# Coastal Fishes and Flows in the Onkaparinga and Myponga Rivers

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**October 2009**

SARDI Publication No. F2009/000410-1
SARDI Research Report Series No. 400

Report to the Adelaide & Mount Lofty Ranges Natural Resource Management Board
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Government of South Australia
Department of Water, Land and Biodiversity Conservation

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Government of South Australia
Adelaide & Mount Lofty Ranges Natural Resources Management Board

This Publication may be cited as:

McNeil, D.G., Fredberg, J. and Wilson, P.J. (2009). Coastal Fishes and Flows in the Onkaparinga and Myponga Rivers. Report to the Adelaide and Mount Lofty Ranges Natural Resource Management Board. South Australian Research and Development Institute, Aquatic Sciences. SARDI Publication No. F2009/000410-1. 76pp.

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Printed in Adelaide: October 2009

SARDI Publication No. F2009/000410-1
SARDI Research Report Series No. 400

ISBN: 978-1-921563-21-8

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Signed:

Date: 16 October 2009

Distribution: Adelaide and Mount Lofty Ranges NRM Board, SARDI Aquatic Sciences Library

Circulation: Public Domain

# TABLE OF CONTENTS

## Executive Summary

This study was developed as part of the Mount Lofty Ranges Environmental Water Provisions Trial (EWP), lead by the Department of Water, Land and Biodiversity Conservation (DWLBC) and the Adelaide and Mount Lofty Ranges Natural Resource Management Board. This study is one of a cluster of ecological projects commissioned under the EWP to provide knowledge and baseline data regarding the environmental flow requirements of riverine ecosystems in the Western Mount Lofty Ranges. Specifically, the scope of this study was to assess the status of coastal riverine fish populations on the Adelaide coast, and to identify their ecological requirements, particularly as they pertain to connectivity between marine, estuarine and freshwater linkages. Also, the project aimed to identify specific freshwater flow requirements of native fishes that may be critical to maintaining viable populations of native fishes within coastal riverine habitats in the future. A secondary aim was to collect baseline data prior to the delivery of environmental flow provisions to enable the assessment of ecological responses of native fish following the delivery of environmental flows.

The project assessed the coastal fish community structure in the Onkaparinga River, where environmental water provisions are planned, and the Myponga River where no environmental flows are currently planned. The two catchment approach enabled a baseline assessment of fish populations that may provide an indication of trajectories of change once flow provisions are delivered. Potential outcomes of environmental flows that cause changes in the Onkaparinga River may not be reflected in the Myponga River, which will continue to operate under the status quo. Therefore, these catchments may be used in the longer term to assess the outcomes of planed environmental flows. This study therefore represents 'before' data that can be used to determine the effectiveness of environmental flows in restoring coastal freshwater and estuarine ecosystems.

The fish community in coastal reaches of both rivers were surveyed over a three year period to ascertain the composition of the fish community and to identify life history and ecological requirements of these species, in particular those that relate to freshwater river flows and the linkages between riverine and marine environments. The study found that some fish populations that rely heavily on freshwater flows and riverine/marine linkages have already been lost from these rivers, particularly those that require access to upper catchment habitats. The remaining fish community was found to have a high level of dependence on freshwater flows to carry out essential life history strategies and biological functions.

Many of the fish species require freshwater flows to commence in autumn and continue until at least late spring to support spawning, recruitment and migrational requirements. Under regulated conditions, these flows must be provided through the intentional provision of environmental flow events. Flow volumes during existing flow seasons should also be maximised to support spawning and recruitment of estuarine fish communities. Importantly, flow provisions are required to reduce the period of zero flow, particularly during long hot summers and periods of drought. The study has

revealed that hypersaline conditions that develop within estuaries in the absence of spring and autumn flows may directly cause large fish kills and again, intentional allocation and provision of environmental water is required to prevent deteriorations in water quality resulting from extended periods of no flow. This function should be accounted for by ensuring that flow seasons are extended into late spring and early summer and that appropriate volumes of flow are provided to flush out estuarine systems and alleviate building levels of lethal water quality parameters.

## Acknowledgments

This work was carried out with extensive field support from Matt Pellizzari, Mike Guderian, Simon Westergaard and Rod Ward (SARDI), and Emma Cannon and Cole O'Brien also provided assistance in the field. Peter 'Pedro' Schulz oversaw the project for the AMLRNRMB and for the long lost Environmental Flows Steering Committee. The Myponga site was sampled with the tremendous support and assistance of Jim and Linda Stacey at Myponga Beach who provided much background information as well as access to their property and assistance with processing the catch. We still don't believe that Galaxiids were popping out of your lawn sprinklers, but we will go along with it in light of a lack of evidence to the contrary. The MLR Waterwatch (now NRM Education) team: Jeremy Gramp, Matt Cattanach, Mark Nichols, Malinda Roberts, Claire Butler and Alisia Brooks also provided tremendous support helping out with field collection and ID and great company. Special thanks to Jeremy Gramp for providing accommodation at the Myponga beach house and for letting Dale win trivial pursuit. All work conducted in the Onkaparinga recreational park was covered under DEH Permit No. Y25128-4.

# 1. Introduction

The coastal rivers of the Adelaide region drain the catchments of the Western Mount Lofty Ranges (WMLR), historically discharging freshwater flows into Gulf St. Vincent through large estuarine and coastal wetland systems (Holmes and Iversen 1976). These systems provided largely perennial connectivity between rivers and their associated wetlands and tributary streams and the brackish and marine ecosystems around the gulf coast (Hicks and Hammer 2004).

Accordingly, a number of local native fish species have evolved within these systems and exhibit critical life history traits, requiring movement between marine, estuarine and freshwater habitats (McNeil and Hammer 2007). For example, common (*Galaxias maculatus*) and climbing (*Galaxias brevipinnis*) galaxiids typically display a diadromous (catadromous) life history whereby newly hatched larvae, from eggs deposited in the lower reaches of rivers, are washed into the sea during winter and spring flows (McDowall 1976, Koehn and O'Connor 1998). Larvae develop in the marine environment (McDowall *et al* 1975) before returning *en mass* as 'whitebait' (juveniles) to recolonise the freshwater rivers and streams of the Western Mount Lofty Ranges during spring. Further growth and adult residence occurs in freshwater habitats, before downstream spawning migrations to coastal areas in winter and spring, completing the catadromous life cycle. Both pouched (*Geotria australis*) and short-headed lamprey (M*ordacia morax*) exhibit the opposite form of diadromy known as anadromy. This includes a parasitic marine adult life stage with upstream spawning migrations into the freshwater reaches of rivers (Potter 1970). Juvenile lampreys (ammocetes) develop in freshwater rivers and stream sediments before metamorphosing and migrating into Gulf St Vincent as adults.

A range of other fishes do not undertake such lengthy migrations but move between coastal freshwater environments into estuarine and marine environments at more local scales. Congolli (*Pseudaphritis urvillii*) lived within coastal habitats where large females lived in freshwater swamps and rivers, moving each year into estuaries and near coastal reaches to spawn with smaller males that live within brackish or marine habitats (Piddington 1964, Hortle 1978, Koehn and O'Connor 1990).

A range of estuarine species such as black bream (*Acanthapagrus butcheri*), flat-tailed mullet (*Liza argentia*), yellow-eye mullet (*Aldrichetta forsteri*) and blue spot goby (*Pseudogobius olorum*) are known to move into freshwater coastal systems from time to time and may take advantage of food and habitat resources and use freshwater as a tonic for cleansing away marine parasites that are intolerant of the low salt conditions (McNeil *et. al.* 2009a). In short, the Adelaide coast supports a dynamic array of native fishes, many of which make obligate or facultative movements between marine and freshwater reaches.

During European settlement, the harnessing of water resources to support agricultural, industrial and urban development resulted in highly modified riverine systems in the Western Mount Lofty Ranges and Adelaide Coast. The construction of weirs and large reservoirs dammed huge volumes of water and began the process of drying up coastal wetland and river systems as less and less freshwater flows reached the coast. Furthermore, the constructed weirs and dam walls prevented the movement of fish between the hills and coast and between lowland rivers and the sea (Hicks and Hammer 2004, McNeil *et al*. 2009b). Additionally, the growth of Adelaide led to the reclamation of coastal wetland systems to meet urban needs. These factors largely lead to the loss of these coastal diadromous fishes from rivers such as the Torrens (Hicks and Hammer 2004, Gray *et al*. 2005), although the recent construction of a fish ladder at Breakout creek within this river system, has seen the return of diadromous species such as the common and climbing galaxias and congolli. (McNeil *et al*. 2009b).

Other coastal catchments in the WMLR have retained marine and freshwater linkages to a varying degree. The Onkaparinga River for example is highly regulated, but diadromous fish have the ability to move from the sea through the Onkaparinga Gorge to Clarendon where the Clarendon Weir blocks further upstream passage. In the Onkaparinga, some diadromous fish species such as common galaxias and congolli have persisted, although others such as the lampreys appear to have become locally extinct (SKM 2002, McNeil *et al*. 2009a). Other species, such as climbing galaxias have been found in such low numbers that they are likely to be highly threatened within the lower catchment (McNeil *et al*. 2009a). The Myponga River has been similarly regulated with water storage between the township of Myponga and the coast which prevents the vast majority of freshwater flows from reaching the coast. Spring fed baseflow and local catchment runoff however, maintains freshwater habitats downstream of the weir and the stream flows into the estuary at Myponga Beach after flowing through a short gorge section. In both catchments, freshwater and estuarine connectivity is maintained even though the catchments have been widely modified and flows severely regulated, with catchment flows only reaching the coast under high flow or flood events following significant rainfalls.

