River water inputs a likely source of silt deposits. Silt deposits are likely to prove an ecological issue through the loss of interstitial spaces in the upper Torrens, but in the lower Torrens formed more significant deposits that dominated substrates below Gorge Weir, commensurate with lower flow velocities and lower hydraulic energies.

Riparian vegetation was commonly dominated by redgums which were mostly patchy and interspersed with native wattle, bottlebrush and ti-trees, that were spatially restricted to the bank-side. Riparian vegetation was almost never well connected to catchment vegetation, an issue likely to impact on invertebrate population structure and, therefore, ecological and food web structure, that support native fish sustainability (Peterson *et al.* 2004). None of the habitats had large accumulations of woody debris although larger snags were present in some of the bigger pools.

Local land use included forestry (*Pinus radiata*) in the upper Torrens, state management Recreational Parks (Parra Wirra, South Para Weir, Brooks Rd, Old Noarlunga), council parks (Clarendon, Breakout Creek) and private agricultural land uses (Nolan's, Woodlands weir and sections of other sites). Most reaches possessed well structured rocky riffles between target pools which provided areas for electrofishing when inundated. Some adjoining reaches however, were highly choked with emergent macrophytes and/or through the encroachment of weeds. In particular riffle areas at Clarendon, Brooks Rd and Old Noarlunga (Onkaparinga); and Gorge Weir and Silke's Rd (Torrens) were largely choked by cumbungi, *Phragmites* or amphibious weeds.

A few reaches had excellent riffle habitat present when flowing, in particular Cuddly Creek, sections of Brooks Rd and Old Noarlunga, and Parra Wirra, where native riparian and overhanging vegetation and rocky riffle habitats were present. *Whilst land use, habitat and fish populations are likely to be closely linked, this analysis was not a part of the present study, although data collected here may be used to assess such linkages.* Emergent macrophytes were common to some degree at all sites but



were less prevalent at Brooks Rd, Parra Wirra, South Para sites. In general, the pools across all sites were in relatively intact condition compared to the broader catchment areas and were considered similar enough in regard to physical structure and habitat that ecological responses to EWPs may be identified. Across sites, however, a range of threats were identified that may complicate assessment of flow responses.

It is recommended that these non-water regime related threats be considered for intervention works to further maximize the power of sites to inform on EWP trial outcomes.

Site based summaries of physical habitat issues, threats, key management concerns and other key monitoring outcomes such as the presence of recruitment and identified flow regime issues that are of relevance to site management are included in Table 59.

4.3. Flow Regime at EWP Sites

Flow regimes differed across EWP sites and will be discussed in detail relating to native fish ecology in subsequent sections. As a brief overview, all sites had a highly regulated flow regime and outside of broad 'unmanageable' flow events were largely dependent on localized rainfall run-off and inflows from small tributary or gully inputs. The key exception was the reach downstream of Gumeracha weir, which was subject to highly variable flows resulting from inter-catchment transfer flows managed for Adelaide's urban water use.

In addition, two sites received flows from tributary streams that contributed a reasonable proportion of (and sometimes exceeding) main channel flows. These were Old Noarlunga (receiving significant inflows from Kangarilla Creek between Brooks Rd and Old Noarlunga) and Nolan's, which received inflows from Tenafeate Creek directly into the downstream end of Pool 3 (and therefore not contributing to site flow levels). All sites suffered extensively from extreme drought conditions which served to highlight the lack of upper catchment inflows and allowed the current surveys to identify the most critical impacts of flow regulation. In turn this provided an opportunity to judge some of the worst impacts and issues presented through regulation and therefore identify opportunities to better develop environmental flow components that may alleviate the extreme impacts of drought in highly regulated river systems. The provision of managed flows was identified as being a critical component of drought response management. The provision of environmental flows into these reaches should therefore be integrated into drought response plans, rather than being suspended as was the case during the current surveys.



Table 59. Summary points for EWP sites regarding Habitat and flow characteristics/issues, key threats to native fish and fish habitat and principal issues requiring natural resource management attention.

Site	Habitat	Flow	Threats	Key Issues	Specific Management Concerns
South Para	Structural habitat is reasonably intact although riparian vegetation restoration would greatly improve habitat structure	Flows are highly restricted to local rainfall events and very high floods. High flows may be critical in restricting gambusia from upper reaches of the gorge, but appear to re-seed the reach with large numbers of redbfin perch carried over the weir from upstream reaches.	Exotic species competition and predation. Loss of flow regime and flow volumes for maintaining habitats.	Depauperate native fish fauna Dominant pest fauna Fish Passage –sea & upstream Extremely low flow inputs	Loss of natural flow regime to diversions. Barriers to migration prevent establishment of diadromous species (galaxias, lamprey, congolli, blue spot goby). Exotic predation levels are very high. Stock and land use impacts reduce the habitat quality.
Torrens (Upper)	In channel habitats are of high quality	Flows are erratic and based on water transfer requirements. Present regime is inadequate for sustaining a diversity of viable populations of native fishes.	Alterations to flow regime through water management. Transfer of Murray River water and aquatic biota via cross catchment water transfers. Exotic predators redbfin perch and trout. Reduced riparian and catchment revegetation reduces habitat quality. Sedimentation and turbidity due to Murray transfers impact on water quality, substrate complexity and refuge pool maintenance.	Erratic flow regime. Dominance of main-channel habitats by trout and redbfin perch. Loss of riffle habitats	Turbid Murray water deposits sediments throughout this section, introduces new biota from the Murray system and is delivered through un-seasonal flow pulses. Addressing the nature of these slow transfers is the principal concern specific to this reach.
Torrens (Lower)	Very highly modified through urbanisation, channelization, vegetation clearance and modification and encroachment of reeds. Highly sedimented substrates are prevalent in lower reaches.	Flows are driven by rainfall events, especially through stormwater run-off. Natural flow regimes are not present. Stable flow condition likely to support exotics such as gambusia and carp.	Urbanisation, Vegetation clearance, pollution, sedimentation, barriers to fish movement, loss of flow regime, water quality impacts, exotic species.	Urban impacts including loss of riparian vegetation Stable flow regime supporting gambusia Fish Passage (to seas and upstream) Loss of flow regime (medium flows especially).	Habitat restoration is urgently required including riparian and instream restoration. Removal of barriers required to restore diadromous populations from Breakout Creek. Protection of flow inputs under storm water harvesting programs, particularly key flow aspects that support fish life history requirements. Restoration of ecosystem processes, wetlands and estuarine habitats lost through urban development. Restoration of coastal wetlands and swamp habitats that provide nurseries for freshwater and marine fishes.
Onkaparinga	Habitat structure relatively good. Riparian restoration and weed removal programs will enhance structural habitat complexity and bolster ecosystem processes. Catchment re-vegetation using perennial species will improve rainfall runoff and flow structure, and increase flow duration from local rainfall events.	Largely from local rainfall events in the reach, higher below the confluence of Kangarilla creek at Bakers Gully. Insufficient durations and volumes of flow for fish movement requirements throughout the reach observed	Weed encroachment, catchment land-use and runoff patterns. Water abstraction for viticultural uses. Loss of flow volumes and regime due to flow regulation. Sea-water incursions accompanied by low freshwater flows caused fish kills in lower reaches.	Hydrological connectivity to allow fish movements Loss of spring and late autumn flows to facilitate fish migration and sustain refuge pools through summer Loss of catchment and riparian vegetation and encroachment of weeds.	Flow restoration vital to optimise the sustainability of native fishes and allow diadromous fish movements. Integration of freshwater, estuarine and marine ecological management is important as this represents the largest natural lowland river-estuary system remaining for mainland SA.

4.4. Fish Ecology of EWP Reaches – South Para

4.4.1. Sustainability of Native Fish in the South Para River

In the South Para catchment, only four native fish species were captured over the course of the survey period, representing three less than previously listed for the catchment based on recent reliable records (see Table 1). Importantly, these three species, pouched and short-headed lamprey and climbing galaxias, are all diadromous species suggesting that the reason for their absence may be due to downstream barriers to migration, rather than flow regime inadequacies alone. Additionally, catches of other diadromous species (common galaxias and congolli) in the South Para were linked to human translocation of these species from below Gawler Weir and that these species would otherwise also be absent from this reach.

Furthermore, no recruitment was observed for either species during the project suggesting that connectivity to the sea is insufficient in this reach to support diadromous fish populations. Similarly, assumed land-locked populations of climbing galaxias are known to be present upstream of the South Para Reservoir (Waterwatch 2010) and the failure for this species to establish in the EWP reach is likely to be due to a combination of altered flow regime, presence of redfin perch predation as well as barriers to migration.

It is therefore a recommendation of this report, that barriers to fish migration be assessed and removed where possible or bypassed by fishways to allow the movement of these species between the trial reach and the marine environment.

If sufficient stocks of these species remain in the reach to reignite recruitment, then diadromous species may be re-established in the South Para River. Subsequent EWPs should be tailored to account for the water requirements of these species in the future.

Also of concern was the disappearance of mountain galaxias from Tenafeate Creek (Nolan's electrofishing site) after the first survey in autumn 2006 after, when it became dry due to a new instream dam. As a result, only one out of the seven native fish species previously recorded (flathead gudgeon) remained in the reach by the end of the study. Flathead gudgeon were common and widespread at the start of the survey period, but declined in abundance over the three years. The loss and decline of native fish species was accompanied by net decreases in flow, loss of large flows and loss of spring flows to provide suitable conditions for reproduction and recruitment, as well as the ongoing barriers to movement of diadromous fish which were exacerbated by decreased flow.



The loss of over 85% of native fish biodiversity and a decline in the abundance of the remaining species raises concern over the current management of this reach.

It is recommended that in addition to delivery of planned EWPs, management attention be given to key threats including barriers to migration, introduced predators (redfin perch), and flow regime and habitat changes resulting from abstraction from private dams in Tenafeate Creek.

There were five introduced fish species captured in the South Para River identical to those reported in past surveys, indicating no recent loss or gain of exotics in the reach. Of concern is the high numbers of redfin perch, which is a voracious predator of smaller native fishes (Wilson *et al.* 2008). In contrast to the decline of native species, gambusia became more abundant but not more widespread, while the redfin perch population remained stable with consistent recruitment and adult survival. Increased abundance and diversity of native fish and restoration of natural flow regime are likely to disadvantage gambusia populations (Costelloe *et al.* 2010) and therefore, management recommendation made for this reach are likely to lead to natural controls to this pest population. Restoration of flow will also open up habitat with greater complexity, providing protection from predators and spawning sites for many native species.

4.4.2. Flow Regime and Ecology of Fish in the South Para River

The loss and decline of native fish species in the South Para revealed through this survey is likely to be related to several aspects of flow regime and management. During the study period there was a net decrease in flow volume, loss of large flows and spring flows, leading to suitable conditions for reproduction and recruitment. Barriers to the movement of diadromous fish were also exacerbated by decreased flow. Decreased duration of flow led to longer periods of drying resulting in habitat loss and increased interaction with introduced predators and competitors, such as redfin perch and gambusia.

In the South Para catchment the ecological objectives of EWPs are listed below together with comments relating to this survey.

1. Connect in instream pools to increase aquatic habitat diversity and improve water quality.

Pre-flow data collected in the South Para was largely collected during a period of extremely low flow, following a very large flushing flow in November 2005. Under these low flow conditions, fish survived the dry season in isolated refuge pools, with reconnecting flows occurring each winter/spring. The flow conditions in the South Para reflect those of arid environment streams where survival in refugia, and subsequent re-colonisation and population building occurring during brief periods of reconnectedness and habitat inundation (McNeil and Schmarr 2009). However, survival under this harsh climatic driven



regime requires excellent levels of physiological resistance to drought and flash flooding and traits that drive rapid resilience following the flood and drought disturbance (McNeil *et al.* 2011b). The result was that the upper reach was entirely dominated by redfin perch and flathead gudgeon, with gambusia restricted to the area below Para Wirra Gorge where flood velocities would have been somewhat lower as gambusia are not well adapted to high flow velocities (Costelloe *et al.* 2010). Other more sensitive native species were excluded from the reach under such harsh conditions.

A related study was undertaken to further explore the dynamics of the fish population and climatic drivers within the EWP reach of the South Para. The study revealed that climatic harshness eliminated redfin perch from refuge waterholes during harsh summer conditions, allowing the highly tolerant flathead gudgeon to persist without predation (Wilson *et al.* 2008).

In combination, these results indicate that the addition of connecting flows to maintain pool habitat and water quality over low flow months may pose two significant risks to native fish sustainability. Firstly, improved water quality during summer is likely to promote the survival and persistence of redfin perch, increasing predation pressure on natives. Secondly, increased connectivity with relatively low flows during summer will allow the recolonisation of upper reaches by gambusia which will in turn add competitive pressure for resources.

It is therefore recommended that flow allocations (summer/low flows) to the South Para River be reconsidered to avoid these impacts and be designed to maximize seasonal flow cues for spawning and migration of native fishes. Also, attention should be given to associated management issues such as migratory barriers and management of pest redfin perch to optimize the outcomes of EWPs for native fish sustainability. In addition, the diverse diet of redfin perch was found to ease predation pressure on native fish and therefore management interventions that maximize invertebrate biodiversity and abundances will also relieve impacts of introduced predators on native fish.

2. Restore components of natural seasonality including high flow flushing events.

Summer base flows pose potential risks to native fish as explained above, however, the delivery of EWPs that provide connectivity and spawning cues and habitat in late autumn-late spring will provide important support for the restoration of native fish biodiversity in the reach, especially if mountain galaxias are able to recolonise through tributary stream. If downstream barriers are removed, then diadromous fish populations could also re-establish and be maintained in the lower South Para under the improved flow regime.

The last high flow flushing event in South Para River was prior to the surveys in November 2005. During the subsequent surveys there were no high flows and most seasonal flow was intercepted by



the reservoirs upstream. In comparison to 2005 and earlier, flows began later and ceased earlier in the year, freshes were rarer or absent altogether and peak flows were significantly lower.

Whilst flows prior to 2006 were by no means natural, being highly restricted by water from the upper catchment captured by the reservoirs, they provided more variable and therefore suitable conditions for native fish species within the region. The decline in species diversity and abundance, and the increase in introduced species following decline in high flow flushing events reflected that loss of natural seasonality.

4.4.3. Flow Management for Native Fish in the South Para River

The normal flow conditions for the South Para River from 1968 to present indicate flows beginning in about May, continuing on through December and ceasing in early January. Average flow from June to December is a minimum of 10 ML/day although December is quite variable (Figure 139). Average flows during the survey period were much lower, began later in the year and ceased earlier (Figure 27 & 33). Peak flows, flushes and freshes were also much lower than normal conditions.

The proposed EWPs (Figure 140) should enhance flows under naturally occurring flow periods. By re-timing allocations of freshes and flushing flows to extend current flow duration into late autumn and spring, cease to flow periods may be reduced, enhancing the persistence and quality of refuge pools during summer and protecting against loss of native fish through desiccation and extreme collapses in water quality. However, preservation of natural cease to flow during summer should protect somewhat against 'overcorrecting' climatic impacts that then might provide conditions that allow gambusia and redfin perch to persist, spread and become more abundant than they are currently.



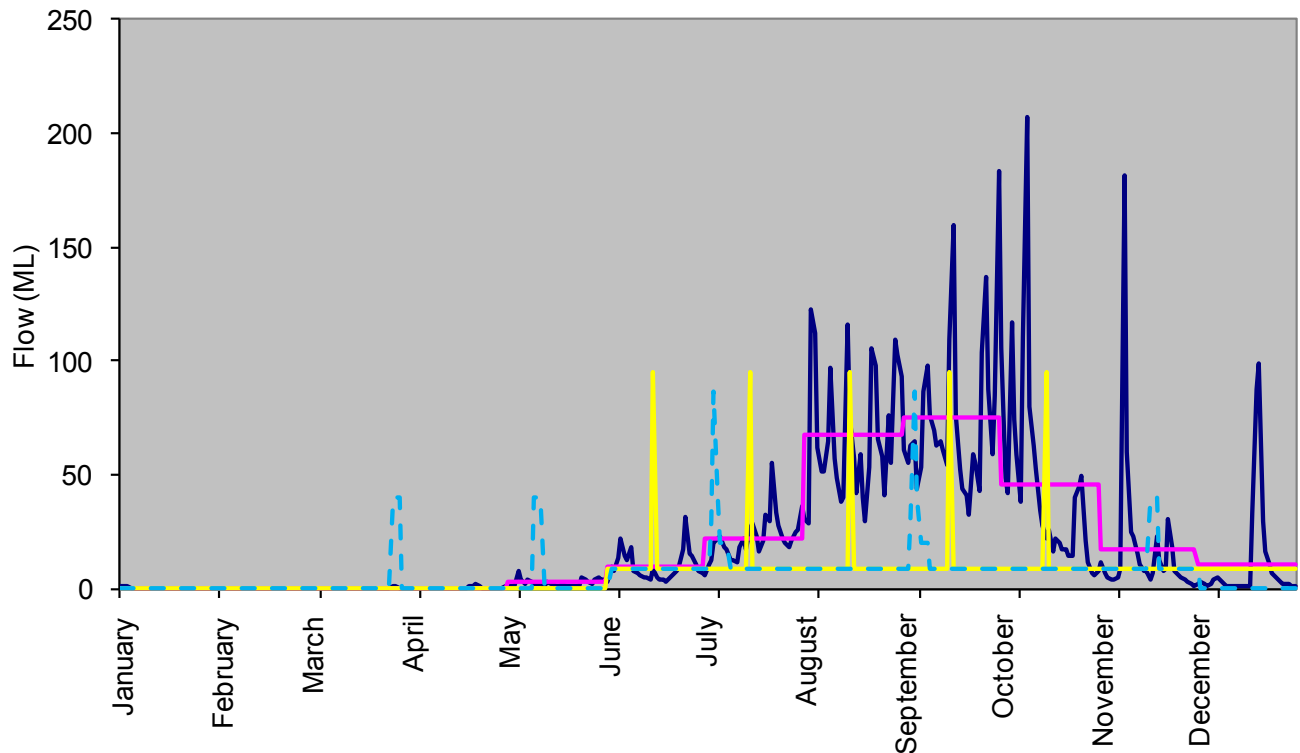


Figure 140. Dark blue - Annual flow regime in South Para River between 1968-present measured at Woodlands Weir (Gauge A5050503). Pink – monthly average flow per day. Yellow – original EWP. Light blue – suggested EWP. Summer Base flows should be avoided.

4.5. Fish Ecology of EWP Reaches –Torrens River

4.5.1. Sustainability of Native Fish in the Torrens River

The Torrens River had the most diverse and abundant fish population with at least 26 native species captured during the surveys, although only 11 of those are considered freshwater species (or spend a major part of their life in freshwater).

The short-headed lamprey was observed to accumulate in large numbers at the Torrens Mouth in the past, but as long ago as 1951, it was observed that aggregations were unable to ascend into the river due to the Breakout Creek Weir (Scott 1961). The re-discovery of this species in the lower Torrens during this survey raises hopes that this species may yet re-establish in the catchment if appropriate access, habitat and flow regimes can be developed and maintained. Pouched lamprey is more recently recorded from the reach, but has also been observed in aggregation, trapped below the City Weir on the Torrens River (Hammer *et al.* 2009). Whilst not recorded during the current survey, they



were recorded from the reach under an associated project during the survey period (McNeil *et al.* 2010b). There is no evidence as yet that lampreys are able to utilise the Torrens fishway, but they may move into the river on high tidal surges and exit during very large flows. Both events would have to be timed with spawning migrations and cues (McNeil and Hammer 2007). In addition, natural populations of short-finned eel would require similar passage during years where coastal conditions were adequate to carry migrating juveniles to the Adelaide coast.

A further 3 Australian native species; Murray rainbowfish, freshwater catfish and carp gudgeon were present having been historically translocated from the Murray-Darling catchment but previously translocated species, Murray cod and silver perch were not recorded and have most likely failed to maintain viable populations in the Torrens following translocation. Sadly, the once common southern purple-spotted gudgeon was not caught and is almost certainly extinct in the Torrens catchment. Flathead gudgeon were the only widespread and common native species throughout the catchment. There were also 7 introduced species observed, all of which were previously recorded in the catchment, although the Brook trout (*Salvelinus fontinalis*) which was reportedly released in the area but not since recorded, was not found.

The upper reach (Gumeracha to Kangaroo Creek Reservoir) was dominated by exotic species but possessed relatively high numbers of *Galaxias olidus* and *Galaxias brevipinnis*. However, high levels of exotic predators in the main channel are likely to severely impact populations of these species. As a result, tributary populations are likely to be essential in maintaining these species in the upper Torrens, even though they occur from time to time within the main channel, and would be well suited to the main channel habitat if not for the presence of predators.

Breakout Creek, created to divert flows from the lower Torrens to the sea, had the most stable and diverse population of native species but was somewhat dominated by introduced and translocated species. Additionally, a marine fish fauna dominated below the Breakout Creek Weir, with a lack of connectivity preventing the maintenance of a true estuary at the Torrens Mouth.

The recently constructed fishway at the mouth of the Torrens is attributed with providing diadromous fish access to the reach, with large numbers of common galaxias, congolli and many blue spot gobies captured after being absent from recent surveys of the reach (Hicks and Hammer 2004, Gray *et al.* 2005). However, upstream barriers such as the City Weir and several smaller weirs prevented any diadromous fish from moving further into the catchment.



This report recommends that barriers to fish migration in the lower River Torrens be assessed and considered for removal or provision of fish passage to maximize the benefits provided by the Torrens fishway and recent habitat restoration programs at Breakout Creek to the rest of the catchment.

4.5.2. Flow Regime and Ecology of Fish in the Torrens River

4.5.2.1. Upper Torrens

Flow regime in the Torrens River was variable and inconsistent throughout the study period. Flows in the upper catchment were dominated by water transfers between reservoirs for human use. Flows were characterised by stable high flows during transfers, or stable low flows tending towards zero flows, with a small degree of variation due to local rainfall events. The flow regime of the upper Torrens was largely independent of natural climatic regimes that would have driven flow regime prior to European development.

Local galaxiids are well adapted to permanently flowing reaches (Lintermans 2007) and were commonly caught in riffles with high flows. Equally they are tolerant of warm summer conditions and moderate hypoxia that occur during periods of low/zero flow (Closs and Lake 1996, McNeil and Fredberg 2011). However, the presence of predators like trout and redfin perch decreased or eliminated galaxiids from many habitats in the upper Torrens. Exotic species such as trout, redfin perch and gambusia, all benefit greatly from stable flow environments, whether they be stable flowing (trout, redfin perch) or stable and low (gambusia, redfin perch).

A key recommendation for this reach is that transfer flows be timed to more closely match climatic rainfall patterns where possible, as this regime corresponds with ecological flow requirements of native fish, and reduces the benefit of stable unseasonal flow regime to exotic species.

As previously outlined, the flow regime in the upper Torrens catchment consisted of high-flow transfers between reservoirs and occasional rainfall related flow, punctuated by periods of no flow. The original ecological objectives of the EWPs for the Upper Torrens reach are listed below and discussed with reference to the actual flow regime outcomes:

Low flows

1. Increase permanent pool habitat for macroinvertebrates, frogs and fish.

Transfer of water between reservoirs and water pumped from the Murray River resulted in long periods of permanent pool habitats and increased availability of high-flow riffle habitats for invertebrates and galaxiids. However, when transfers were not required, there were very long periods



of no flow to the extent that some pools dried out completely. The loss of habitat resulted in decreased abundance of all species and a decline in fish diversity at most sites.

2. Decrease temperature fluctuations, reduce salinity, increase dissolved oxygen.

Extended periods of zero flow resulted in significant desiccation of pools in the upper Torrens, with high salinity levels accompanying shrinking pools. In addition, highly turbid (and somewhat saline) water transferred from the Murray River has led to some sedimentation and reductions in pool depth and general streambed diversity, particularly in larger pools where flushing flows are less able to move sediments downstream. The result was a low flow scenario in the upper Torrens of exotic dominated fauna persisting in shrinking pools with declining water quality. As these pools provide critical refuge habitats for fish during dry periods, cease to flow periods must be shortened by additional autumn and spring flows to ensure that water quality is less impacted by zero flows during summer.

3. Increase fish movement

There was very little evidence of fish movement within the upper catchment. The most compelling evidence was the downstream movement of mountain galaxias from Gumeracha Weir to Cudlee Creek and Gorge Weir in spring 2008. Strong flow transfer between reservoirs may move fish downstream into isolated or unsuitable habitats, whilst several impassable barriers prevent the movement of fish back upstream. Movement of galaxiids into the main channel from tributary streams was able to occur, however, unsuitable and predator dominated main stream habitats appear to prevent establishment of viable long term native populations in the Torrens pools.

4. Increase area and diversity of submerged macrophytes

Due to the transient and unpredictable provision of flow in the upper catchment, submerged macrophytes were not abundant and did not increase in area or diversity under the observed flow regimes. Macrophytes are highly reliant on natural flow regime (Blanche *et al.* 2002) and as a result, beds were largely confined to areas in shallower, or riffle areas that dried out periodically.

Medium to high flushing flows

1. Arrest current stream contraction and infilling
2. Control encroachment by emergent macrophytes

Emergent macrophytes were controlled by regular transfer flows followed by desiccation in the upper catchment.

3. Sediment transport



Murray River water was higher in turbidity than other WMLR flows and some level of sedimentation is inevitable.

4. Creation of deeper pool habitat

Large floods were observed to create new pool habitats through movement of large volumes of substrate including rocks and gravel. Turbid (Murray sourced) flows appear to lead to sedimentation of larger pools.

5. Provide appropriate breeding cues for native fish

The timing and magnitude of flows were not suitable to stimulate significant breeding and recruitment in native fish. However, the magnitude and timing of the flows did stimulate recruitment of redfin perch and gambusia. Upper Torrens flow regimes therefore should be tailored more closely to the requirements of native fishes and away from those that support introduced fishes.

6. Improve riparian vegetation health

Large floods inundated riparian areas in the upper Torrens and high transfer flows also prevented desiccation of riparian vegetation on a regular basis.

7. Restore connection between river and floodplain

Again, only larger floods were of significant volume to inundate floodplain areas in the upper Torrens.

4.5.2.2. Lower Torrens

Downstream of Gorge Weir, the flow regime consisted of several large flushes punctuated by periods of low or zero flow and a few small freshes, largely from urban stormwater runoff. This runoff maintained pool levels but often resulted in a series of stagnant pools containing poor quality water. Flows were short-lived and related to stormwater runoff in the lower catchment, with very little flow coming from the upper catchment.

Low flows below Gorge Weir provided very low levels of flow which maintained extremely consistent and stable water levels throughout the study. Consequently fish adapted to these conditions thrived in the lower Torrens, including introduced gambusia, flathead gudgeon and three translocated species, carp gudgeon, freshwater catfish and Murray rainbowfish.

In addition, downstream barriers prevented connectivity to lower Torrens environments and marine habitats and as a result, historically abundant diadromous species are no longer present or abundant in the reach.



Issues of flow regime in this reach are complicated by urban development. However, restoration of key aspects of natural flow regime (especially autumn and spring freshes and flushes) would have multiple ecological benefits including: support of native fish flow requirements; control of exotic fish, and improved water quality to stream pools improving aquatic assets such as the Linear Park and Lake Torrens in the Adelaide city centre. Base-flows may contribute to the maintenance of aquatic habitats and somewhat improve water quality, but not to the degree that freshes and flushing flows will as they mobilise and remove organic materials that drive stagnation.

The ecological objectives of the planned EWPs for the lower Torrens, downstream of Gorge Weir are as follows:

1. Maintain and further improve water quality, visual amenity, and habitat for aquatic biota with low flows.

Throughout the survey period there were sufficient flows to keep water levels in permanent pools topped up and to provide permanent habitat and maintain visual amenity. However, the water quality in many reaches was degraded due to the poor quality of stormwater flowing into the system. The result for the fish community was that low-flow adapted species - including introduced carp and gambusia and Murray River translocated species – thrived in the lower Torrens catchment. Serious water quality declines in Lake Torrens during the study period indicate the failure of flows into the lower Torrens to ameliorate build up of pollutants, nutrients and the development of blue green algal blooms.

It is recommended that EWP design in this reach be extended toward lower catchment outcomes, specifically, the extension of existing EWP targets to downstream reaches including Lake Torrens and Breakout Creek. If possible, consideration should also be given to the assessment and remediation of barriers to passage of fish downstream of Gorge Weir to optimize the outcomes of EWPs throughout the lower Torrens.

2. Scour sediment build-up and control encroaching vegetation with winter pulse flows.

The lack of winter pulse flows contributed to the increases in encroaching vegetation and a build-up of anoxic sediment. Spraying of resultant encroaching vegetation by local councils may also contribute to loss of native fishes through poisoning of waterways, loss of cover from predators, and trophic collapse.



4.5.3. Flow Management for Native Fish in the Torrens River

The natural flow regime in the upper Torrens catchment was difficult to define; the data for the study period represents a record of flow transfers between reservoirs mixed with local rainfall (Figure 141). However, in future the transfer of water in the upper Torrens catchment should be managed with ecological objectives in mind. The flow conditions observed during these surveys revealed that flows were often arbitrarily released with no consideration of ecological outcomes. At times, reaches were isolated for months without flow interspersed with periods of very high flow.

Future management of water transfer could take this into account by releasing water at a slower rate over a longer time period and maintaining a minimum flow of 2.5 ML/day to provide more consistent and diverse aquatic habitat, with a possible hiatus of transfers during summer to allow some natural summer low or zero flow conditions to occur. Further ecological objectives would be met by providing a 1 GL flush spread over a week at least three times a year between late autumn and early spring.