The lack of coastal freshwater flows was recently recognised as a management priority (Pikusa and Bald 2005), particularly following reduced catchment flows within the 'millennium drought' which began in 1997 and continues through 2009 (Bond *et al*. 2008, Lake *et al*. 2008). Since this time, varying degrees of effort have been made to develop and plan for environmental flow releases across Mount Lofty Range catchments (Lloyd 2000, Lloyd 2001). In the Onkaparinga, there has been significant investment into determining the environmental water requirements of the catchment (SKM 2003) and identifying associated water and catchment management issues (Gatti *et al*. 2005). In 2005, the South Australian Minister for Environment and Conservation prescribed all watercourses in the WMLR, including catchments, surface and ground-waters as well as water supply reservoirs.

In response to this, an Environmental Water plan was developed by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC), the Adelaide and Mount Lofty Ranges Natural Resource Management Board (AMLRNRMB) and SA Water and the SA Murray-Darling Natural Resource Management Board to account for environmental water requirements as part of prescription (Pikusa and Bald 2006). The resulting Environmental Water Provisions (EWP) trial aimed to provide environmental water allocations to key reaches of the Torrens, Onkaparinga and South Para Rivers, with the explicit aim of sustaining freshwater and estuarine ecosystems and preventing the desiccation of freshwater habitats and loss of native aquatic biota. A key outcome of providing an EWP to these systems, is the improved connection between freshwater and estuarine reaches, allowing the movement and spawning of a greater diversity of fish and other aquatic life (Bald and Scholz 2007).

Whilst significant research has been undertaken to elucidate the linkages between river flows and ecological outcomes and to provide flow recommendations for the delivery of environmental flows, this has largely focussed on inland rivers of the Murray Darling Basin (Lloyd *et al.* 2002, CRCFE 2003, King *et al.* 2003, King *et al.* 2004), with limited applicability to the coastal ecosystems of the WMLR and Adelaide coast. A further complication is the lack of detailed ecological and biological knowledge regarding the native fish of these river reaches, where even species presence and absence patterns are poorly understood (SKM 2002, Hammer 2006, McNeil and Hammer 2007). What little inventory work that has been conducted, suggests key populations of diadromous fish species still persist within Adelaide's coastal streams (Hammer 2005), although they may have persisted within small land-locked populations and have lost the ability to migrate to the sea. In the lower Onkaparinga, limited sampling of the fish assemblage was undertaken as part of the process for determining environmental flow requirements for the reach (SKM 2002). This survey sampled three sites in the freshwater reach of the river and two in the mid estuary section. This provided some information about the fish species that were likely to be impacted by flows in the reach, but was limited in scope and detail and provided species assemblage data that is likely to be erroneous (McNeil and Hammer 2007). A more detailed review of the fishes of the Onkaparinga estuary was subsequently compiled from a range of historical records (Hammer 2006).

Recognising this knowledge gap, the EWP steering committee developed further studies to inform the project as to the baseline ecological condition of these river reaches and to ascertain the environmental outcomes that would be achieved through the delivery of environmental flows. If possible, explicit ecological targets were to be identified so that the delivery of environmental flows could be tailored to meet specific freshwater ecosystem requirements or provide water to meet the biological and life history requirements of freshwater biota, including native fish. To this end, ecological research projects were commissioned to provide baseline knowledge regarding the sustainability of freshwater fishes in the WMLR and to elucidate the likely responses of aquatic biota, including fish, to environmental flows. The collection of baseline ecological data from those reaches, verified that there was significant populations of native fishes present within those reaches and that current freshwater flow regimes were likely to be insufficient to sustain these populations in the long term (McNeil *et al.* 2009a). In addition, the collation of biological information pertaining to the native fish of the MLR revealed that many of these fish species were likely to have very specific flow requirements that are necessary to sustain viable populations within those reaches (McNeil and Hammer 2007). A particular aspect of these flow requirements was that diadromous fish species and those that persist within and near coastal freshwater and estuarine reaches, were highly dependent on freshwater flows reaching the sea to carry out essential life history functions such as spawning, recruitment and migration. In combination, ecological sampling under the fish sustainability project and attempts to create ecological response models that capture the flow requirements of key fish species, (under the e-water Cooperative Research Centre), revealed that observed declines in the distribution and abundance of key native fish species in the Onkaparinga River were likely to be the result of insufficient volumes and duration of river flows in that reach (Mackay *et al.* 2008, McNeil *et al.* 2009a).

The current project was therefore developed to investigate the ecology of native fish in near coastal freshwater and upper estuarine habitats in the lower Onkaparinga River and to assess the nature of freshwater/estuarine linkages; in particular, the responses of coastal native fishes to freshwater flow events. This information would address a key knowledge gap as well as collecting baseline flow response data that can be used to inform the delivery of appropriate environmental water provisions and to provide 'before' data that can be later utilised in assessing the outcomes of environmental flows. With this last point in mind, it was decided to include a 'control' site that is not targeted for environmental water provisions. By assessing the baseline condition of both sites together, it may provide additional information regarding any deviation in condition of the Onkaparinga River from the baseline once environmental flow trials begin. The Myponga River was selected as a control due to its proximity to the Onkaparinga, similarity in the nature of regulation and the presence of significant estuarine habitat with freshwater connectivity.

The specific aims of the project were:

A: To assess the native fish community of lower Onkaparinga and Myponga Rivers, with particular focus on fishes that are dependent on freshwater and estuarine linkages.

B: To determine the distribution of these species in the lower Onkaparinga and Myponga Rivers and their utilisation of freshwater and estuarine habitats as well as their dependence on freshwater/marine linkages.

C: To determine the ecology of these species regarding spawning, migrational and habitat requirements in these catchments.

D: To determine the relationship between critical life history characteristics and freshwater flows in coastal habitats.

E: To provide guidance and supporting baseline data for the provision of environmental flow allocations to coastal waterways in the WMLR and Adelaide coast.

# 2. Methods

## 2.1 Site Locations

Sampling was conducted within the lower Onkaparinga and Myponga River catchments, which drain areas of the WMLR and discharge into the Gulf of St. Vincent (Figure 1). These sites represent two of the largest estuary systems on the Adelaide coast, although the Onkaparinga Estuary is much larger and more extensive than the Myponga estuary, which is consistent with the overall area of the catchment. As a result of regulation, large water storages have been constructed within the main river channel of the Onkaparinga River at Clarendon (with a larger barrier further upstream at the Mount Bold Reservoir) (Figure 2) and Myponga Reservoir in the Myponga catchment (Figure 3). During the course of the study, neither of these weirs was breached, restricting study reaches to the coastal reaches downstream of these reservoirs. Even when breached, both reservoirs represent a complete barrier to upstream fish passage and therefore represent the absolute upstream limit of diadromous fish migration, excluding the possibility of climbing behaviours possessed by species such as the climbing galaxias (*Galaxias brevipinnis*). As a result, the fish communities downstream of these weirs represent coastal fish communities with distinct coastal fish components not found above these barriers.


Figure 1. Approximate location of field study catchments on the Adelaide coast in South Australia.

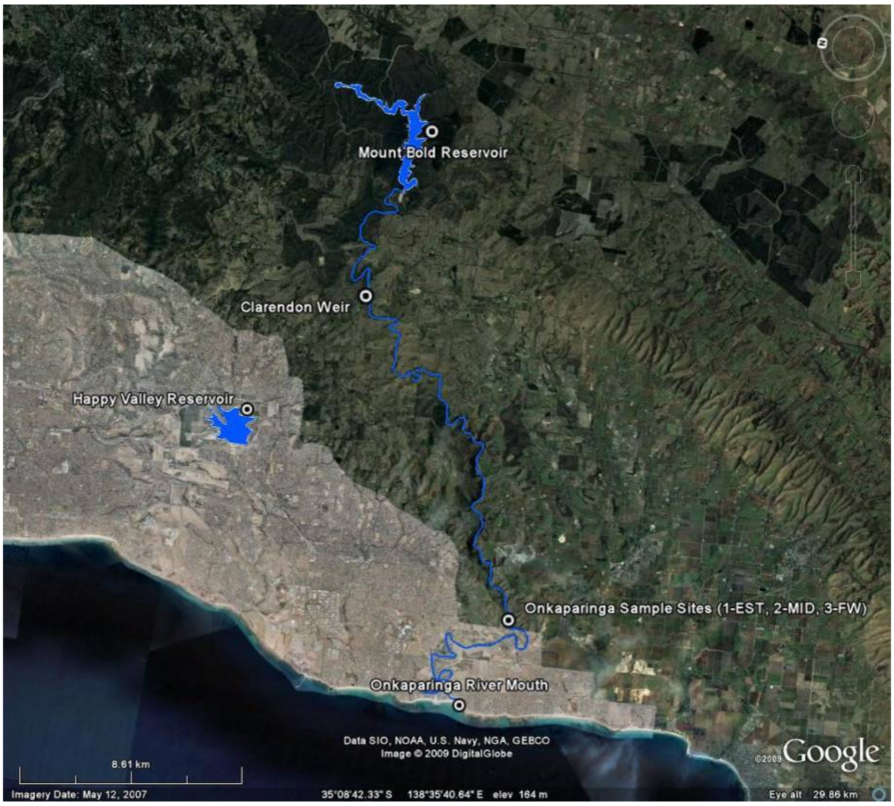



Figure 2. The Lower Onkaparinga Catchment area, located approximately 25 km to the south-east of Adelaide.