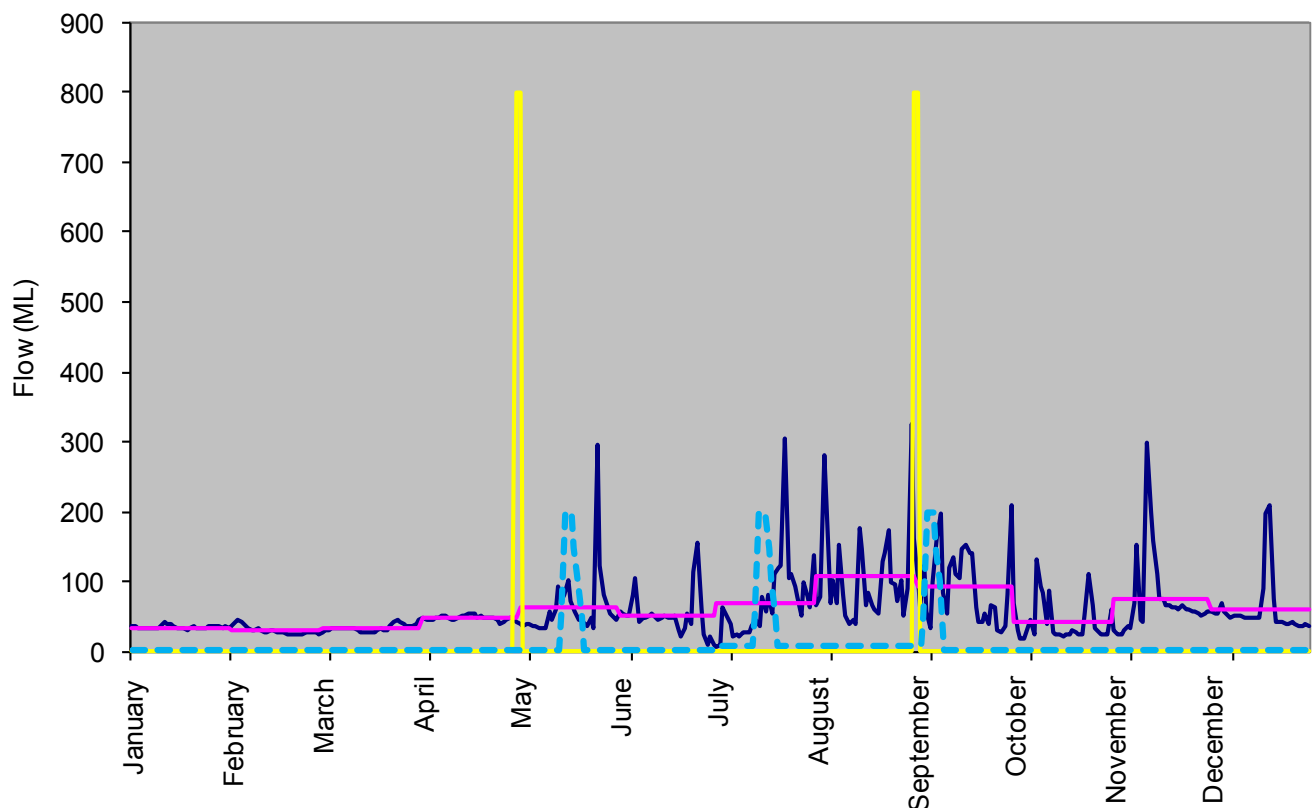


Figure 141. Dark blue - Annual flow regime in upper Torrens River 1974-present measured at Gumeracha Weir (Gauge A5040500). Pink – monthly average flow per day. Yellow – original EWP. Light blue – revised EWP.



The normal flow conditions for the lower Torrens catchment indicate a highly variable, but naturally timed flow regime (Figure 142). Average flow per day is over 10 ML even in the summer months, although variability in the data indicates that over summer it is normal to have periods of no flow interspersed with moderate flows as a result of stormwater runoff. However, the flow during the present surveys was drastically reduced with longer periods of no flow over summer and fewer flows from stormwater due to drought related reductions in catchment runoff.

The proposed EWPs provided for year-round low flows of at least 0.25 ML/day with a 20-day 40 ML/day flush in November. Under normal flow conditions, the proposed EWPs would help to achieve ecological objectives by bridging the gaps between normal flows over summer and autumn and provide more regular freshes with higher quality water from the upper catchment. However, under drought conditions revised EWPs should be considered that provide flows at a higher rate closer to the 10 ML/day observed under normal conditions. These more regular flows should also be interspersed with a low/zero period during summer to mimic natural drops in catchment rainfall and run-off. This variability may disadvantage introduced species such as gambusia, which thrive on very stable flow conditions.

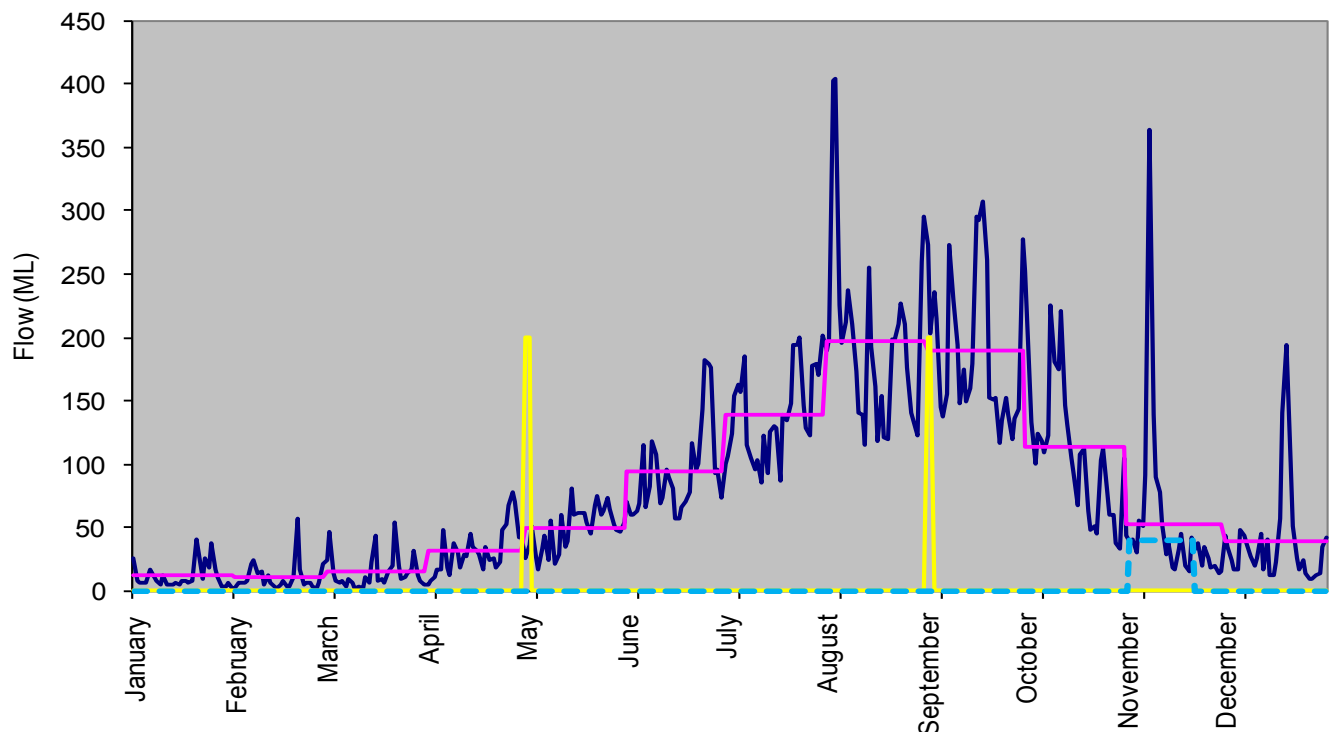


Figure 142. Dark blue - Annual flow regime in lower Torrens River 1978-present measured at Holbrooks road (Gauge A5040529). Pink – monthly average flow per day. Yellow – original EWP. Light blue – revised EWP.



4.6. Fish Ecology of EWP Reaches – Lower Onkaparinga River

4.6.1. Sustainability of Native Fish in the Onkaparinga River

The Onkaparinga fish community was the only EWP reach to be numerically dominated by native fishes. To some degree this is attributable to the openly connected nature of the estuarine/freshwater linkages. Subsequently, diadromous species such as common galaxias and congolli are able to spawn and recruit successfully in the lower and marine reaches and move into the mid and upper reach as adults. The Onkaparinga populations of these diadromous species are likely to be amongst the largest remaining (after the Murray & Coorong populations) and most critical in the state.

It is recommended, therefore, that: specific EWP targets be developed for diadromous species to provide access to marine environments for spawning during late autumn-winter, and extended connecting flows for recolonisation of the catchment during spring.

In other EWP catchments, assessment and management of barriers to migration should also be linked to the re-establishment of connecting flows for migration to ensure flow provisions are not counteracted by an inability to respond.

Robust populations (e.g. high abundances of a full range of age classes) of diadromous species remained despite very low flows during the 2006-09 drought period. In addition, freshwater species are also abundant in the Onkaparinga, with mountain galaxias and dwarf-flathead gudgeon also reaching much higher abundances, at least periodically, in the Onkaparinga than other catchments.

In comparison, numbers of introduced redfin perch, gambusia, carp, tench and goldfish remained relatively low throughout the study period. This pattern suggests that the more naturally seasonal cycles of flow present in the Onkaparinga (especially downstream of Bakers Gully) compared to other reaches has additional benefits for native fishes and that reduced stability may disadvantage invasive species, as has been observed in other Australian systems (Costelloe *et al.* 2010, McNeil and Costelloe 2011). The low abundance of these pest species in the target reach provide a good baseline for EWP applications; any expansion of these populations resulting from EWP delivery could lead to complications in the environmental benefit provided to natives.

Future monitoring should, therefore, pay specific attention to the pest species, to warn of possible expansion of these populations linked to underlying flow processes.

The impact of drought was significant in the Onkaparinga with many refuge pools drying completely and almost all native species responding with reduced levels of recruitment, abundance and/or



distribution in response to progressive drought. The downstream pools in the Old Noarlunga region served as key refuge habitats for diadromous and euryhaline species during dry periods. However, the water quality crash that followed the saline water intrusion in 2009 shows the precarious nature of these habitats during drought, especially when upper catchment flows are captured in storages and not allowed to flow into the lower reaches to counteract tidal peaks and storm surges that would historically be associated with increased river outputs. In upper reaches, EWPs are required to maintain refuge pools throughout summer periods, especially during drought periods.

Therefore, refuge maintenance flows should be considered in late spring (to pre-condition pools) and late autumn (to flush and refresh pools). These flows should be increased during drought rather than be postponed as in the recent example.

In general the sustainability of native fish populations appears to be better supported in the Onkaparinga than other surveyed catchments, however, the extremely low abundance of species such as climbing galaxias reveal that flow regime and/or fish passage are not currently adequate for sustaining viable populations in the EWP reach. Furthermore, the loss of common galaxias under drought conditions reveals that flows of adequate duration and volume to provide fish passage between the sea and Clarendon Weir are not occurring without additional EWPs. This pattern may be contributing both to the absence of climbing galaxias and the decline of other native species across the survey period (e.g. mountain galaxias).

Finally, the interactions between estuarine and freshwater habitats and fish assemblages were revealed during the study. Species such as black bream, jumping mullet, gobies and hardyhead all moved between estuarine and freshwater habitats during connectivity. The integration of estuarine and marine habitats and species must be more closely linked with freshwater ecology and management.

It is recommended that specific steps be taken to integrate estuarine and near shore aspects into assessments and plans for environmental flows in the coastal drainages of the MLR.



4.6.2. Flow Regime and Ecology of Fish in the Onkaparinga River

Following the postponement of EWP trial releases due to ongoing drought in the WMLR, the objectives of fish monitoring program changed slightly, from collecting a single year of “pre flow” data and two years of “post flow” data, to a three year pre-flow study that will provide a stronger baseline of information from which post flow “response” patterns can be compared. As such, the revised study design allows the assessment of EWPs under a Before-After Comparison (BAC) design (Bunn and Arthington 2002) which can provide a balanced assessment of flow release impacts and responses, when compared to identical monitoring data following the release of EWPs to the reach.

It is strongly recommended that at least three years of post-flow data be collected using the same sites and methodology utilised in the present study to allow strong scientific conclusions to be drawn regarding the role of EWPs in driving observed ecological patterns.

The extreme low flows encountered during the pre-flow survey incidentally improve the value of this study as a pre-EWP data set given the additional climatic pressure on flows and flow requirements of native fish.

The ecological objectives of the planned EWPs in the Onkaparinga were as follows:

1. Provide longitudinal connection for fish migration.

A key benefit of providing an Environmental Water Provision to the Onkaparinga River below Clarendon Oval is the improved connection between the river and the estuary, allowing the movement and spawning of a greater diversity of fish and other aquatic life than that occurring with present flows (Bald and Scholz 2007a). The distribution of diadromous fish throughout the reach at the beginning of the survey suggests that the winter/spring baseflow in 2006 provided sufficient flow volume and duration for fish to migrate the length of the reach.

Modelling conducted under a related project suggested that this flow was likely to be sufficient for the passage of diadromous fish from the sea to Clarendon, but that spring flows of this duration and volume were rare under current flow management (Mackay *et al.* 2008). Initial surveys found the fish community in reasonable condition with common, mountain and climbing galaxias all present downstream of Clarendon Weir suggesting that pre-survey flow conditions were supportive of a diverse range of native fish throughout the reach.

The decline in range and abundance of all galaxiid species in the upper reach is most likely associated with the deterioration in flow conditions as drought increased. Congolli and common galaxias maintained healthy populations at Old Noarlunga partly because of the proximity to the estuary and



partly because the extra unregulated flow emanating from Kangarilla Creek provided longer flow duration for springtime recruitment, allowing migratory exchange between the sea and the extreme downstream reaches of the Onkaparinga.

2. Maintain and improve water quality

Water quality as measured during these surveys was often within the physiological limits of the native and introduced species. However, increased salinity from tidal incursion into the most downstream pool at Old Noarlunga resulted in a switch to hypoxic ($<0.2\text{mg/l}$), marine conditions (salinity $>35\text{ppt}$) and a subsequent fish kill event (McNeil *et al.* 2009). Maintaining end of catchment flows over spring and summer is likely to have prevented this incident, or at least provided a means of escape for fish to move upstream. Freshes and flushes would have also prevented the pool from remaining salty for long periods as occurred in autumn 2007 and 2008. With potential for increasing marine intrusion associated with climatic warming and rising sea levels, it may be prudent to address the possibility of freshwater flow releases to counteract intrusive saline water related to storm swells and king tides. There are, however, obvious risks to flooding associated with additional flows during high tidal conditions.

3. Maintain self-sustaining fish populations

The general decline in fish diversity and abundance over the survey period suggests that current flow conditions are barely sufficient for maintaining self-sustaining populations of most native fish species, with exception of flathead gudgeon. Recruitment of native species was minimal, while introduced species thrived. Without improved flow conditions, the pattern observed during the current survey are likely to lead to long term impacts on the ability of the native fish community to maintain viable self-sustaining populations within the lower Onkaparinga River.

It is therefore imperative that EWP trials begin as soon as possible to enable the rebuilding of resilient native fish populations that are able to survive periods of environmental harshness in the future.

This is particularly critical for rebuilding resilience following the recent drought (McNeil *et al.* 2011b).

4. Maintain and restore habitat diversity for macroinvertebrates

This aspect of the ecological outcomes was not monitored during this survey, however, observed lack of extended periods of riffle inundation are likely to lead to reduced invertebrate diversity and therefore impact upon food webs that support native fish populations.

5. Control terrestrial vegetation of the river channel



A very large flushing flow in 2005 had cleared terrestrial vegetation from the river channel. Over the duration of the survey period, terrestrial vegetation increased again to the extent that much of the channel and in particular riffle areas became overgrown by introduced plant species, especially African fountain grass. The incursion of this species is likely to provide reasonable habitat for native fish species, but consideration should be given to replacing this introduced weed with similar native species such as local *Lomandra* spp. (see Nicol and Bald 2006).

6. Reset aquatic habitat

The very large flow in November 2005 had reset the aquatic habitat by removing built up sediment, nutrients and organic matter. Similarly, flooding flows in November 2009 provided similar services following the study period. Flows of this large magnitude are likely to be adequate at these (~4 year) intervals to flush and reset ecological processes.

7. Summer low flows – maintain shallow water habitat for macroinvertebrates and improve water quality in pools

Flow provisions and in particular spring and summer baseflow have been developed to maintain volume and quality of aquatic habitats throughout summer and prevent the annual loss of biota from drying river reaches (Bald and Scholz 2007b). There were no summer low flows throughout the survey period and shallow water habitats such as riffles and runs between pools were not maintained. These are the preferred habitat of galaxias species, which declined in distribution and abundance over the course of the survey, in particular climbing galaxias which become incredibly rare as drought progressed.

8. Summer freshes – flush pools to improve water quality and increase habitat value

Summer freshes were not provided. However, naturally occurring winter/spring freshes were insufficient for restoring freshwater habitats in the lower Onkaparinga following the marine intrusion event. Larger flushing flows may be required to provide this ecological function, especially towards the bottom of the reach.

9. Winter low flows – create surface water flow sufficient to fill low flow channels providing migration opportunities for fish and macroinvertebrates, not significantly impacting depth of pools

The only winter low flow to meet the volume targets set in planning was that provided by the EWP in 2006, and its duration was not long enough. Low flows in subsequent winters did not even meet



targets for summer low flows and were of very short duration. The observed decline in abundance and distribution of diadromous fish indicates the inadequacy of the meagre low flows in this reach.

10. Winter freshes – provide longitudinal connection between pools and allow migration for fish and macroinvertebrates but not scouring biofilms or sediment

Winter freshes meeting the targets set during planning did not occur at the two upstream sites throughout the survey period. One small fresh was provided along with the trial EWP in 2006. At the downstream site, flows from Kangarilla Creek resulted in winter freshes over 100 ML/day although they flowed for less than the 5 day targets set in planning. Regardless, these freshes were unable to provide passage between the lower and upper sites. Rainfall events in Kangarilla Creek catchment should be matched with releases of freshes from Mt Bold to take advantage of the unregulated flow regime from that catchment.

11. Large winter pulses – reset habitat and ecosystem processes by scouring sediments and biofilms, also aiding in vegetation control

Significant rainfall events in the Kangarilla Creek catchment resulted in one large winter pulse flowing down the lower part of the river each year, however the two upstream sites did not receive any large winter pulses as the rainfall was captured by the reservoir.

4.6.3. Flow Management for Native Fish in the Onkaparinga River

Normal flow in the Onkaparinga at Old Noarlunga reflect both the regulated input from the upper catchment and the relatively unregulated input from Kangarilla Creek and several other smaller tributaries (Figure 143) Winter and spring rainfall contributes most towards flow, with no summer and very little autumn flow. Flow during the present surveys was even more restricted to winter and early spring flows. Under normal flow conditions, the proposed EWPs would have provided connectivity over summer and autumn, although they would only enhance winter and spring flows and they would potentially miss extending flows from spring into December. The natural flow regime in the Onkaparinga should allow flow year-round in most years. To achieve this, a revised EWP would begin in spring and extend flows over summer to provide passage back up the river for diadromous fish. It would also provide large flushes and freshes over spring and summer to stimulate spawning and recruitment and to maintain high water quality over a longer period of time.

During this survey, EWPs were not delivered because of extreme drought conditions. As a result, most of the ecologically important aspects of flows were unavailable to the lower Onkaparinga for over three



years. Low flows were only present for short periods over winter, there were very few freshes and no flushes.

Passage between the estuary and upstream sites was severely limited or absent and the timing and magnitude of flows was unsuitable to promote spawning and recruitment. This caused severe decline in the abundance and diversity of native fish species. Under natural conditions, even in drought years there would be significantly greater flow duration, magnitude and frequency of pulses due to water not being captured by dams and reservoirs.

In future, emergency allocations of water should be considered to maintain some ecological values in the river rather than completely removing all flow.

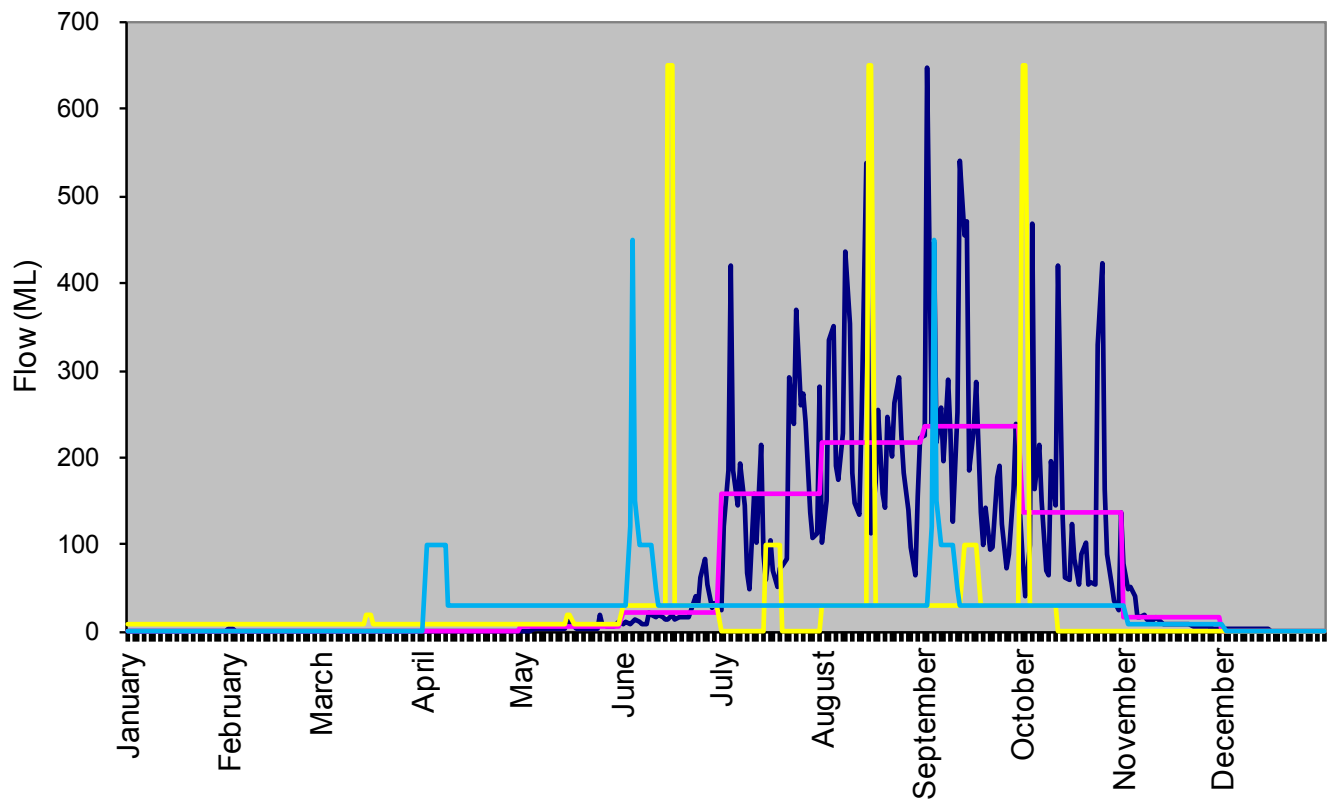


Figure 143. Dark blue - Annual flow regime in Onkaparinga River 1973-1988 measured above Old Noarlunga (Gauge A5030522). Pink – monthly average flow per day. Yellow – original EWP. Light blue – revised EWP.



4.7. Summaries

4.7.1. Native Fish Management and EWPs in the WMLR

Overall, the status of native fish populations throughout EWPs was considered relatively poor, with native biodiversity at some sites represented by a single species only. In addition, many native fish species were under-represented within catch data suggesting that they are struggling to maintain large and viable populations in the trial reaches. This may threaten the long term sustainability of these reaches in supporting native biodiversity.

The four target reaches for EWP trials all possess very different fish communities that are most likely impacted by a range of historical factors and impacts of past management practices. Whilst habitat structure in most of the reaches was found to be reasonably intact, the presence of introduced competitors and predators, combined with highly modified flow regimes and instream barriers are likely to have heavily influenced current assemblage structure.

The most impacted reach was the South Para River which is reduced to only a single common native fish that co-exists with gambusia and redfin perch. Native galaxiids that persist in tributaries and in the upper catchment area, and diadromous natives that persist below the confluence with the North Para River are not able to establish within the reach because of numerous impassable barriers to migration and the presence of large redfin perch throughout the reach, which are likely to exclude them through predation, given their potential desirability as an easily obtainable (pelagic) and high energy food source (McDowall 2006, Wilson *et al.* 2008).

The South Para River, therefore, has several ecological challenges to the sustainability of native fish that are exacerbated by impacts of flow management in the reach. Consequently, identification and removal of barriers and control of introduced species are desirable management actions for this reach. In addition, EWPs for this reach should be tailored towards disadvantaging pest fish as well as assisting in the re-establishment of a native fish assemblage in the reach.

The Torrens River was also dominated by introduced species, but indications from this survey are that native fishes are still present and would benefit from targeted riverine management, and in particular, flow regime changes. In the upper catchment, more careful, ecologically considerate management of water transfers is likely to play a key role in maintaining sustainable and viable native fish populations. Indications are that galaxiids are able to move into the reach from tributaries and establish during flow events in riffles and shallower habitats. However, contraction of the reach back to pools, without any seasonal cues, or gradual drawdown practices that may incite migration to safe refuge leads to



sporadic catches of the fishes, which are unlikely to survive in larger pools given the high densities of trout and redfin perch that persist in those habitats. In the lower catchment, habitats and flows are both highly modified and likely to benefit greatly from both habitat restoration activities as well as the provision of seasonally timed flows to promote spawning and recruitment of native fish species, and to drive natural ecological processes that can build native fish populations.

The Onkaparinga River possesses the most natural fish community and has the most intact habitat structure and the lowest number of barriers to migration into the reach (with the notable exception of the Bakers Gully gauging weir). The principal barrier to migration is that flow levels are of insufficient volume and duration to inundate natural cease to flow points and facilitate the regular migration of fish throughout the reach. EWPs are therefore, most likely to have measurable results in this reach due to the lower contribution of other factors impacting upon the native fish community. Care must be taken, however, to guard against EWP regimes that encourage the expansion of introduced fish communities, which are currently at low levels in the lower Onkaparinga, potentially due to the harsh summer conditions that discourage less tolerant exotics (Wilson *et al.* 2008).

4.7.2. Designing EWPs for native fish

The data collected during this monitoring program provides an opportunity to investigate the role of river flows in structuring and building sustainability into native fish populations in the four EWP reaches prior to the delivery of trial EWPs. The flow regime of all reaches is highly modified from natural through water resource developments to support human needs throughout the city of Adelaide. The collection of baseline biological data can therefore provide important information regarding the flow-dependant habitat requirements of native fishes, including water quality and the timing and volume of flows required by fishes for spawning and migrational cues; recruitment and the survival of robust demographic population structure.

The data is not consistent across target reaches, but some common issues have arisen regarding critical components of the flow regime. Specific issues may also support the further modification of flow regimes in these reaches. In addition, the collection of data occurred during extreme drought with record low catchment rainfall and runoff, leading to extremely low flow conditions. These circumstances revealed additional information about the exceptional flow requirements that may be required during drought to protect freshwater fish, over and above those required to maintain and restore native fish populations during periods of more normal climate and rainfall.



Three broad flow requirements identified are listed below:

1. Seasonal flow cues to initiate spawning development/behaviour, access to and inundation of spawning habitats.
 - Flow cues timed in late autumn/early winter to allow congolli, and common and climbing galaxias to access spawning areas in the lower freshwater/upper estuarine reaches of rivers.
 - Flows must be of significant volume at the end of the catchment to inundate wetlands, riparian vegetation and bank shoulders that provide spawning habitats for these species.
 - Spring flows timed to allow return migration of larval/juvenile congolli, galaxiids, eels and adult lampreys; and to provide spawning cues for obligate freshwater species such as mountain galaxias, blue spot goby, and gudgeon.
 - Flows must be of sufficient duration to allow return migration between spawning, larval and adult habitats.
2. Minimum durations of zero flow periods over summer to prevent impacts of habitat and water quality decline on native fish (whilst maintaining enough variability in habitat and water quality to disadvantage exotic pests).
 - Natural climatic cycles often drive patterns of habitat loss and recolonisation during drought periods and subsequent flow seasons (Bond *et al.* 2008). Refuge habitats of sufficient depth and habitat quality are critical for protecting native fishes during seasonal and extended periods of drought.
 - Although native fish are well adapted to the decline in water quality and habitat associated with seasonal climatic drying (McNeil and Closs 2007), minimum zero flow periods are required to ensure that the tolerance thresholds of native fish are maintained in a critical number of refuge habitats.
3. Extended duration connecting flows to allow fish movement across freshwater reaches, tributaries.
 - In addition to the role of refuge habitats in the survival of fish, flows sufficient to re-inundate aquatic habitats, and to provide recolonisation pathways are essential for building up population resilience following drought seasons or periods.
 - Freshwater species such as mountain galaxias require spring flows to recolonise high quality habitats and to maintain appropriate mixing for maintaining genetic diversity.



- Late spring flows with gradual decline in flow levels, provide cues and pathways of 'retreat' to key refuge habitats where species can survive climate impacts.

A generalized summary of recommended flow bands for EWP reaches are presented below in Figure 144. This flow recommendation matches extremely well with various flow seasons identified under the MLR Environmental Water Requirements project (vanlaarhoven and van der Wielen 2009) which was at least partly based on earlier findings from this project. A key addition to arise from the current report is the delivery of spring flows (yellow line on Figure 144) to ensure the linkage between the high flow season and T2, and the additional flow bands (green and pink bands in Figure 144) under low flow and T1 seasons to protect autumnal flows.

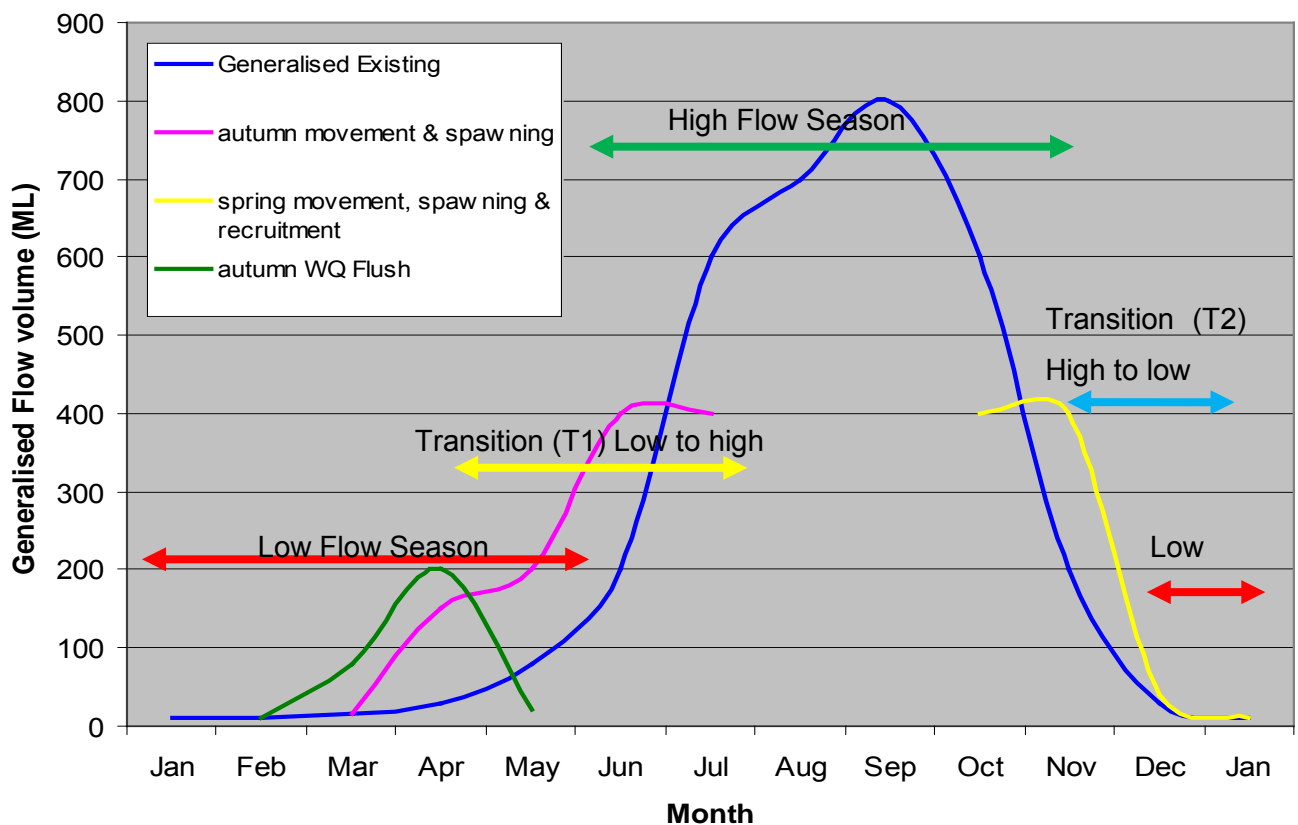


Figure 144. Generalized model (blue) of existing Flow Regimes in EWP reaches (assuming average local rainfall) and suggestion flow targets to support autumn flushes for water quality (green line), late autumn flows to connect adult habitats, inundate spawning sites and allow access of larvae to sea (pink - especially for climbing galaxias) and spring flows to maintain hydrological connectivity for return movement of adults into spawning habitats and provide passage for recruiting juveniles from downstream (yellow line). Spring flows also top up water quality pre-summer and reduce water quality impacts throughout the summer period. Flow seasons identified in the MLR EWR process for MLR streams (vanlaarhoven and van der Wielen 2009) are shown as labelled coloured arrows.