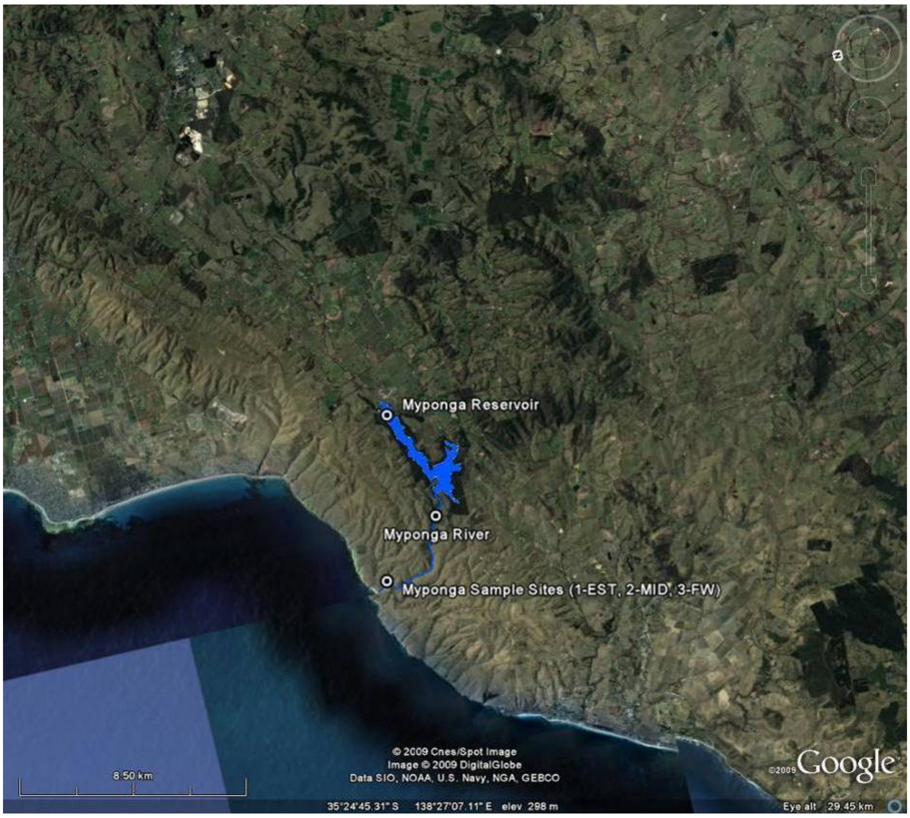



Figure 3. The lower Myponga Catchment area, located approximately 70km south of Adelaide on the Fleurieu peninsula.

### 2.1.2 The Onkaparinga Catchment

The Onkaparinga Catchment covers an area of 560 km² and is located approximately 25 km to the south-east of Adelaide and is controlled by the Mount Bold Reservoir and Clarendon Weir (Figure 4). The upper catchment receives significant additional inputs of flow piped in from the Murray River to supplement Adelaide's water supply (Pikusa and Bald 2005). Clarendon Weir is a diversion point whereby water is diverted to the Happy Valley Reservoir to be made available as SA Water supplies to Adelaide and Onkaparinga Catchment urban areas. Clarendon Weir spills in only 20% of years and water is rarely released directly into the lower reaches of the Onkaparinga River main channel (Kawalec and Roberts 2005). The Bakers Gully (Kangarilla Creek) catchment is the only unregulated catchment in this section (Kawalec and Roberts 2005). Low flows from the Scott Creek, Angels Gully and Upper Onkaparinga catchments are no longer available to the Onkaparinga Gorge due to the construction of the Clarendon Weir (Kawalec and Roberts 2005). The lower section of the Onkaparinga River is dominated by the Onkaparinga Gorge, with the majority of its length in national park and therefore largely inaccessible. At the Old Noarlunga Township the river becomes estuarine for several km before entering the Gulf St Vincent at Port Noarlunga.


Figure 4. a) Clarendon Weir release point upstream of the study site and b) the estuary at Old Noarlunga.

### 2.1.2 Myponga Catchment

Myponga Catchment is situated approximately 70km south of Adelaide on the Fleurieu Peninsula. The catchment is used for grazing, dairying, market gardening, forestry and urban development as well as water harvesting, and as a consequence of all these activities, the quality of its watercourses has declined post European settlement (Thomas *et al.* 1999; Brookes *et al.* 2005). It is highly managed to supply water for the inhabitants of the Southern Fleurieu Peninsula and is principally controlled by the Myponga Reservoir at the downstream section of the catchment, below which no significant tributary inputs occur (Lewis *et al.* 2004). The reservoir has a storage capacity of 26,800 ML at a full supply level (Thomas *et al.* 1999, Lewis *et al.* 2002). Downstream of the reservoir, the river passes through a relatively short steep gorge section with bedrock substrate before opening into a very short alluvial floodplain (1-2km). The river estuary extends for a further 2 km before entering the Gulf St. Vincent at Myponga Beach.


Figure 5. a) Myponga Reservoir spillway upstream of the study reach and b) Estuary at Myponga Beach.

## 2.2 Sampling Protocols

Within each catchment, three sites were selected around the freshwater/estuarine junction: site 1 was situated within the estuary proper (EST), site 2 at the interface of the freshwater and estuarine influence (MID), and site 3 upstream in true freshwater reaches beyond tidal or marine influence (FW). This design allowed the capture of fish within the estuarine and freshwater reaches of these rivers but also provided a focus on the movement of fish between estuarine and freshwater reaches. In both catchments, the boundary between estuary and freshwater was governed by a small barrier. In the Onkaparinga at the church track causeway where a contracted crossing divided historically freshwater and estuarine habitats, and in the Myponga, a natural erosion weir was formed where freshwater flows dropped ~ 20-40cm into the upper extent of the estuary. In both cases, these barriers provided fish passage under higher tidal or stream flow conditions. The middle site was therefore set with the aim of sampling downstream moving fish caught above the junction in freshwater, and upstream moving fish below the junction in brackish/marine water.

## 2.3 Fish Monitoring

The three Onkaparinga sites; Estuarine (Figure 6), Middle (Figure 7) and Freshwater (Figure 8), and the three Myponga sites, Estuarine (Figure 9), Middle (Figure 10) and Freshwater (Figure 11), were sampled on 7 occasions over a 2 year period (2006\2008), largely in response to the occurrence of flows in the lower Onkaparinga. The first two sampling occasions were carried out in response to flow events after which time it was decided to continue more regular sampling every two-three months rather than waiting for flow events. This explains the long gap between the first and second sampling trips. At each site a pair of double winged fyke nets (Figure 12) were set with one net open downstream (catching fish trying to move upstream) and one facing upstream (catching fish trying to move downstream) (see Figures 6-11). Each net was set for a 24 hour period, and then processed on site recording species composition, abundance and total fish length (TFL). For particularly large catches, length was measured from a sub-sample of 100 fish of each species per net. Fish were 'stripped' to determine sex and spawning condition and the presence of any disease or other conditional indicators recorded. After processing, fish were returned to the water at the site they were caught from (Figure 13). The catchments were sampled on concurrent days with the nets set in the Onkaparinga overnight and collected/processed the following day before being re-set in the Myponga catchment.

Figure 6. Onkaparinga Estuary site, showing paired upstream\downstream fyke nets

Figure 9. Myponga Estuary site, showing paired upstream\downstream fyke nets

Figure 7. Middle Onkaparinga site, showing a double winged fyke net, set facing upstream.

Figure 10. Middle Myponga site, showing a double winged fyke net, set facing downstream.

Figure 8. Freshwater Onkaparinga site, showing A double winged fyke net, set facing downstream.

Figure 11. Freshwater Myponga site, showing a double winged fyke net, set facing upstream.

Figure 12. Double winged fyke net, used at each site in each catchment for fish monitoring.

Figure 13. Black bream (*Acanthopagrus butcheri*), in the process of being measured (Onkaparinga).

## 2.4 Water Quality

Along with fish sampling, water quality monitoring was also conducted at each site in each catchment over the entire sampling period using a model TPS 90-FL water quality meter. Approximately 4 measurements were taken at each site on every trip, with two measurements being taken upstream (surface and 1m below the surface) and downstream (surface and 1m below the surface). This was conducted in order to monitor electrical conductivity ($\mu S.cm^{-1}$), dissolved oxygen (ppm), temperature (°C) and pH at each monitoring site over different seasons and relate water quality to environmental flows. Measurements also tested the assumption of site fidelity in that freshwater and estuarine sites remained constant over the sampling period.

## 2.5 Hydrological (Flow) Data

River flow rates for both catchments were obtained from the DWLBC Surface Water Archive, which represents surface water discharge in ML\per day. This data was used to plot all flow hydrographs presented throughout the reports and discussions of hydrological linkages to fish ecology patterns within both the Onkaparinga and Myponga catchments.

# 3. Results

In total 15,871 fish were collected throughout the survey, representing fifteen different species. These included three freshwater obligates, one diadromous, two euryhaline and nine species of predominantly estuarine fish (Table 1). All fifteen fishes, bar yellowfin whiting (*Sillago schomburgkii*), were caught in the lower reaches of the Onkaparinga catchment, whilst eleven of these were also caught in the Myponga catchment. Of particular note was the absence of any freshwater obligate species from the Myponga sites; however, most of the estuarine species as well as the diadromous common galaxias were common to both the Onkaparinga and Myponga catchments.

Table 1. Fish species caught in the lower Onkaparinga and Myponga Rivers indicating zones in which each was captured.

| Common Name | Scientific name | Class. | Onkaparinga | | | Myponga | | |
|---|---|---|---|---|---|---|---|---|
| | | | FW | Mid | Est. | FW | Mid | Est. |
| Flathead gudgeon | (*Philypnodon grandiceps*) | Freshwater | X | X | X | | | |
| Dwarf flathead gudgeon | (*Philypnodon macrostomus*) | Freshwater | X | | X | | | |
| Eastern gambusia | (*Gambusia holbrooki*) | Freshwater | X | | X | | | |
| Common galaxias | (*Galaxis maculatus*) | Diadromous | X | X | X | X | X | X |
| Congolli | (*Pseudaphritis urvillii*) | Euryhaline | X | X | X | X | X | X |
| Blue-spot goby | (*Pseudogobius olorum*) | Euryhaline | X | X | X | | X | X |
| Yelloweye mullet | (*Aldrichetta forsteri*) | Estuarine | X | X | X | X | X | X |
| Black bream | (*Acanthopagrus butcheri*) | Estuarine | | X | X | | X | X |
| Tamar River goby | (*Afurcagobius tamarensis*) | Estuarine | | X | X | | X | X |
| Glass goby | (*Gobiopterus semivestitus*) | Estuarine | | X | X | | X | |
| Flat-tail mullet | (*Liza argentea*) | Estuarine | | X | X | | X | X |
| Small-mouthed hardyhead | (*Atherinosoma microstoma*) | Estuarine | | | X | | X | X |
| Bridled goby | (*Arenigobius bifrenatus*) | Estuarine | | | X | | | X |
| Salmon trout | (*Arripis truttaceus*) | Estuarine | | | X | | | |
| Yellowfin whiting | (*Sillago schomburgkii*) | Estuarine/Marine | | | | | X | X |

## 3.1 Species composition & abundance:

### 3.1.1 Onkaparinga

Overall, 7,910 fish were collected in the Onkaparinga representing 14 of the 15 species collected throughout the study (Table 1). A total of 2, 815 fish (~36% Onkaparinga total catch) were sampled at the estuarine site (Site 1), comprising of 14 different species. The catch at the estuary site was dominated by three species: black bream (35%), common galaxias (20%) and yelloweye mullet (18%) contributing 73% of the total catch in combination (Figure 14). Three species, congolli (5%), flatheaded gudgeon (8%) and glass goby (9%) made up a further 22% of the total catch with the remainder consisting of lower abundances of bridled, blue-spot, and Tamar gobies, flat-tail mullet, small-mouth hardyhead, and salmon trout as well as freshwater species, such as eastern gambusia and dwarf flatheaded gudgeon (Figure 14).

A total of 1,279 fish were sampled at the middle Onkaparinga site (Site 2), at the freshwater/estuarine junction, representing 16% of the total catch recorded across the three Onkaparinga sites. In total, 10 different fish species were found at site 2, with common galaxias (65%), flatheaded gudgeon (17%) and congolli (9%) being the dominant species making up 91% of the total catch (Figure 14). Black bream, blue-spot, bridled, Tamar and glass gobies and both mullet species were also found in lower abundance at site 2 (Figure 14).

The freshwater site (Site 3) had the highest total abundance (n=3,816) across all species over the sampling period, representing 48% of the total Onkaparinga catch. Nonetheless, the freshwater site possessed the lowest species richness of all three Onkaparinga sites, with only 7 out of the 15 species of fish caught there (Figure 14). Furthermore, the freshwater catch was completely dominated by common galaxias (84%) and to a lesser extent congolli (8%) and flatheaded gudgeon (6%), accounting for 98% of the total catch (Figure 14). The remaining 2% was made up of yelloweye mullet, dwarf flatheaded gudgeon, blue-spot goby and gambusia (Figure 14).

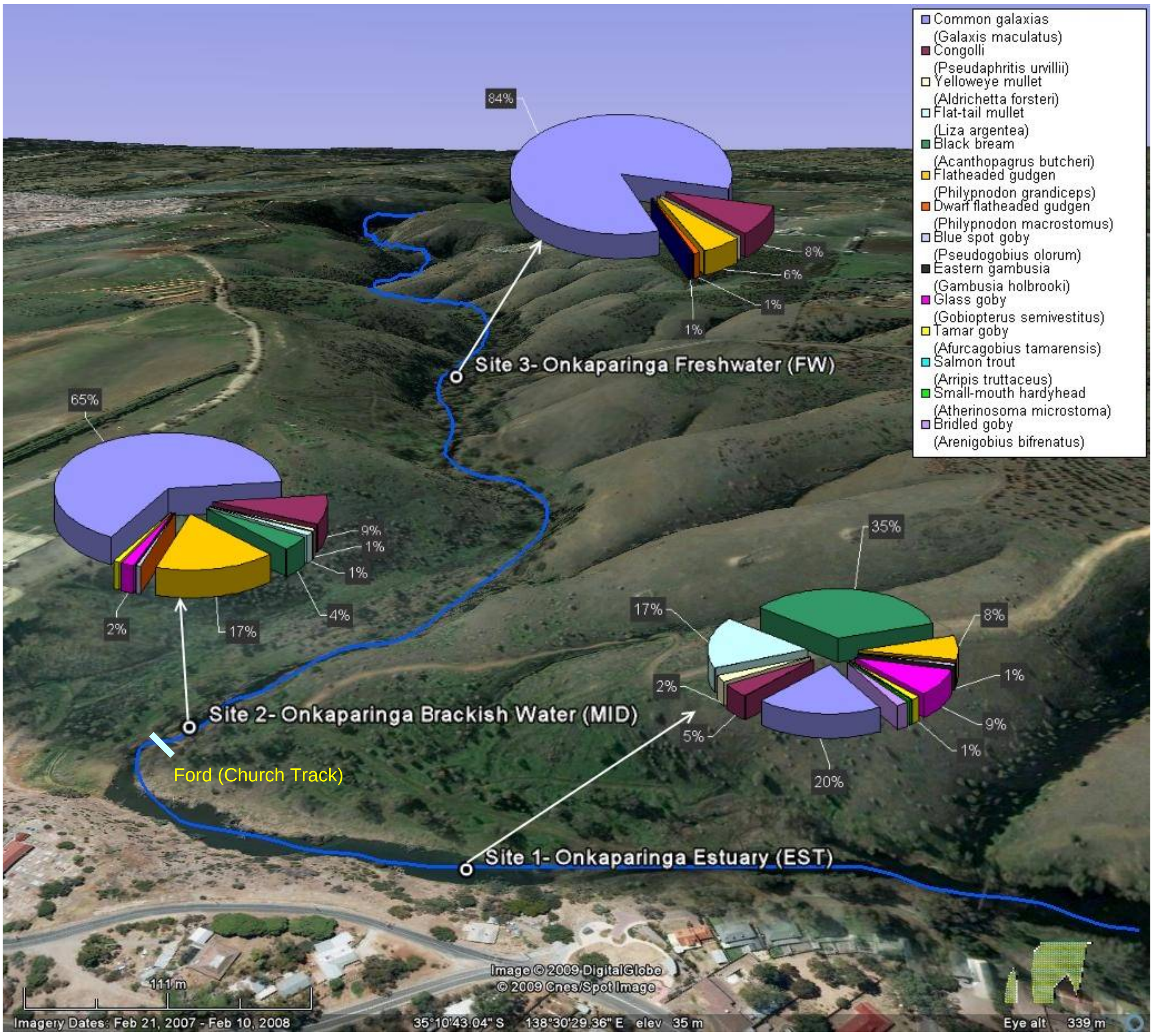



Figure 14. Map of the lower Onkaparinga River at Old Noarlunga, showing fish species composition and relative abundance at each of the three monitoring sites.

### 3.1.2 Myponga

A total of 7,962 fish were collected at Myponga Beach over the course of the survey, a value exceptionally close to that of the Onkaparinga (7,910). The species richness at Myponga; however, was lower than the Onkaparinga, with only 11 species collected (Table 1). Flatheaded gudgeon, dwarf flatheaded gudgeon and the introduced eastern gambusia, all predominantly freshwater species, and salmon trout were not recorded at all in the Myponga sampling sites, whereas they were found in reasonable numbers in the Onkaparinga (Figure 15). The only species found at Myponga that was not recorded in the Onkaparinga catchment was yellowfin whiting, which was recorded in low numbers at the middle Myponga site during a very high tide and storm surge (Figure 15).