4.7.3. Critical flow gaps for fish in EWP reaches

The flow regime of EWP reaches (see hydrographs throughout section 4) was compared with those aspects of flow regime that were identified as critical to fish throughout the current survey. Flow regime in all four EWP reaches was dominated by local rainfall driven peaks in flow (except for the irregular water transfers in the upper Torrens) that were predominantly distributed throughout the winter period and into early spring. However, native fish in the WMLR are reliant on flow peaks that extend from mid-late autumn when many species begin to spawn, through until late spring, where recruitment and migrations are common and pool water quality is determined for the oncoming dry season, where low or zero flows are common and natural.

This crucial difference between natural and altered flow regimes means the restoration of autumn and spring flows are seen as the most critical aspect of restoring flow regime through the delivery of EWPs for native fish. This is further amplified by recent climate-change predictions indicating a decrease in local rainfall (McInnes *et al.* 2003, Bardsley 2006), and in particular, declining rainfall volumes throughout autumn and early winter (Timbal and Jones 2008).

The principal recommendation of the current report is therefore that if nothing else, EWPs should aim to boost autumn and late spring flows and to ensure that these are of significant duration to link up with winter dominated flows driven by local catchment rainfall.

4.8. Utility of Multivariate Data Analysis

A multivariate statistical approach was used to investigate the relationship between fish community with flow and habitat variables. The approach using vector analysis may be an effective way of interpreting long term trends in the data and may be limited by the relatively short duration of data collection. In particular, flow variables for each reach do not vary across sites within a reach and therefore, a large number of seasons are required before trends become meaningful. As a result, the multivariate plots presented here generally show strong seasonal patterns that represent fish community or population shifts between autumn and spring.

These seasonal patterns are clear for some reaches, and at others are obfuscated by the influence of other variables such as flow and water quality. It is envisaged that with long term data collection over several years, the influences of factors such as flow will become clearer. The emergence of some correlative parameters using the current limited data set is encouraging as it suggests that long term data collection is likely to lead to clearer correlative patterns that can help to outline trends in the fish community data and develop linkages between flow and ecological patterns.



4.8.1. Further research

The return toward average rainfall combined with initiatives to secure water supply to metropolitan Adelaide, mean it is vital that the EWP program be reinstated to return ecological health to the three rivers surveyed here. In light of our findings, the EWPs proposed in 2005 (Pikusa and Bald 2005b) should be revisited and revised as necessary. This project has highlighted the benefits of longer-term monitoring to assess ecological health. Further EWP trials should incorporate long-term monitoring surveys with both general and specific aims to ascertain the performance of the EWPs. The surveys should monitor the general ecological health of each river, but they should also be designed to monitor the specific hypothesis based ecological outcomes proposed for each river.

There also remain a number of unanswered species specific research outcomes, most of which relate to the response of species to a natural flow regime (whether that is truly natural or supplemented by EWP). These knowledge gaps are highlighted in the species matrices below.

4.9. Summary of Key Recommendations

4.9.1. South Para River

- Management attention given to key threats including barriers to migration, introduced predators (redfin perch) and flow regime, and habitat changes resulting from abstraction from private dams in Tenafeate Creek.
- Flow allocations to the South Para River be designed to maximize seasonal flow cues for spawning and migration of native fishes and disadvantage exotics.
- Barriers be removed downstream to re-establish native fish community in the South Para River, in particular, common and climbing galaxias, congolli, blue spot goby, short headed and pouched lamprey.

4.9.2. Torrens River

- EWP design in this reach be extended toward lower catchment outcomes, specifically, the extension of existing EWP target to downstream reaches including Lake Torrens and Breakout Creek.



- Barriers to fish migration in the lower River Torrens be assessed and considered for removal or provision of fish passage to maximize the benefits provided by the Torrens fishway and recent habitat restoration programs at Breakout Creek to the rest of the catchment.
- Transfer flows in the upper catchment be timed to more closely match climatic rainfall patterns where possible, as this regime corresponds with ecological flow requirements of native fish, and reduces the benefit of stable unseasonal flow regime to exotic species.
- Restoration of key aspects of natural flow regime in the lower Torrens to improve water quality in stagnant stream pools improving aquatic assets such as the Linear Park and Lake Torrens in the Adelaide city centre. Base-flows may contribute to the maintenance of aquatic habitats and somewhat improve water quality, but not to the degree that freshes and flushing flows will as they mobilise and remove organic materials that drive stagnation.

4.9.3. Onkaparinga River

- Future monitoring should pay specific attention to the pest species to warn of possible expansion of these populations under EWPs.
- Specific EWP targets should be developed for diadromous species to provide access to marine environments for spawning during late autumn-winter, and extended connecting flows for recolonisation of the catchment during spring.
- EWPs should be designed to maintain water quality levels in pools in lower Onkaparinga during low flow periods, specifically to overcome saltwater incursion on king tides.

4.9.4. General

- EWP trials should begin as soon as possible to enable the rebuilding of resilient native fish populations that are able to survive periods of environmental harshness in the future.
- Regular, broad spatial surveys should be considered to support the development of accurate and realistic water resource and flow allocations for sustaining native fish biodiversity and ecological sustainability in the WMLR.
- At least three years of post-flow data should be collected using the same sites and methodology utilised in the present study to allow strong scientific conclusions to be drawn regarding the role of EWPs in driving observed ecological patterns.



- EWPs should aim to boost autumn and late spring flows and to ensure that these are of significant duration to link up with winter dominated flows driven by local catchment rainfall.
- Assessment and management of barriers to migration should also be linked to the re-establishment of connecting flows for migration to ensure flow provisions are not counteracted by an inability to respond.

Flow regime is considered a key determinant of aquatic biodiversity in rivers and streams, and can be seen to influence aquatic biodiversity through four key principals (Bunn and Arthington 2002). These principals provide a means of summarizing the major findings of the fish monitoring programs.

4.9.5. Flow is a major determinant of physical habitat and therefore biotic composition

In the WMLR, flow is related to a number of aspects of fish habitat:

- Aquatic species have evolved life history strategies primarily in direct response to their natural flow regimes:
- Most of the native fish in the WMLR possessed life history traits closely linked to flow regime:
- Very large floods (before and after survey period) mobilised sediments, maintained benthic diversity, prevented vegetation intrusion and formed new pools in all EWP reaches during natural high rainfall events.
- Autumn-spring baseflow and minimization of cease to flow periods maximized the persistence of refuge pools throughout summer dry seasons in all EWP reaches. These conditions seemed to be linked closely to the sustainability mountain galaxias populations.
- Very low flows during seasonal dry periods, (increased cease to flow period, reduced baseflow in autumn and spring), exacerbated by drought, led to the widespread loss of pools (and therefore all resident fish) in all EWP reaches except for the lower Torrens where baseflow was more constant throughout summer.
- Water quality deteriorated in refuge pools during summer dry periods. Marine intrusion drove salinity levels upwards in the lower Torrens and Onkaparinga during storm surges, leading to fish kills. Whilst most native species are tolerant of low dissolved oxygen and warm temperatures, fish health in shrinking pools in the Onkaparinga deteriorated significantly with disease and malnutrition prevalent in some pools, especially for common galaxias and congolli.



5. SPECIES SPECIFIC BIOLOGICAL INFORMATION AND MATRICES

A key aim of the current report was to expand the current level of specific knowledge regarding the biology of native fishes in the WMLR, initially summarized from a review of literature and local knowledge in McNeil and Hammer (2007), prior to the EWP surveys. Species matrices, presenting current knowledge for each of the WMLR species presented in that document have, therefore, been updated here to include additional biological information gathered through the current survey. Updated species matrices are presented in Section 5.4 Species Matrix Updates

Table A-P).

A brief summary of information collected through the survey is also outlined for each species below. Of the 16 species dealt with here, two species – pouched lamprey and lagoon goby – were not captured; however, future surveys should be responsive to captures of these species.

5.1. Native Fishes of the WMLR

5.1.1. *Shorthead lamprey*

Only two shorthead lampreys were captured, but the timing of their capture indicates that they may have been migrating into freshwater in response to moderate autumn flow (perhaps trapped at Breakout Creek since spring owing to poor spring/summer flows). Along with the



key threats already identified (predominantly regarding barriers to migration), reduction in permanent habitats due to loss of flow and impacts to downstream migration by regulation of high flows were identified as additional threats to this species. Whilst no pouched lamprey (left) were collected at EWP sites under the current survey structure, one was captured in the Lower Torrens at Breakout creek during associated sampling of the reach.



5.1.2. Shortfinned eel



Two short-finned eels were captured (one each in the Torrens and Onkaparinga), extending the known range of this species into the Western Mount Lofty Ranges. Due to the highly migratory life history of this valuable species, barriers to upstream and downstream movement should be

assessed for removal or bypass. Nothing is known about the migratory nature of this species in the WMLR (i.e. it is likely that natural recruitment is a rare event during strong coastal currents) and future research should investigate the natural recruitment of this species from east coast Australia.

5.1.3. Freshwater catfish

Freshwater catfish have a healthy, albeit translocated, population in the Torrens River. Freshwater catfish utilise low-flow habitats a pattern confirmed by strong recruitment following low



winter flow in 2006. Although there wasn't direct evidence of competition with carp, recruitment of freshwater catfish and carp were inversely related. This introduced Torrens population is an ideal study candidate for threatened Murray species given the co-occurrence of both native and introduced Murray River species, and the non-indigenous nature (and therefore low conservation value) of the Torrens populations. Future research opportunities exist to investigate life history and recruitment requirements for this species and to explore the interaction between carp and catfish under varying flow regimes as a test case for carp management in the Murray River.

5.1.4. Bony Herring

A single bony herring was captured in the upper Torrens catchment, and is the first record of this species in the SAG. This is almost certainly the result of translocation from the neighbouring Murray River catchment. Whilst the translocation



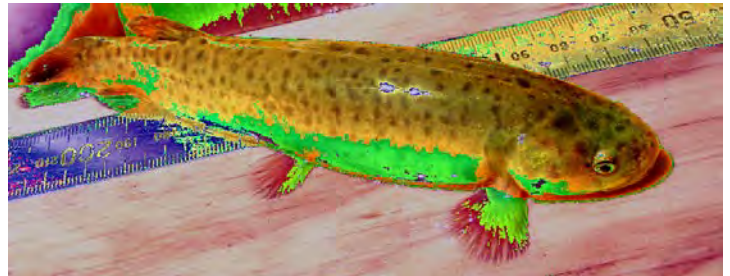
could be the result of a pelican or duck vector, it is more likely (especially given the good physical



condition of the specimen) that translocation has occurred through Murray water pipeline, which enters the Torrens just upstream of the capture site. Conditions in the lower Torrens catchment are quite suitable for bony herring which could proliferate if a population established there with adverse consequences for other native species. Assessment of the translocation potential of Murray River pipelines should immediately be undertaken to counteract the risk of unwanted future species movements into the WMLR, especially given new invasive species such as weatherloach have recently moved into the lower Murray where the pipelines originate.

5.1.5. *Climbing galaxias*

Climbing galaxias had a limited distribution, primarily restricted to the upper reaches of the Torrens and Onkaparinga Rivers. Loss of riffle habitat due to flow restriction is likely to have had a major impact on their abundance and distribution. Climbing galaxias were not captured at downstream sites near the estuary and are likely to be a landlocked population in these rivers. Redfin perch and trout were identified as key threats to their abundance and distribution. Management priorities should concentrate on re-establishing habitat diversity by managing low flows to maintain riffles and limiting the distribution and abundance of key predators.



5.1.6. *Common galaxias*

Common galaxias were captured in the South Para, Torrens and Onkaparinga Rivers although their abundance declined over the course of the surveys with declining flow and lack of spring connectivity. They showed good recruitment to lower reaches in spring, but were unable to move further upstream due to flow restriction. It was difficult to determine the general effect of water quality on abundance, but common galaxias were absent from pools with extreme high salinity and low dissolved oxygen. The fishway at the mouth of the Torrens River was effective for fish passage, but numerous other barriers exist in the



Torrens and other rivers to prevent movement to upstream habitats. The presence of this species above woodlands weir in the South Para was the result of translocation by the friends of the Gawler



River and the steady decline and recruitment failure suggests that removal of barriers to re-establish diadromous movement is the best management solution for restoring this species to the South Para River. The restoration of estuarine linkages and lowland stream habitat, and provision of autumn/spring flows reaching the sea to facilitate spawning and larval recruitment and migration should be pursued.

5.1.7. Mountain galaxias



There was good recruitment of Mountain galaxias in the Onkaparinga despite low numbers of adults at those sites. Redfin perch were identified as a key predator and their presence marking a low abundance or absence of mountain galaxias. Low flow volumes reduced the availability of small pools and riffles where this species might avoid redfin perch and trout which dominate pool habitats. Management should concentrate on delivering EWPs to reinstate riffle habitat. A remaining gap in our knowledge of mountain galaxias is their water quality tolerances.

5.1.8. Murray rainbowfish



This River Murray translocated species was only captured in the Torrens. Their distribution and recruitment dynamics were consistent with their preference for low flow reaches. They were also able to tolerate

very warm and saline waters in the lower reaches of the Torrens. This population is another ideal study candidate for threatened Murray species. Along with freshwater catfish, future research could investigate the interaction between carp, gambusia and rainbowfish under varying flow regimes as a test case for pest fish management in the Murray River.

5.1.9. Small-mouthed hardyhead

Small-mouthed hardyhead were only captured on a limited number of occasions in the estuarine reaches of the Torrens and Onkaparinga Rivers.



Although they have been reported to tolerate freshwater conditions, they were only captured in saline waters during these surveys. The very limited estuary at the mouth of the Torrens should be managed



to protect this and other species from development activities on the metropolitan coast, such as sand carting, which was observed to disconnect riverine, estuarine and marine reaches on several occasions. The impacts of coastal management activities on native fish along the Adelaide coast remain unaddressed.

5.1.10. *Congolli*

Many of the knowledge gaps identified by McNeil and Hammer (2007) have been filled or verified during this survey. Male-female habitat separation was observed in each river with the larger females occupying freshwater pools and males occupying the downstream saline pools or estuary. However, a unique situation was also observed where ripe males and females were both aggregated within freshwater



pools in the lower Onkaparinga. The increasing salinity in the lowest pool in the Onkaparinga made it an increasingly important habitat for juvenile congolli despite poor water quality. Loss of connectivity and barriers to movement were an issue for spawning and recruitment, especially in the South Para River where Woodlands Weir remains a significant barrier to all fish movement. Management actions should be directed at removal or bypass of instream barriers and restoration of estuarine linkages, restoration of flow for female passage to upstream habitats and restoration of lowland reaches, particularly the Breakout Creek wetland area in the Torrens.