Myponga estuary (Site 1) had a total catch of 6,085 fish throughout the study, approximately 76% of the total catch recorded for all Myponga sites. In total, 10 different fish species were found at the Myponga estuary, which was dominated by three species: small-mouth hardyhead (49%), common galaxias (32%) and flat-tail mullet (13%), making up 94% of the total estuarine catch (Figure 15). Yellow-eye mullet made up 4% of the total catch, whilst bridled, blue spot and Tamar gobies, along with congolli and black bream, were also present, but in lower numbers. Of particular note is black bream which were found in the Myponga Estuary in considerably lower numbers than in the Onkaparinga Estuary.

The middle site (Site 2) had a total catch of 676 fish across all species over the course of the study, representing approximately 8% of the total Myponga catch. As with the Myponga Estuary site, a total of 10 different fish species were found, and again, small-mouth hardyhead (38%), common galaxias (26%) and flat-tail mullet (11%), were the dominant species making up 75% of the total catch (Figure 15). Congolli made up 10% of the catch at the middle Myponga site and yellow-eye mullet 4%. The remaining 11% of the catch was made up of black bream (2%), bridled, glass, blue spot and Tamar gobies and yellowfin whiting (Figure 15).

The freshwater site (Site 3) had a total catch of 1,200 fish across all species over the course of the study, representing approximately 15% of the total Myponga catch. As with the Onkaparinga freshwater site, there was low species richness compared to the middle and estuarine sites, with only 3 species being recorded. The site was dominated comprehensively by common galaxias (91%), with congolli (8%) and yellow-eye mullet (1%) also present in lower numbers (Figure 15).

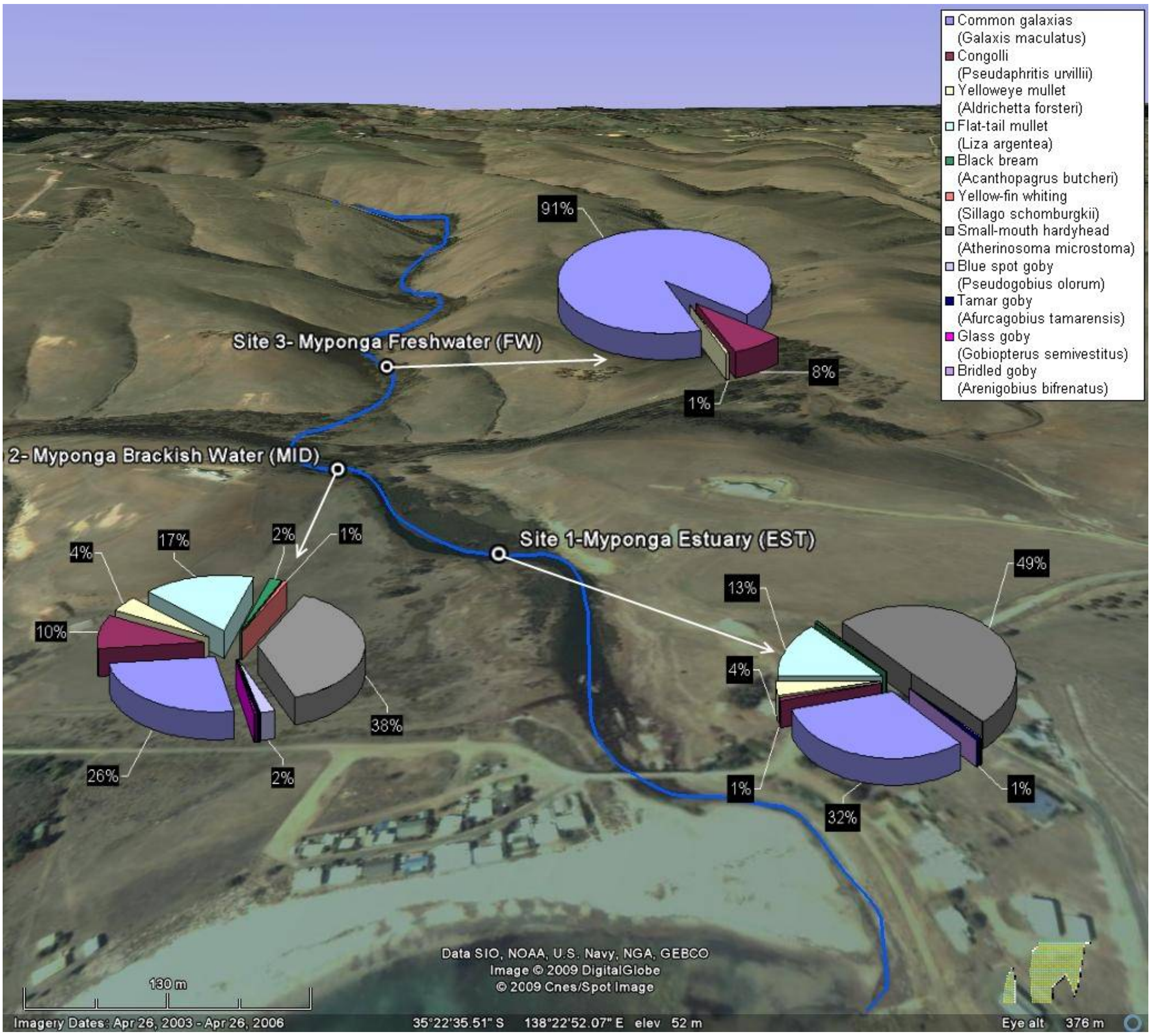



Figure 15. Map of the lower Myponga River, indicating fish species composition and relative abundance found at each of the three monitoring sites.

## 3.2 Fish Ecology and River Flows

The following section presents the patterns in hydrological (flow) variability within both study reaches in relation to key aspects of the fish ecological data. In the first instance this is presented as total numerical abundance for each fish species to show community composition patterns. Secondly, juvenile and adult abundances are shown separately to elucidate patterns in recruitment and adult survival against the background of flow variability. This split is based on the length frequency data presented comprehensively in Appendices A & B and was carried out in order to summarize the complex data presented in those figures. In the third instance, upstream versus downstream migrational movement was assessed by comparing upstream and downstream facing nets with each site represented by a single pair of nets. Directional migration is inferred by the difference in catch in upstream versus downstream facing nets.

### 3.2.1 Discharge Patterns

### Onkaparinga

The hydrograph for the lower Onkaparinga River shows distinct flow periods each winter between January '06 and January '09 (Figure 16). In '06 and '07, flows began around June and continued with varying intensity through to September with periods of flow following through October and November before ceasing altogether during that month. In '08, flow did not begin until well into July and ceased before the start of October, with pools remaining disconnected until '09. Peak discharge across the three seasons was consistent, peaking at ~450-600ML/Day. Peak flows occurred in July during '06 (478 ML\day) and '07(598 ML\day), and slightly later in August during '08 (523 ML\day) (Figure 16). A key aspect of the Onkaparinga hydrograph in '06 was a sustained low-level of flow (~80 ML/day) throughout August (~80 ML/day) and September/October (~20 ML/day). This significant flow event is not reflected in either '07 or '08 where winter flows decline sharply during August. This event was believed to be the result of a trial release for environmental flow allocations similar to those planned under the MLR Environmental Water Provision trial (P. Schulz - AMLRNRMB pers. comm.).

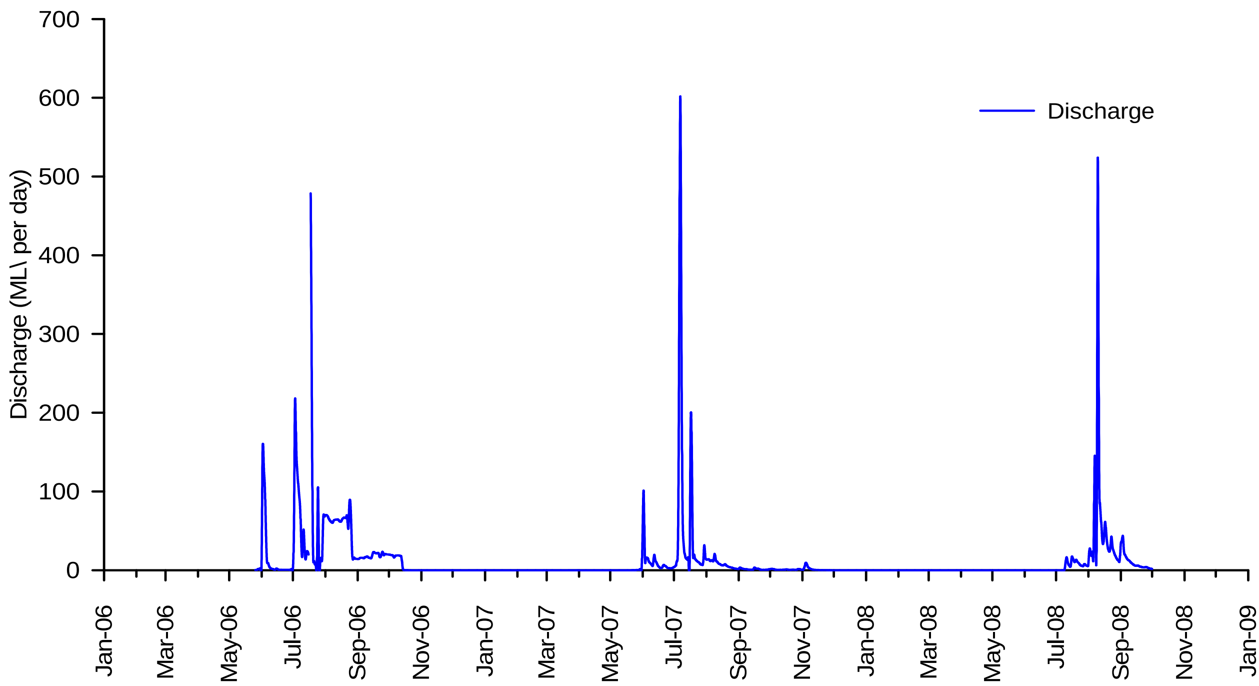



Figure 16. Hydrograph showing lower Onkaparinga River flows throughout the study period.