5.1.11. *Carp gudgeon*

Another River Murray-Torrens translocation, this species highlighted its preference for low flow reaches, increasing abundance as flow decreased in the lower Torrens. It was absent from areas of higher flow or in the presence of redfin perch and trout in the upper catchment. It is also another potential population to use as a model for carp and gambusia interactions in the Murray.



5.1.12. *Flathead gudgeon*

Flathead gudgeon were the only native species present at every site and were adaptable to the



all flow conditions. It appears that this species may benefit from river regulation and degradation, but habitat complexity and cover remain important. It tolerated poor water quality including high salinity and low dissolved oxygen conditions. Size frequency analyses indicate that this species may recruit throughout the year. The main threats to its abundance were predation by redfin perch and competition and predation by gambusia. Specific management is not required for this common species but interventions targeted to other species (i.e. reducing the impact of introduced redfin perch and gambusia and restoration of stream habitats) will also benefit this species. Further research into the reproductive and recruitment dynamics of this species would be beneficial as a key component of current ecological structure in WMLR streams.

5.1.13. Dwarf flathead gudgeon



Dwarf flathead gudgeon were only captured in the Torrens and Onkaparinga Rivers. This species is potentially a River Murray translocation, although this remains unverified, and was present close to outlets of Murray pipelines in both rivers. It occupies similar habitats to

the highly tolerant flathead gudgeon, although it was found in higher abundance in the upper reaches of both rivers. High levels of disease identified in this species may threaten WMLR fishes, particularly if translocation has occurred. Management should focus on preventing further translocation of this Murray River species into other streams in the western Mount Lofty Ranges, especially the South Para River.

5.1.14. Western blue spot goby

This species was captured consistently in low numbers in the estuarine pool in the Onkaparinga river and the lower Torrens. It was tolerant to a broad range of salinities, and it appears that adults may aggregate in the



estuary in response to freshwater flushes. Key threats remain as the reduced quality of estuarine habitat, but flows may be essential for triggering spawning aggregations. Further research is required into general biology, reproductive and recruitment dynamics, distribution and abundance. This species



would also benefit from further protection of estuarine habitats and restoration of fish passage which has proved effective in Breakout Creek, restoring this species to that resection of the Torrens.

5.2. Exotic Fishes

5.2.1. Redfin perch



Redfin perch were a common component of fish assemblages across the WMLR, particularly in the South Para River, upper Torrens and Clarendon sites. Redfin perch were absent from the lower Torrens and rare in the Onkaparinga except for at Clarendon Weir. A fierce predator of native fishes (McDowall 1996) this species

appeared to exclude larger-bodied natives, especially galaxiids, from refuge pools and are likely to make it difficult for those species to build resilient and viable populations in main channel habitats due to high levels of predation. A short study was conducted to explore the impact of this species on flathead gudgeon in the South Para (see Wilson *et al* 2008) where it was found that diverse prey items (e.g. Yabbies and water bugs) and harsh summer drying prevented predatory exclusion of native fish despite high levels of predation. It is important that flow regimes and habitat quality is maintained to minimize the impact of this species on native fish, however, targeted removal is also recommended. Caution must be taken not to implement flow regimes (e.g. permanent flow; cool water releases) that will benefit this species.

5.2.2. *Gambusia*

Gambusia were widely distributed in the WMLR. This species is a well established pest fish that is an aggressive competitor with native fishes, and commonly dominates shallow and



stable habitats but may be disadvantaged by high flow variability and abundant native fish assemblages (McNeil 2004, Tonkin *et al* 2010, McNeil and Schmarr *in prep*). Accordingly, the species was absent from the South Para Gorge where extremely high flow velocities occurred prior to surveys in November 2005. Below the gorge section, however, the species was abundant and connectivity



provided by constant low flows may facilitate their expansion into the upper reaches. In the Onkaparinga, abundant native fish populations that included galaxiids, flathead gudgeon, dwarf flathead gudgeon and congolli were related to lower abundance of gambusia and may provide high levels of competition. Alternatively, the relatively low abundances of all exotic species through the lower Onkaparinga may relate more closely to the highly variable flow regime through this gorge section. For all EWP reaches, it is recommended that highly stable, low flow conditions be avoided, particularly throughout summer when gambusia populations expand.

5.2.3. Carp



Carp were widespread throughout the Torrens River and were found in the Onkaparinga at Clarendon and South Para below Woodlands Weir. The highly stable and/or regulated water regimes in the Torrens are likely to support carp to a high degree as this species is known to

dominate highly regulated river reaches across south eastern Australia (Gehrke *et al.* 1995). The presence of carp below Woodlands Weir serves as a warning that removal of fish passage barriers, and the provision of more stable flow regimes, may facilitate the movement of this species (as well as tench and goldfish) into the upper EWP reach in the South Para. Similarly, monitoring in the Onkaparinga should watch for any expansion of carp in that reach that may result from the delivery of EWP flows.

5.2.4. Goldfish

Goldfish were scattered throughout lower reaches of EWP sites, with no goldfish present above Gorge Weir in the Torrens or Woodlands Weir in the South Para. Other comments are as for carp, although potential for ongoing release of this species from the aquarium trade makes it a likely species to appear regularly in new reaches and catchments despite best management practice for environmental issues.



5.2.5. Tench

Tench are patchy and were only found below Clarendon and Woodlands Weirs. This introduced fish is likely to have low impact but may be an indicator of reasonable water quality. Tench are a documented threat to native fishes.



5.2.6. Trout

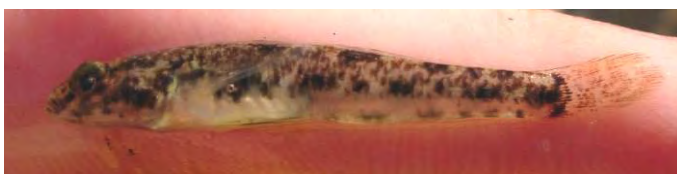


Brown trout and rainbow trout were both present throughout the mid-upper Torrens River, predominantly in the Gorge Weir EWP where they were a dominant component of the fish fauna. Their impact on native fauna is likely to be severe as gut

contents found high numbers of native shrimp, fish and Yabbies in all trout sampled. Preferring cool permanently flowing water, summer low flows are likely to assist in the control of these species, or at least assist in reducing their impact on native species. Their presence in large pools will likely exclude native galaxiids which are a primary target prey species (McDowall 2006). Intentional stocking and translocation of this recreational species provides a threat to native fishes throughout the WMLR, however it is now illegal for their release in the three target EWP catchments.

5.2.7. Estuarine Fishes

The key species of estuarine fish that were found to move into freshwater habitats were the black bream and Tamar goby. Both species moved into Old Noarlunga Pool 3 after connectivity with the tidal estuary and persisted in brackish to



fresh conditions, being removed by the subsequent fish kill that occurred in that reach. Both species should be considered carefully, however when designing coastal flow volumes, connectivity or flow regimes



5.3. Species Matrix Updates

Table 60, A-P. Factors important for maintaining sustainable populations of key fish species of the MLR-model of interactive factors. [No knowledge identified (*blank*) (2) requires verification for MLR (*blue text*), (3) low confidence/comprehensiveness (*Maroon text*), (4) updated information from recent surveys (*green text*)]

A		Life History Stages			
		Reproduction	Recruitment	Adult Survival	
Pouched lamprey (<i>Geotria australis</i>)		Ammocoete larvae burrow into soft substrates and remain for ~3 years. Substrate organic material and chlorophyll related to burrow density.	Marine. Adults die in upstream reaches following spawning.	Food	Environmental Variables
	Adults migrate from sea in late winter-summer to spawn in headwater streams. Migration upstream may take up to 16 months. Nests in stony substrates.	Organic material and macrophytes important for burrowing phase. May be restricted to areas of permanent flow and high habitat quality. Migrate downstream to sea, late July after metamorphosis (Feb-July).	Spent adults die in freshwater following spawning. Parasitic phase is unknown, host fish are unknown	Habitat	
		Temperature influences density of larval burrows. Ammocoetes very tolerant to hypoxia. Intolerant of very high temperatures (30oC+)	Marine	Water Quality	
	Spawning occurs in higher flow headwaters Oct-Nov. Adults may not be able to migrate upstream through extremely turbulent water.	Prefer lower flow habitats for burrows.	Marine	Flow	
	Barriers to upstream migration. Loss/deterioration of upstream spawning sites.	Loss of burrowing habitat. Reduced organic input (riparian vegetation) and macrophytes, increased temperatures around burrowing sites, i.e. Deforestation and flow alteration	Loss of adult marine host species. Survival through upstream spawning migration.	Key Threats	
Research		Targeted species research: (1) radio tracking of adult upstream migrants to identify instream barriers, spawning sites and larval nests. (2) Assessment of larval nesting habitats, extent and condition. (3) Identify specific target flows and identify barriers for migration. (4) Investigate marine parasitic phase, host species abundances etc. (4) Impact of climate change.			
Research Outcomes		<ul style="list-style-type: none">Not captured during surveys, identified during other sampling in Breakout Creek during survey period and should be considered a rare and highly impacted species for the WMLR, or at least for the Torrens catchment.Anecdotal evidence collected during survey suggests very high abundance at Breakout Creek in the mid 20th century, of harvestable quantities trapped below weir.			
Management		(1) Removal of migrational barriers. (2) Environmental flow programs for larval habitat and provision of appropriately timed flows for spring/summer migrations to/from the sea.			

B	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Shorthead lamprey (<i>Mordacia mordax</i>)	Larvae (Ammocoete) burrow into sand or silt in lower flow areas of streams and rivers.		Feed parasitically on marine fish for 1-2 years. Burrow in sand when not feeding.	Food	Environmental Variables
	Adults move into freshwater (late winter-summer) to spawn. Have a strong climbing ability. Utilise burrows & stony substrates during daylight and migrate upstream at night. Nests in sand, gravel or pebble substrates.	Ammocetes occur in perennial, high quality habitat (e.g. sound riparian and instream structure). Downstream migrants move to the sea Aug-Nov.	Marine. Spent adults die in freshwater following spawning.	Habitat	
	Increased temperature stimulates migration into freshwater. Wide range of salinity tolerance.	Larvae are unable to survive salt water.	Marine.	Water Quality	
	Reduced flows stimulate migration into freshwater. Spawning occurs in higher flow headwaters. Migration into freshwater after moderate flow May	Require permanent habitats. Downstream migration associated with high river flows.	Marine.	Flow	
	Barriers to upstream migration	Barriers to downstream migration Reduction in permanent habitats due to low flow volumes. Downstream migration impacted by regulation of high flows. Significant barriers to migration exist in all coastal catchments potentially excluding migrants from reaching spawning and juvenile habitats upstream.	Reduced stocks of marine host species.	Key Threats	
Research	Targeted species research: (1) radio tracking of adult upstream migrants to identify instream barriers, spawning sites and larval nests. (2) Assessment of larval nesting habitats, extent and condition. (3) Identify specific target flows for migration, (4) Investigate adult parasitic phase, host species abundance impacts etc. (4) Impacts of climate change.				
Research Outcomes	<ul style="list-style-type: none"> Only 2 adults captured at Torrens Mouth in marine pool in May 2007 Captured just after moderate flow at end of April May indicate migration into freshwater for reproduction, contrasts to general ecology of spring migration = potentially trapped at mouth since spring. Anecdotal evidence collected during survey suggests very high abundance at Breakout Creek in the mid 20th century, of harvestable quantities trapped below weir. 				
Management	(1) Removal of migrational barriers. (2) Environmental flow programs for larval habitat and provision of appropriately timed flows for spring/summer migrations to/from the sea.				

C	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Short-finned eel (<i>Anguilla australis</i>)			Carnivorous, fish, insects, crustaceans, molluscs etc.	Food	Environmental Variables
	Downstream migrations in spring/summer/autumn to the Coral Sea for Mass spawning.	Migration of juveniles along SE coast and into freshwater. Mass migration of glass eels upstream into adult habitats all year, specific to region (i.e. winter in Tas, spring summer on mainland). Adults captured in Torrens and Onkaparinga extend the natural range of this species to include the WMLR.	Wetlands, swamps, creeks, streams. Adults live 10-20years. Reproduce once only in marine habitats.	Habitat	
	12°C triggers spawning runs.		Tolerant of high salinity, temperature, turbidity and low oxygen.	Water Quality	
	Downstream adult migration triggered/assisted by high flows.	High flows inhibit upstream migration.	Utilise a range of flow conditions.	Flow	
	Migrational barriers, predation of juveniles.	Migrational barriers, predation of juveniles.	Migrational barriers, predation of juveniles. Only found in reaches where barriers absent or bypassed by fishway.	Key Threats	
Research	(1) Establish endemnicity and distribution across MLR. (2) Recruitment to Murray mouth and to WMLR streams (ocean current patterns, cues, barriers etc). (3) Water quality and flow impacts on elver upstream migration.				
Research Outcomes	<ul style="list-style-type: none">Only 2 adults captured. One at Clarendon Weir in May 2006 after period of low flow preceded by large flood in 2005The other at Breakout creek upstream of the fishway in November 2008 after period of very low but continuous flowTwo ways they could get to these locations: via the gulf and migrating upstream, or translocation via the Murray estuary and transferred via Murray pipelines, or deliberate release e.g. from aquariums or aquaculture where they are available commercially.				
Management	(1) Establish endemnicity and distribution. (2) Removal of migrational barriers.				

D	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Freshwater catfish (<i>Tandanus tandanus</i>)	<ul style="list-style-type: none"> Sexual maturity at three years. 	<ul style="list-style-type: none"> Juveniles feed on zooplankton and insect larvae, especially chironomids. 	<ul style="list-style-type: none"> Benthic carnivores. Eat carp gudgeon, shrimp, molluscs, worms and a wide range of aquatic and terrestrial insects and insect larvae. 	Food	Environmental Variables
	<ul style="list-style-type: none"> Circular nests built into gravel or coarse sand, often amongst dense macrophyte beds late spring-summer. Nests 0.6-2.0 meters in diameter. 	<ul style="list-style-type: none"> Juveniles probably remain close to adult habitats, no migrational movements for spawning. Juveniles captured in high numbers around aquatic vegetation in restored sections of Breakout Creek in the Torrens. 	<ul style="list-style-type: none"> Found sluggish waters and lakes, associated with aquatic vegetation. Remain within confined reach as adults. Abundant populations with broad age structure present in sluggish reaches of Breakout Creek around vegetation beds of emergent (<i>Typha</i>, <i>Phragmites</i>) and submerged (<i>Potamogeton crispus</i>, <i>Elodea argentea</i>) macrophytes. 	Habitat	
	<ul style="list-style-type: none"> Adults aerate eggs within nests. 	<ul style="list-style-type: none"> Recruitment observed under turbid and warm conditions in larger pools. 	<ul style="list-style-type: none"> Inhabit turbid streams. Tolerate very high, but not low temperatures. Turbid, warm and possibly polluted water in the lower Torrens highly compatible with catfish. 	Water Quality	
	<ul style="list-style-type: none"> Rise in flow may induce spawning. Larvae and juveniles caught following freshes in Breakout Creek. If low flows expose nest it is abandoned. 	<ul style="list-style-type: none"> Best recruitment after period of low flow i.e. winter 2006. 	<ul style="list-style-type: none"> Utilise low flow habitats. Found in high abundance in low flow habitats in Breakout Creek. 	Flow	
	<ul style="list-style-type: none"> Destruction of eggs in nests through water quality or predation of eggs/ larvae. Correlated increase in carp with decrease in catfish. 	<ul style="list-style-type: none"> Loss of macrophyte cover. Predation of juveniles. Translocated populations should not be considered a high priority for species based conservation, but serve as a good indicator species for river health. Recreational use in the Torrens observed. 	<ul style="list-style-type: none"> Loss of macrophyte cover. Cold water pollution. Potential competition with exotic carp. Possible evidence of competition with carp. Good carp recruitment in spring 2007 and 2008, but not good recruitment of catfish. 	Key Threats	
Research	(1) Determine impacts of sedimentation, water quality and predation on eggs in nests. (2) Dependence of larvae and juveniles on macrophytes and related food sources, competition and predation. (3) Impact of flow on spawning and recruitment.				
Research Outcomes	<ul style="list-style-type: none"> Translocated populations in the Torrens are self-sustaining and abundant. Best recruitment after period of low flow i.e. winter 2006. Possible evidence of competition with carp. Good carp recruitment in spring 2007 and 2008, but not good recruitment of catfish. 				
Management	Introduced Torrens population ideal study candidate for threatened Murray species, particularly following habitat restoration in Breakout Creek.				

E		Life History Stages			
		Reproduction	Recruitment	Adult Survival	
Bony Herring (<i>Nematalosa erebi</i>)	Pelagic larvae feed at sea or in lakes.		Aquatic & terrestrial invertebrates	Food	Environmental Variables
			Omnivorous, algae, insects, crustaceans & detritus.	Habitat	
	Spawn in schools in shallow backwaters in spring and summer. Mature after 1-year high number of small eggs.	Smaller fish in littoral habitats.	Open water schools (large masses), lowland rivers and wetlands. Not present in MLR. Identified a single fish in upper Torrens, first record for WMLR.	Water Quality	
	At least 20°C.	At least 28°C. Die on mass under low temperatures. Found in cool waters in upper Torrens.	Linked to turbid waters. Up to 38°C. Considered tolerant. Sensitive to cold water. Uncharacteristically upland habitat below Gumeracha weir, and one off single individual from intense sampling, suggests a very recent arrival via pipeline, possibly not self sustaining in such cool upper reaches.	Flow	
		Larvae found in backwaters and fast flowing anabranches.	Schools in moderately flowing or still waters.	Key Threats	
Research		(1) Spawning behaviour, habitats, (2) Water quality tolerance of adults, eggs and larvae (3) Role within riverine food webs-importance as a food source for cod, callop, cormorants, pelicans etc.			
Research Outcomes		<ul style="list-style-type: none">First record for WMLR identifiedNew translocation into Upper Torrens, probably through Water pipeline.			
Management		<ul style="list-style-type: none">Do well under current management in Murray.Identify translocation pathway and consider modifications to water transfer infrastructure to prevent future translocations by this pathway.Monitor for further translocation and establishment of population in Torrens especially in the calmer waters of the lower Torrens catchment.			

F	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Climbing galaxias (<i>Galaxias brevipinnis</i>)	Pelagic larvae feed at sea or in lakes.		Aquatic & terrestrial invertebrates	Food	Environmental Variables
	Adults migrate to estuaries to spawn, upstream into tributaries in lakes during autumn-winter. Marine (lacustrine) following hatching. Stay at sea for 6 months. No spawning aggregations or ripe adults encountered in near coastal reaches. Running ripe adults found in riffle habitat in the mid Torrens in May, suggests likely spawning location.	Migration upstream from the sea or lakes landlocked populations. Enter stream mouths on rising tides after ~6months during spring. No juveniles observed moving into coastal rivers during survey. Very few juvenile individuals found in mid reaches of Torrens and Onkaparinga sites.	<ul style="list-style-type: none"> Prefer flowing rocky or silt based pools and riffles. Prefer good riparian vegetation and stream canopy. Most abundant in flowing riffles and runs associated with dense, well structured native riparian vegetation communities (redgum, bottlebrush, wattle, tea trees, grasses etc.) in Upper Torrens. Likely to be confined largely to upper tributary streams in the WMLR. 	Habitat	
		Migrating juveniles will avoid high turbidity. (BDWD)	Prefer cooler temperatures. Data deficient. Captured predominantly in cooler upland reaches of the Torrens.	Water Quality	
	Spawn during high flow events in flooded estuaries-tributaries. Eggs laid on banks above limits of regular stream flow.	Connectivity required in spring–summer for larvae and juveniles re-entering freshwater. Can overcome barriers to migration such as weirs, falls etc.	Prefer lower flows when predation is absent. Not found in larger pools that were dominated by redfin perch and trout, despite being present in intervening riffles during flows.	Flow	
	Riparian vegetation removal. Association with riparian vegetation in WMLR supports this hypothesis.	<ul style="list-style-type: none"> Predation and habitat restriction in prime habitats by redfin perch and trout. Barriers to adult and juvenile migration 	<ul style="list-style-type: none"> Predation and habitat restriction in prime habitats by redfin perch and trout. Removal of flowing riffle reaches due to insufficient flow releases. 	Key Threats	
Research	(1) Assessment of local species biology: [(a) Identify distribution in MLR (b) Identify spawning sites, habitat requirements, timing & behaviours for MLR (assess landlocked populations and use of MLR reservoirs for spawning) (c) Assess timing and duration of flows for spawning and recruitment/migration (landlocked and sea-run) (e.g. does diadromy still exist in the MLR)]. (2) Impacts of climate change.				
Research Outcomes	<ul style="list-style-type: none"> Limited distribution in upper reaches of Onkaparinga and Torrens Loss of riffle habitat due to flow restriction Not captured at downstream sites, very few juveniles captured at sites with access to marine habitats, assumed to be predominantly landlocked in WMLR. Very low abundance or absent when trout and redfin perch are present 				
Management	(1) Promote research. (2) Removal of instream barriers/restoration of estuarine linkages. (3) Protection/restoration of instream and riparian habitat. (4) Environmental flows for spawning and migration.				

G	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Common galaxias (<i>Galaxias maculatus</i>)	Feed at sea. Pelagic larvae.	Cease feeding during inland migration. Resume feeding in freshwater after reaching adult habitat	Benthic and drift feeders, insects, crustaceans & molluscs, some surface animals.	Food	Environmental Variables
	Adults move down to estuaries to spawn during autumn. Landlocked populations may use large lakes in a similar manner and move upstream into tributaries to spawn in groups of 2-4. Eggs laid on bank vegetation in estuaries or tributary streams (landlocked).	Larvae will live in marine habitats for 5-6 months before re-migrating to adult habitats as whitebait	Found at lower elevations. Adults are found in streams, rivers and wetlands Can survive in small pools largely bereft of structure (apart from benthic interstices) over summer. Survival to spawning needs to be 1, 2 or 3 years, adults usually die after spawning.	Habitat	
	Eggs tolerate wide range of salinity and temperature.	Migrating juveniles will avoid high turbidity.	Relatively tolerant to wide ranges in salinity, temperature, oxygen & turbidity. Preference for temperatures around 20°C.	Water Quality	
	Connectivity between freshwater and marine habitats is required during spawning period. Larvae carried out to sea/lakes in floodwaters. Reproduction timed with moon phase and tidal patterns. Eggs left on exposed vegetation in first flood/high tide and require a second inundation of bank vegetation. Eggs hatch on re-immersion.	Connectivity between freshwater and marine habitats is required during spring when juveniles migrate upstream. Larvae utilise high flows and associated chemical cues to select rivers for re-entry to freshwater in shoals during high tide in daylight. Juveniles can migrate under high flow velocities and will use fishways and ramps. (Davies <i>et al.</i> 2003)	Adults require refuge pools with reasonable water quality to persist over summer.	Flow	
	No connectivity between marine and freshwater habitats.	No connectivity between marine and freshwater habitats.	Predation in prime habitats, desiccation of refuge riffles.	Key Threats	
Research	(1) Investigate impact of barriers and use of fishways (2) Determine spawning & migration patterns for MLR. (3) General biology such as determined length-age relationships.				
Research Outcomes	<ul style="list-style-type: none">Woodlands Weir on South Para and Torrens Weir barriers to upstream movementDeclining abundance with declining flow and lack of spring connectivity in OnkaparingaRecruitment to lower reaches in springDifficult to quantify contribution of WQ to decline. Fish absent from lower Onkaparinga pool when WQ unsuitable.Fishway at Torrens mouth effective for fish passage but numerous other barriers exist in Torrens for movement to upstream habitat				
Management	(1) Removal of instream barriers/restoration of estuarine linkages and lowland stream habitat. (2) Provision of autumn/spring flows reaching the sea to facilitate spawning and larval recruitment including migration.				

H	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Mountain galaxias (<i>Galaxias olidus</i>)			Aquatic insects, crustaceans, molluscs, worms, spiders.	Food	Environmental Variables
	Adults (1+) may move upstream toward headwaters to spawn in winter-spring but possibly all year round. Eggs are laid around adult habitat beneath rocks. Larvae persist in adult habitats. (Possibly paired mating units??). Male and Female pairs captured in Sth. Para and Onkaparinga during electrofishing.	Juveniles recruited direct to adult habitats. Movement is restricted to small local ranges. Recruitment events observed in Torrens and Onkaparinga around habitats where adults caught in low numbers during the current or previous season. Little recruitment observed outside of areas where adults caught.	Adults survive within small pools and riffles where trout & redfin perch are absent. Found in low numbers in pools with redfin perch and trout, put usually on margins or in runs/riffles. Associated with riparian vegetation and instream habitat, leaf litter, debris, macrophytes and cobbles. Highest abundances in cobbled and rocky streams with reasonable riparian condition. Can persist in larger pools released from predation in ephemeral streams with little structural habitat.	Habitat	
		High quality flowing water was present for all recruitment sites and events.	Can tolerate moderately high and very low temperatures and poor water quality (fatal to trout). Data deficient (e.g. no temperature or oxygen upper limits known). Predominantly good water quality where caught, not found in harsh shrinking pools during drought, possibly due to redfin perch presence..	Water Quality	
	Ripe adults observed during moderate flows.	Recruitment seasonal following winter flows with higher abundances following good spring flows.	Prefer more permanent flowing water or pools with good water quality. Some populations appear to prefer high flow-riffle habitats. Caught almost exclusively in flowing reaches.	Flow	
	Siltation, reduced leaf litter (riparian deforestation), loss of riffle habitats resulting from flow modification.	Predation of recruits to prime habitats such as larger pools. Recruitment not observed in pools where predatory redfin perch and trout were caught.	Habitat restricted by predation. Loss of riffle habitats due to flow regulation. Clearing of riparian vegetation. Predation by trout and redfin perch. Siltation of rocky and cobbled substrates due to erosion or turbid water transfers via Murray pipelines.	Key Threats	
Research		(1) Determine distribution, taxonomic status and genetic uniqueness of different populations. (2) Undertake research on local biology, especially (a) flow relationships for spawning and recruitment and (b) juvenile and adult tolerances. (3) Impacts of climate change. (4) Assess predation impacts.			
Research Outcomes		<ul style="list-style-type: none">Good recruitment every spring at Brooks Road despite low numbers of adults. Good recruitment in 2/3 springs at Clarendon despite no adults capturedRedfin perch a major predator on mountain galaxias in all riversLow flows reduced availability of small pools and riffles where redfin perch and trout are usually absent. Therefore reduced habitat and increased interaction with predators.			
Management		(1) Promote research on biology and environmental relationships (2) Reduce predation impacts in larger streams (3) maintain/enhance habitat values in headwater streams (4) Restoration of lowland stream reaches (i.e. Lower Onkaparinga/tributaries)			

I	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Murray rainbowfish (<i>Melanotaenia fluviatilis</i>)			Aquatic insects, crustaceans, molluscs, worms, spiders.	Food	Environmental Variables
	Eggs laid on macrophytes Oct-Jan.	Recruit successfully to adult habitats associated with lowland reaches and macrophyte beds (emergent and submerged)	Lower Flowing lowland Rivers around macrophyte beds and wetlands. Associated with thick vegetation and habitat complexity. High abundances in Torrens around low flowing, warm reaches around macrophyte beds. Pelagic schooling <30 individuals.	Habitat	
	Aquatic macrophytes. Larvae attach to plants before free swimming.	Larvae found in weir pools, flowing creeks and shallow ponds. Recruitment occurred in turbid water, warm temperatures <28°C and very high salinity.	Prefer clear water, low flow and sunlight. Tolerant of turbid water, warm temperatures <28°C and very high salinity.	Water Quality	
	Warming of shallow floodwaters implicated in spawning initiation. Eggs and fry tolerant of high salinity.	<28°C. Moderately salt tolerant.	Cold water pollution results in fungal and bacterial infections. Avoid murky water.	Flow	
	Low flow.	Consistent recruitment in low-flow warm summer conditions	Not Avoid fast flowing waters. Prefer backwaters, billabongs and wetlands.	Key Threats	
Research	(1) Interactions with other species, native and introduced.				
Research Outcomes	<ul style="list-style-type: none"> Abundant translocated populations present in the Lower Torrens and Breakout Creek in association with other translocated Murray species (freshwater catfish, carp gudgeon). Tolerant of poor WQ in still murky water of lower Torrens and high salinity at estuarine pool on one occasion Consistent recruitment in low-flow warm summer conditions 				
Management	Translocated species in Torrens and should not be considered a conservation priority in the WMLR. Translocation impacts within the MLR. Is Control required?				

J		Life History Stages				
		Reproduction	Recruitment	Adult Survival		
Smallmouthed hardyhead (<i>Atherinosoma microstoma</i>)				Small crustaceans and insects.	Food	Environmental Variables
	Submerged structures and macrophytes.	New recruits found in October.	Mostly estuarine, will inhabit coastal lakes and lagoons. Form large schools. Associated with macrophyte beds (especially <i>Zostera</i>). Life cycle probably only 1 year. Only found in estuarine reaches of Onkaparinga and Torrens	Habitat		
			Supposedly intolerant of freshwater but found in freshwater habitats.	Water Quality		
				Flow		
	Destruction of estuarine habitats (i.e. Murray Estuary).	Destruction of estuarine habitats	Destruction of estuarine habitats (i.e. Murray Estuary). Very limited estuarine habitat in Torrens	Key Threats		
Research		(1) Interactions with other species, native and introduced. (2) The importance or impacts of freshwater flow inputs into the ecology of estuarine species and ecosystems in the WMLR.				
Research Outcomes		(1) Investigate use of and distribution within freshwater habitats. (2) Determine the impact of the loss of estuarine habitat on the species.				
Management		Only found in estuarine pools of Onkaparinga and Torrens. Very limited estuarine habitat in Torrens where most were captured in one survey in autumn 2008. Estuarine and freshwater linkages may be critical to sustaining these and other estuarine species.				