## Myponga

The hydrograph for the lower Myponga differs from that of the Onkaparinga in a number of aspects. Firstly, discharge is far more constant over the year with flow commencing in April and continuing until October or November each year (Figure 17). In '06 flow began in late March, continuing until late November with a number of peaks reflecting local rainfall events. In '07, Rainfall events in January and April were reflected in small flow events, whilst flow was continuous between late April and late November. A further small flow peak in December again reflecting local rainfall. This was followed by a period of zero flow until the end of April '08, with flow continuing until mid October. Secondly, peak flow in the lower Myponga River was around a third of the volume in the Onkaparinga, peaking at 248 ML/day in '06, 177 ML/day in '07 and 194 ML/day in '08 and was dominated less by sharp peaks in the hydrograph than the Onkaparinga River. As a result it appears that the lower Myponga is supported by spring fed baseflow between autumn and spring and that local rainfall events are closely reflected in the hydrograph. In contrast, the Onkaparinga flow is more confined to the late autumn and early spring and is more dominated by catchment runoff leading to fewer but more significant peaks in discharge during mid winter, and drying quickly in mid spring through to late autumn.

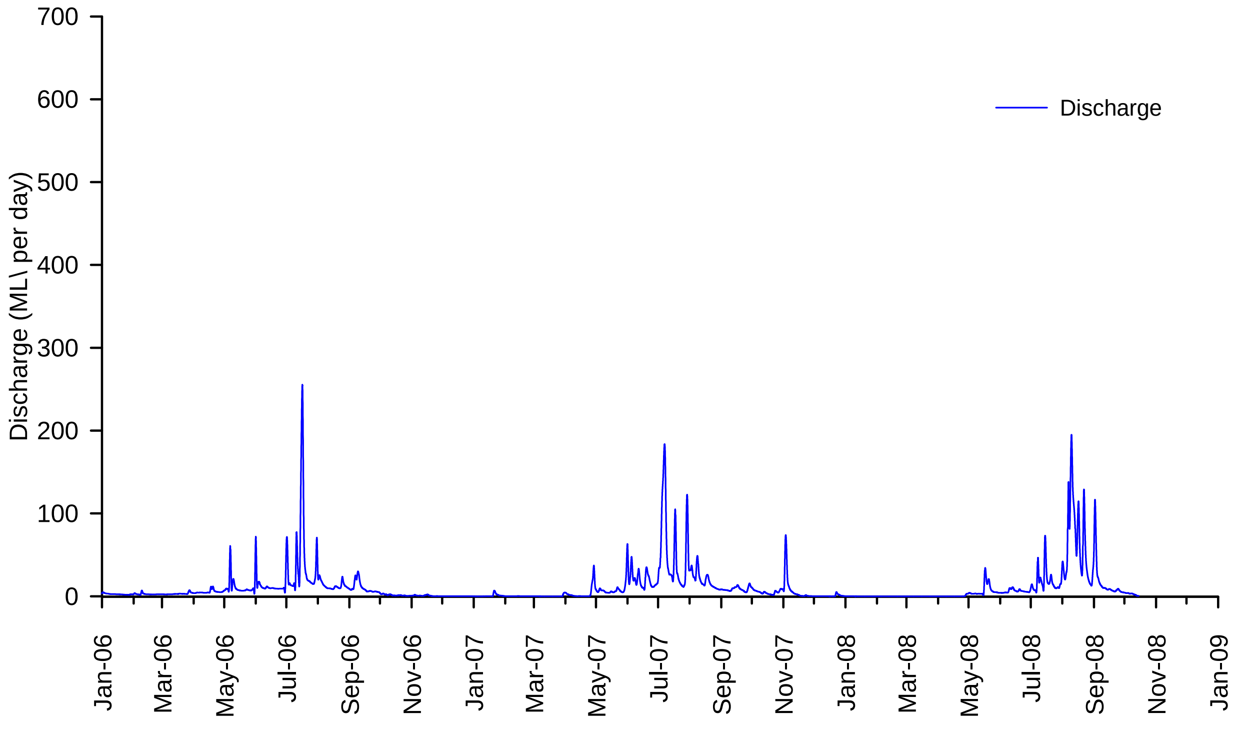



Figure 17. Hydrograph showing lower Myponga River flows throughout the study period.

### 3.2.2 Numerical abundance patterns

In line with the relative abundance patterns outlined above, many sites were dominated by three or four highly abundant taxa and; therefore, the total numerical abundance differs greatly in scale between these and less abundant species. As a result, numerical abundances have been presented separately for A: Highly abundant ($n \geq 60$) and B: Lower abundance species ($n<60$) for each site over the entire sampling period.

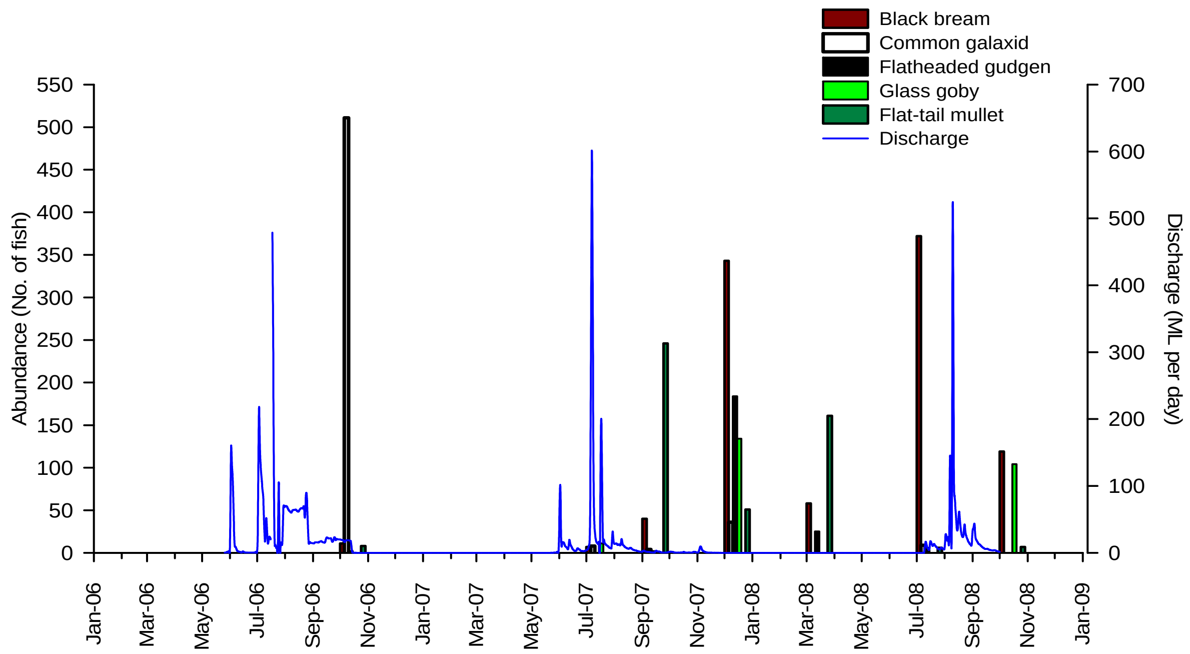
### Onkaparinga abundance

The highly abundant species ($n \geq 60$) in the Onkaparinga estuary were common galaxias, black bream, flat-tail mullet, flatheaded gudgeon and the glass goby (Figure 18a). The most striking feature in numerical abundance is the very large peak in common galaxias abundance ($n$=500+) that followed the large flow event in August-October '06. Throughout the remainder of the study period, common galaxias abundances remained relatively low. Following spring '07, the total catch became dominated by estuarine species, in particular black bream and flat-tailed mullet. In Oct '07, flatheaded gudgeon and glass gobies were highly abundant in the Onkaparinga Estuary with a further peak in glass goby in October '08. Of the less abundant species ($n<60$), congolli showed low abundance in '06 following the large flow event but were sampled in greater numbers for the remainder of the project following winter '07 with between 13 and 40 fish in each sampling period. This pattern was also repeated for Tamar gobies at lower abundance (Figure 18b). Alternatively, a number of species showed distinct peaks in abundance with yelloweye mullet abundance very high ($n$=56) in September '07, blue-spot goby showing a peak ($n$=23) in December '07 and Bridled goby a sharp peak ($n$=54) in March '08.