K	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Congolli (<i>Pseudaphritis urvili</i>)			Juvenile galaxias and shrimp.	Food	Environmental Variables
	Females reproduce ~ 4-6 years old. Spawning takes place around estuaries-marine habitats in August-October (although observed spawning in May in the Onkaparinga 2006). Males present around estuary and lower stream reaches. <ul style="list-style-type: none">In some seasons, ripe males and females both caught in freshwater habitats in spawning condition in lower Onkaparinga.Disappear from Torrens estuary following high flows with subsequent recruitment of juveniles and return of adults.	<ul style="list-style-type: none">Juveniles remain around tidal zone for 9-12 months and gradual move upstream in spring-summer.Recruitment observed through the Torrens fishway into freshwater habitats of Breakout creek.No recruitment observed for translocated populations (above woodlands weir with no upstream access to the sea) in the South Para River. Landlocked populations therefore not viable.	Prefer slower flowing waters with general habitat preferences. Male-female habitat separation. Males remain around estuaries with females utilising lowland freshwater habitats (decreasing upstream).	Habitat	
	Tolerant of salt and fresh water	Tolerant of salt and fresh water. Found under both conditions in lower Onkaparinga and Torrens.	Tolerant of salt and fresh water, utilise low water quality habitats. Collapse of water quality in lower Onkaparinga following marine incursion and hypoxia resulted in loss of congolli and large fish kill.	Water Quality	
	High flow induces downstream migration of females to estuaries in April-July. Males move into estuarine fringes away from freshwater flow influence.	Low flows stimulate upstream migration of juveniles.	Prefer slower flows, limited ability for dealing with high velocity flows.	Flow	
	Removal of connectivity between freshwater and estuarine habitats. Recruitment observed following higher flows. Flows essential for breeding, reconnecting males with females.	Loss of connectivity between freshwater and estuarine habitats.	Desiccation of lowland freshwater reaches will remove females.	Key Threats	
Research	(1) Research on biology – identify spawning behaviour/biology, migration, habitat requirements and flow requirements in MLR (2) Identify population structure and habitat use for males versus females (3) Assess their use of fishways and swimming ability.				
Research Outcomes	<ul style="list-style-type: none">Consistent recruitment of juveniles in spring at downstream sites in Onkaparinga and Torrens, but not at all in South Para. Barriers to juvenile movement upstream or females not moving downstream to spawn.Lowest Onkaparinga site has become more marine over time and resulted in more juveniles captured therePoor WQ at Onkaparinga pool 3 has little effect on Congolli except for the large fish kill event which removed all fish following hypoxic marine incursion event.				
Management	(1) Removal of instream barriers/restoration of estuarine linkages. (2) Restoration of lowland stream reaches (i.e. Lower Torrens/Break Out Creek).				

L	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Carp gudgeon (<i>Hypseleotris</i> spp.)			Zooplankton, insect larvae, especially chironomids.	Food	Environmental Variables
	Deposit eggs on aquatic vegetation and twigs during summer in littoral areas, backwaters, wetlands and billabongs. Male builds and guards nest.	Found in low flow habitats. Some migration upstream occurs in rivers and anabranches after moderate inundation of floodplain.	Highly abundant in lakes, backwaters, anabranches, billabongs and rivers especially where physical structure and aquatic macrophytes are present/abundant. Present in high abundance in lower Torrens observed to be washed into estuary during high flows and to return to freshwater using fishway.	Habitat	
	Spawn above 21°C. Eggs vulnerable to low oxygen.		Tolerant of low oxygen, moderately high temperature and salinity.	Water Quality	
	Utilise low flow areas.	Upstream migration in response to flows. Upstream migration of juveniles recorded from estuary via fishway. Regular recruitment to adult habitat in lowland reaches of the Torrens.	Prefers low flow habitats but present also in higher flow areas.	Flow	
	Loss of floodplain habitats and macrophytes.	Loss of floodplain habitats and macrophytes.	Loss of floodplain habitats and macrophytes. Introduced predators i.e. redfin perch. Translocated populations not a priority in the WMLR.	Key Threats	
Research	(1) Taxonomic resolution providing targeted ecological studies, (2) Trophic importance, role as food source for larger native fish. (3) Impact of introduced predators especially redfin perch.				
Research Outcomes	<ul style="list-style-type: none"> Abundant translocated population in Breakout Creek and Lower Torrens linked to other Murray translocations. Increased abundance as flow decreased in lower Torrens catchment Not present in higher flow areas or in pools where redfin perch/trout are present. 				
Management	(1) Environmental flows and habitat protection in EMLR streams. (2) Assess the impact of translocated populations into the MLR				

M	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Flathead gudgeon (<i>Philypnodon grandiceps</i>)	Egg clusters attached to structure and guarded/fanned by males.	Larvae are facultative drifters recruiting direct to adult (low flow) habitats.	Adults are predominantly benthic and widely distributed in slower flowing pools, runs, estuaries and wetlands. Emerge from cover (rocks/vegetation) after dark.	Food	Environmental Variables
		Recruitment occurred throughout most of the year in the Torrens	May be favoured by habitat degradation, but habitat complexity important.	Habitat	
		Some recruitment variability at large scales, may not recruit well in high flows.	<ul style="list-style-type: none"> Prefers low flow habitats. Will persist in low water quality habitats Tolerant of high temp & salinity and low O2 	Water Quality	
	Predation by redfin perch, competition & predation with gambusia.	<ul style="list-style-type: none"> Predation by redfin perch, competition & predation with gambusia. Predation by redfin perch found to be ameliorated by poor water quality impacts on redfin perch and trout and relatively intolerance to seasonal harshness. Alternative food items such as yabbies, bugs and shrimp also relieve predation pressure, at least in the South Para (Wilson et al. 2008). 	<ul style="list-style-type: none"> Predation by redfin perch, desiccation of refuge pools or removal of refuge habitats. May be favoured by river regulation and resultant stability. 	Flow	
	Egg clusters attached to structure and guarded/fanned by males.	Larvae are facultative drifters recruiting direct to adult (low flow) habitats. Post-Larvae observed floating around banks through rock and tree root habitat in the South Para.	Adults are predominantly benthic and widely distributed in slower flowing pools, runs, estuaries and wetlands. Emerge from cover (rocks/vegetation) after dark. Appear tolerant of impacts of river regulation and habitat degradation. Abundances appear higher than suggested historically (Scott 1962).	Key Threats	
Research	(1) Assess general biology, habitat use, spawning and feeding ecology (2) Investigate impact of predation				
Research Outcomes	<ul style="list-style-type: none"> Common and abundant throughout the WMLR regardless of habitat or flow conditions. Abundance directly impacted by redfin perch juveniles, but not as much by larger adult redfin perch Seem to be able to recruit at any time of year Tolerant of higher salinity in estuarine pool in Onkaparinga 				
Management	(1) Reduce impact of predation (2) Restoration of stream habitats				

N	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Dwarf flathead gudgeon (<i>Philypnodon macrostomus</i>)				Food	Environmental Variables
			Pools or low flow areas in streams and wetlands. Often found near emergent macrophytes on mud, silt or rocky substrates.	Habitat	
			Utilise similar habitats to the highly tolerant <i>P. grandiceps</i> .	Water Quality	
		Abundance in Onkaparinga peaked following the high flow season of Spring 2005 with high abundance, reducing over consecutive years of drought.	Seem to prefer lower flow habitats such as pools.	Flow	
	Predation by redfin perch, competition & predation with gambusia	Predation by redfin perch, competition & predation with gambusia	Predation by redfin perch, desiccation of refuge pools or removal of refuge habitats.	Key Threats	
Research	(1) Assess the endemnicity of this species to MLR (i.e. possibly translocation via Murray pipeline) (2) Assess general biology, habitat use, spawning and feeding ecology				
Research Outcomes	<ul style="list-style-type: none"> Only found in Torrens and Onkaparinga Similar habitats to <i>P. grandiceps</i>, but only found in upper catchment of Torrens and more prevalent in upstream sites of Onkaparinga. These pattern support possible translocation through Murray water pipelines that empty into those river channels upstream of both sites. Tolerant of higher salinity in estuarine pool in Onkaparinga except for extreme salinity and poor WQ in Autumn 2008. 				
Management	(1) Restoration of stream habitats (2) Reduce translocation potential from inter-basin pipelines.				

O	Life History Stages				
	Reproduction	Recruitment	Adult Survival		
Western blue spot goby (<i>Pseudogobius olorum</i>)				Food	Environmental Variables
	Spawns in upper reaches of estuary in brackish water. Spawn in early-late spring laying eggs beneath solid structure, male guards nest.		Estuaries and coastal lakes and wetlands, associated with abundant macrophytes. Occurs inland in the North Para system. Benthic on muddy or rocky substrates. Also present in the freshwater reaches of the Lower Torrens at Breakout creek and the Onkaparinga near Old Noarlunga. Possible recolonisation following Torrens fishway.	Habitat	
			Can tolerate fresh and saline water. Broad salinity tolerance (1.8-50 mS), appear to prefer saline reaches in the Onkaparinga.	Water Quality	
	Adults aggregate in estuary in response to flow			Flow	
			Reduced quality of estuarine areas. Loss of permanent pool habitats in North Para (e.g. decline in the condition and pool permanency of Walker Creek)	Key Threats	
Research	(1) General biology and life history, abundance and distribution				
Research Outcomes	<ul style="list-style-type: none"> Low numbers captured consistently in lowest of the Onkaparinga sites near estuary Broad salinity tolerance (1.8-50 mS) Large numbers captured once at Torrens mouth in spring 2006, 2 weeks after a small flushing flow. 				
Management	(1) Protect inland habitat in North Para Catchment, (2) Maintain connectivity between lower Torrens/Onkaparinga and marine habitats – restore estuary for Torrens River.				

P	Life History Stages			Environmental Variables
	Reproduction	Recruitment	Adult Survival	
Lagoon goby (<i>Tasmanogobius lasti</i>)				
	Spawns in estuaries, probably beneath structures.		Estuaries and coastal lakes and wetlands, benthic on sandy or rocky substrates.	
Research	(1) General biology and life history, abundance and distribution (2) Assesses and determine presence in WMLR (e.g. confirm unverified records from Patawalonga Creek)			
Research Outcomes	<ul style="list-style-type: none"> Not captured at survey sites. 			
Management	Restore and protect estuarine habitat			

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7.APPENDIX 1 – RAW ABUNDANCE CHART

River	Site	Season	<i>Acanthopagrus butcheri</i>	<i>Afurcagobias tamarensis</i>	<i>Aldrichetta forsteri</i>	<i>Anguilla australis</i>	<i>Arenigobius bifrenatus</i>	<i>Aripis truttaceus</i>	<i>Atherinosoma microstoma</i>	<i>Carassius auratus</i>	<i>Cyprinus carpio</i>	<i>Engraulis australis</i>	<i>Galaxias brevipinnis</i>	<i>Galaxias maculatus</i>	<i>Galaxias olidus</i>	<i>Gambusia holbrooki</i>	<i>Gobiidae</i> spp	<i>Hypseleotris vittatus</i>	<i>Hyperlophus argentea</i>	<i>Melanotaenia fluviatilis</i>	<i>Mordacia mordax</i>	<i>Nematolosa erebi</i>	<i>Oncorhynchus mykiss</i>	<i>Perca fluviatilis</i>	<i>Phyllipnodon grandiceps</i>	<i>Phyllipnodon macrostomus</i>	<i>Pseudogobias olorum</i>	<i>Pseudaphritis urvillii</i>	<i>Salmo trutta</i>	<i>Sillaginodes punctatus</i>	<i>Sillago schomburgkii</i>	<i>Tandanus tandanus</i>	<i>Tetractenos glaber</i>	<i>Tinca tinca</i>		
South Para	Para Wirra	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	270	0	0	0	0	0	0	0	0	0		
		Spring 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	724	0	0	0	0	0	0	0	0	0		
		Autumn 2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	104	0	0	0	0	0	0	0	0	0		
		Spring 2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	765	0	0	0	0	0	0	0	0	0	
		Autumn 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	2	0	0	0	0	0	0	0	0	0	
		Spring 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	24	0	0	0	0	0	0	0	0	0	
	S.P. Weir	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	165	124	0	0	0	0	0	0	0	0	0	0	
		Spring 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64	173	0	0	0	0	0	0	0	0	0	0	
	Nolans	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	4	205	0	0	0	0	0	0	0	0	3	211	0	0	0	0	0	0	0	0	0	0
		Spring 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	2154	0	0	0	0	0	0	0	0	56	341	0	0	0	0	0	0	0	0	0	0
		Autumn 2007	0	0	0	0	0	0	0	0	0	0	0	2	0	84	0	0	0	0	0	0	0	0	1	169	0	0	0	0	0	0	0	0	0	0
		Spring 2007	0	0	0	0	0	0	0	0	0	0	0	0	0	5542	0	0	0	0	0	0	0	0	56	372	0	0	0	0	0	0	0	0	0	0
		Autumn 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	10	2	0	0	0	0	0	0	0	0	0	
		Spring 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	590	0	0	0	0	0	0	0	0	30	49	0	0	0	0	0	0	0	0	0	0
	Woodlands Weir	Autumn 2007	0	0	0	0	0	0	0	0	0	0	0	53	0	178	0	0	0	0	0	0	0	0	0	957	0	0	7	0	0	0	0	0	0	0
		Spring 2007	0	0	0	0	0	0	0	0	10	15	0	7	0	541	0	0	0	0	0	0	0	0	0	892	0	0	5	0	0	0	0	0	0	1
		Autumn 2008	0	0	0	0	0	0	0	0	0	0	0	2	0	1721	0	0	0	0	0	0	0	0	0	1810	0	0	0	0	0	0	0	0	0	0
		Spring 2008	0	0	0	0	0	0	0	0	3	0	0	0	1	0	513	0	0	0	0	0	0	0	0	644	0	0	1	0	0	0	0	0	0	0
Torrens	Cudlee Creek	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	55	89	4	0	0	0	0	0	0	0	0		
		Autumn 2007	0	0	0	0	0	0	0	0	0	5	0	12	0	1	67	0	0	0	0	0	0	0	2	42	9	0	0	0	0	0	0	0	0	
		Spring 2007	0	0	0	0	0	0	0	0	0	1	0	4	0	0	4	0	0	0	0	0	0	0	6	1	1	0	0	0	0	0	0	0	0	
		Autumn 2008	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2027	0	0	0	0	0	0	0	9	16	28	0	0	0	0	0	0	0	0	
	Spring 2008	0	0	0	0	0	0	0	0	0	7	0	6	0	6	21	0	0	0	0	0	0	0	7	13	3	0	0	0	0	0	0	0	0	0	
	Gumeracha Weir	Autumn 2006	0	0	0	0	0	0	0	0	0	2	0	0	1	10	0	0	0	0	0	0	0	0	10	128	0	0	0	18	0	0	0	0	0	0
		Spring 2006	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	15	323	0	0	0	11	0	0	0	0	0	
		Autumn 2007	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	164	112	0	0	0	9	0	0	0	0	0	
		Spring 2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	29	28	0	0	1	2	0	0	0	0	0	
		Autumn 2008	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	12	405	1	0	0	2	0	0	0	0	0	
		Spring 2008	0	0	0	0	0	0	0	0	0	4	0	0	0	2	17	0	0	0	0	0	0	0	8	19	2	0	0	0	0	0	0	0	0	0
	Gorge Weir	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	83	0	0	0	0	0	0	0	16	3155	55	0	0	0	0	0	0	0	0	0
		Autumn 2007	0	0	0	0	0	0	0	0	0	0	0	0	0	3	37	0	0	0	0	0	0	0	10	8	1	0	0	0	0	0	0	0	0	
		Spring 2007	0	0	0	0	0	0	0	0	0	1	0	1	0	4	7	0	0	0	0	0	0	0	28	5	1	0	0	0	0	0	0	0	0	0
		Autumn 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	4	483	0	0	0	0	0	1	0	39	436	0	0	0	0	0	0	0	0	0	0
	Spring 2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	145	0	0	0	12	0	0	0	0	0	0	
	Silke's Road	Autumn 2006	0	0	0	0	0	0	0	0	0	0	0	0	0	3	262	0	25	0	0	0	0	0	0	401	0	0	0	0	0	0	0	0	0	0
		Spring 2006	0	0	0	0	0	0	0	0	0	0	0	1	0	10	102	0	18	0	0	0	0	0	0	277	0	0	0	0	0	0	0	0	0	0
Autumn 2007		0	0	0	0	0	0	0	0	13	0	0	0	0	1	2548	0	30	0	0	0	0	0	0	818	0	0	0	0	0	0	0	0	0	0	
Spring 2007		0	0	0	0	0	0	0	0	1	2	0	0	3	0	413	0	25	0</																	