In the middle Onkaparinga site only common galaxias and flatheaded gudgeon were highly abundant (n≥60) (Figure 18c). Common galaxias abundance peaked in December '07 and October '08. Flatheaded gudgeon abundance also peaked in December '07. Species found in low abundance in the middle Onkaparinga site included congolli, flat-tail mullet, black bream and various goby species (Figure 18d). Congolli showed a distinct peak in spring '07, and again in late autumn '08, remaining abundant throughout that year. Flat-tail mullet peaked in abundance during winter '07 and gradually declined throughout the survey period whilst black bream abundance peaked in October in both '06 and '07. Tamar goby exhibited a small peak in abundance in March '07.

At the Onkaparinga freshwater site, common galaxias, congolli and flatheaded gudgeon were found in high abundance. Common galaxias showed peaks in abundance each spring and winter ('07 & '08) (Figure 18e). Congolli abundance increased throughout 2007 and decreased through 2008. Flathead gudgeon abundance peaked in September '07, remaining low at other times, a pattern matched closely by dwarf flatheaded gudgeon in lower abundances (Figure 18f). Introduced eastern gambusia were present at the Onkaparinga freshwater site during low-flow periods in December '07 and October 2008. Black bream were recorded from the freshwater site following the large flow event in '06 but disappeared thereafter whilst yelloweye mullet were recorded at the site in December '07.

Site 1- Estuary (High abundance) (18a)




Site 1- Estuary (Low abundance) (18b)

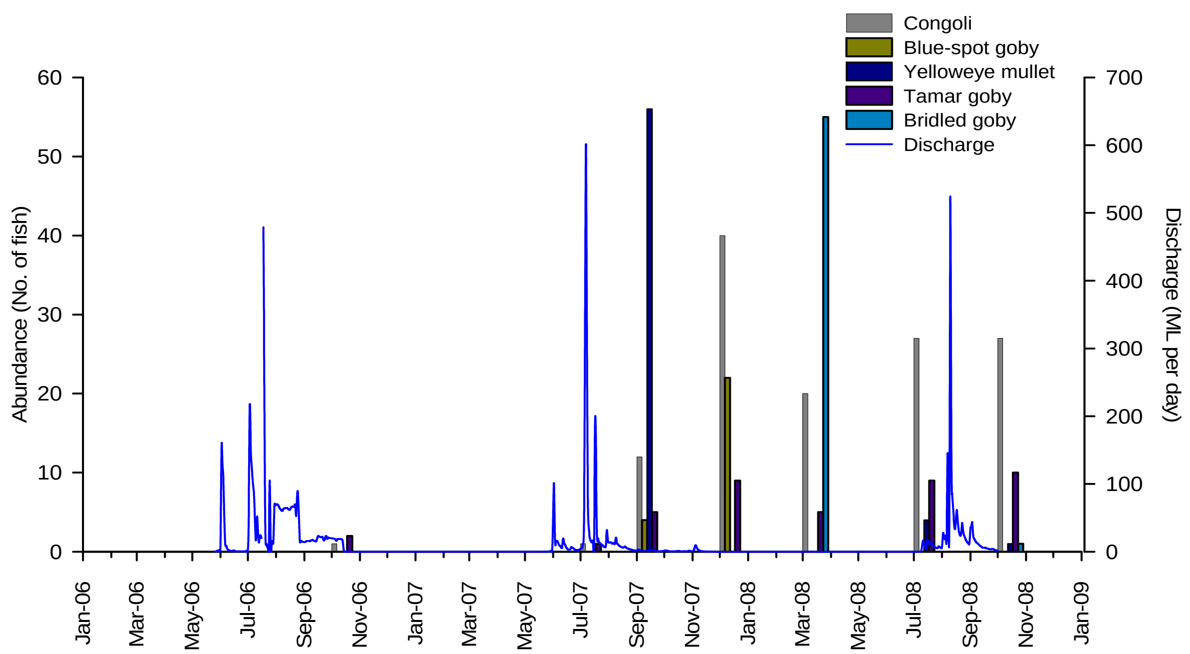
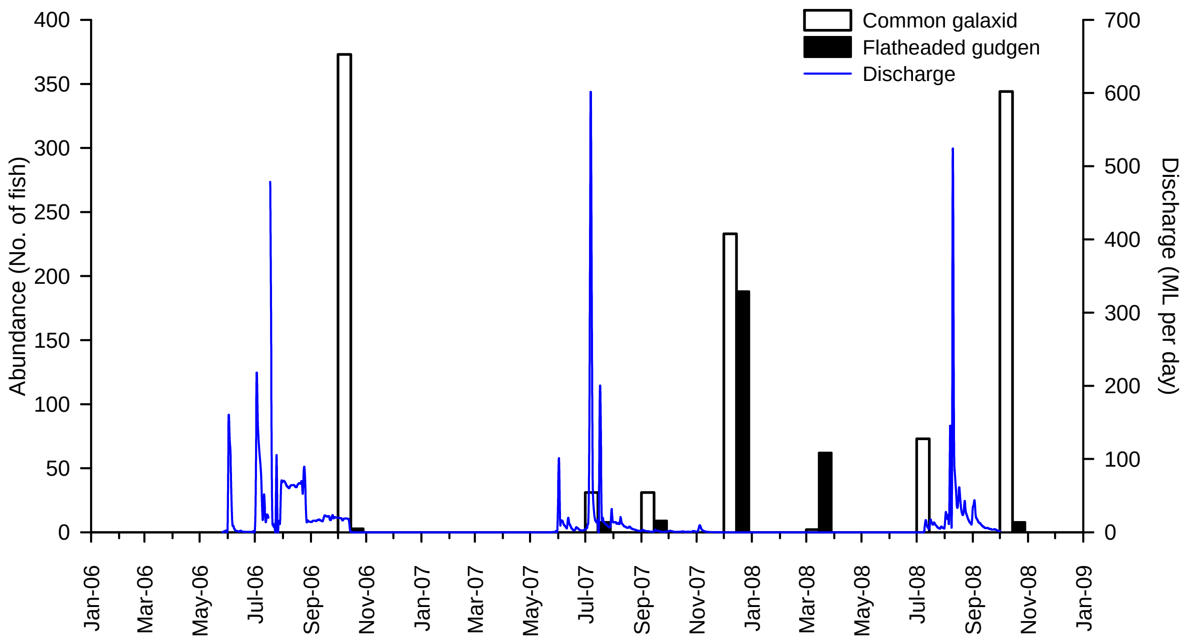



Figure 18a-b. The abundance of fish species in the Onkaparinga Estuary for a: highly abundant species and b: low abundance species in relation to surface water flow rates.

Site 2- Brackish (High abundance) (18c)




Site 2- Brackish (Low abundance) (18d)

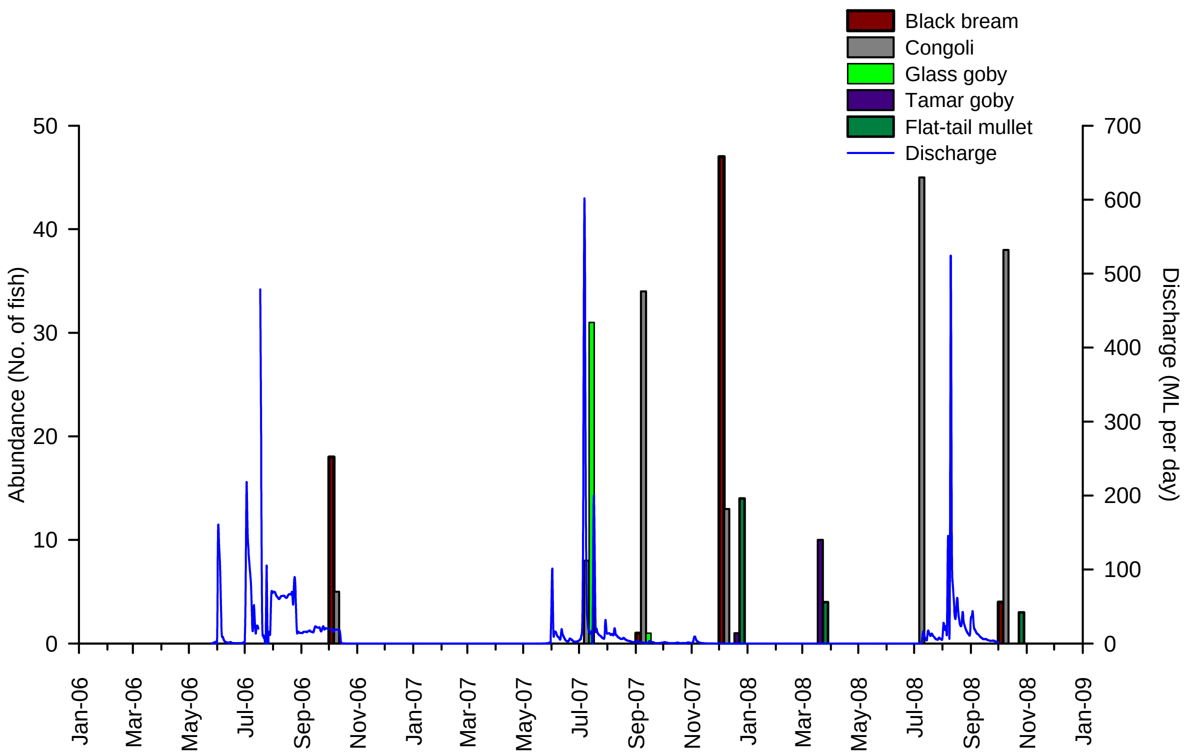
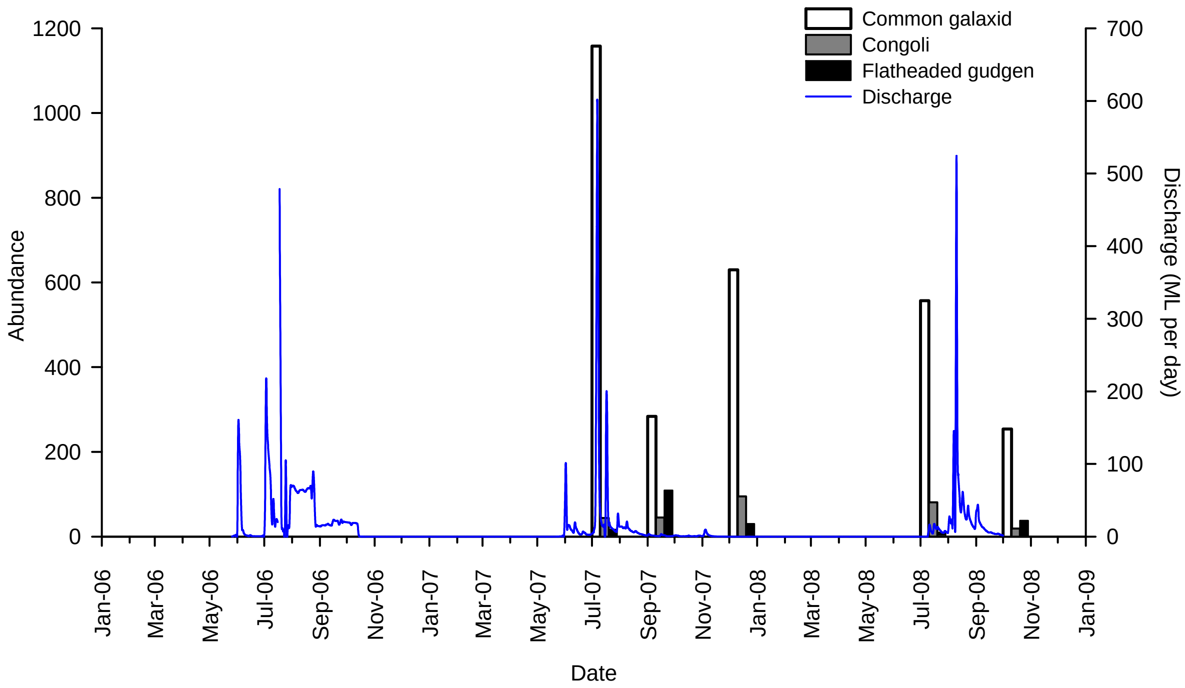



Figure 18c-d. The abundance of fish species in the Middle Onkaparinga site for c: highly abundant species, and d: low abundance species in relation to surface water flow rates.

Site 3- Freshwater (high abundance) (18e)




Site 3- Freshwater (Low abundance) (18f)

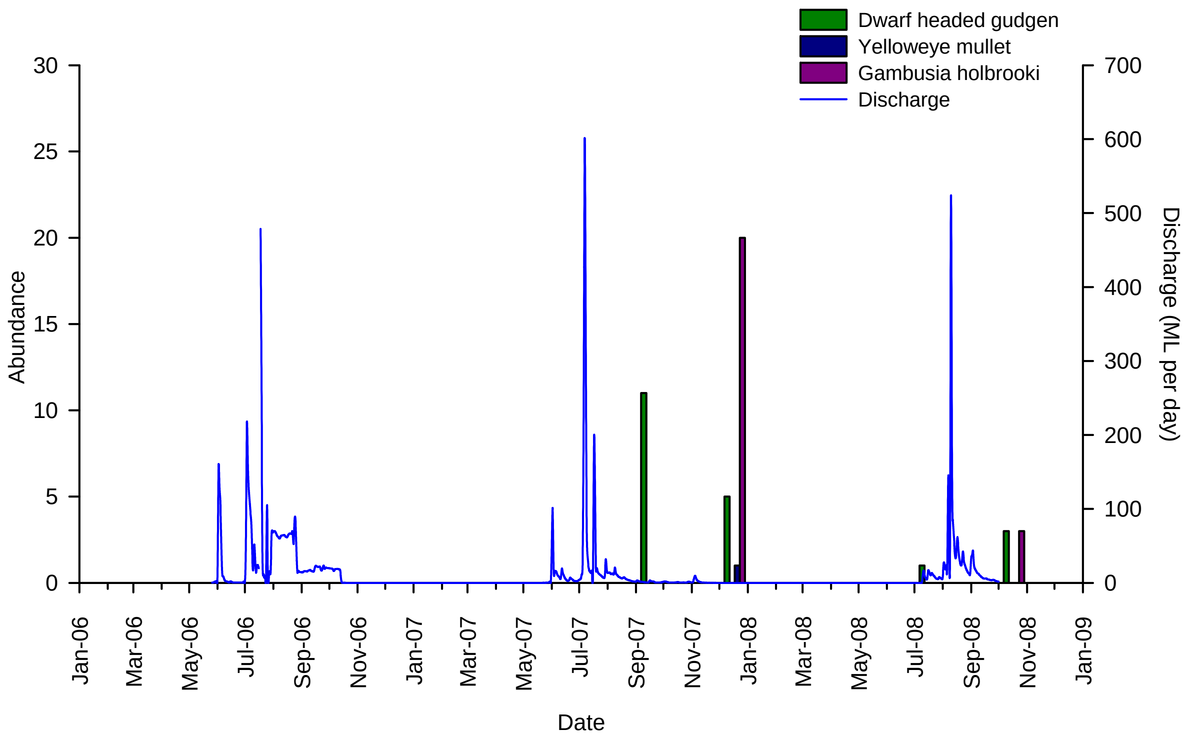



Figure 18 e-f. The abundance of fish species in the Freshwater Onkaparinga site for e: highly abundant species, and f: low abundance species in relation to surface water flow rates.

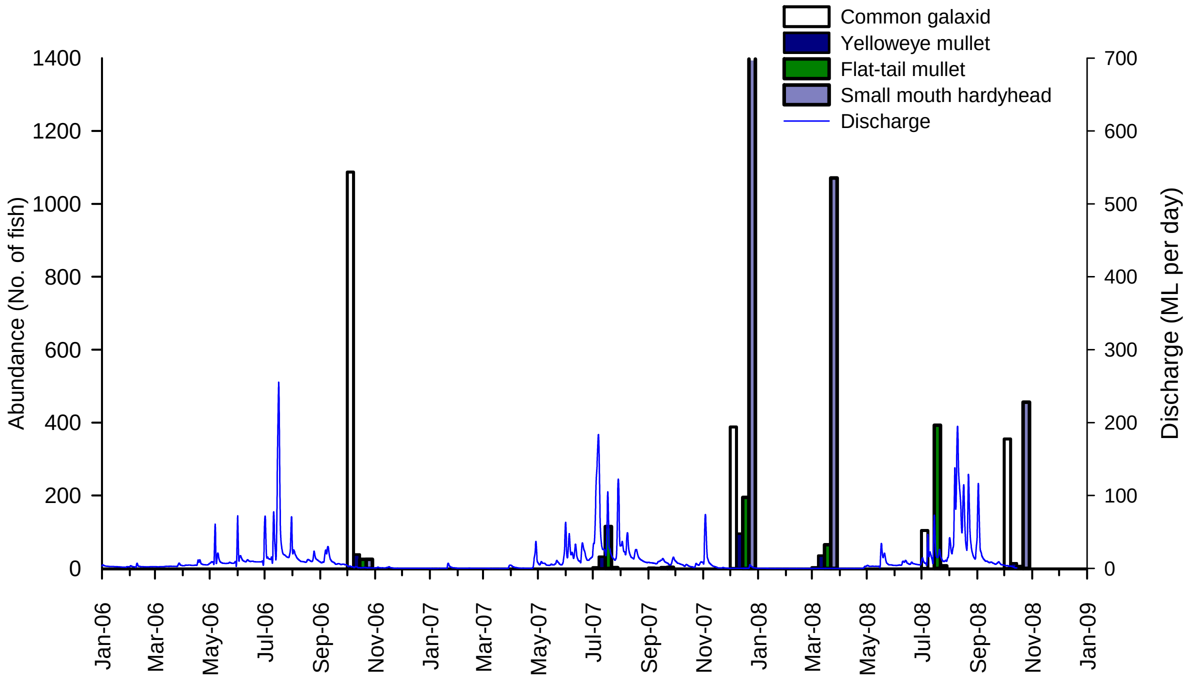
## Myponga abundance

In the Myponga estuary site, four species of fish were found to be in high abundance, namely small-mouthed hardyheads, common galaxias, flat-tail mullet and yelloweye mullet (Figure 19a). Common galaxias exhibited a clear peak in abundance each year following the primary flow period, occurring in spring (Oct) in '06 and '08 and early summer (Dec) in '07, and a small peak in winter '08 with comparatively low abundances at other times. Small mouth hardyhead were highly abundant in the estuary over the summer of '07/08, with a further peak in spring '08. Flat-tail and yelloweye mullet showed variable abundance with yelloweye peaking in Dec '07 and flat-tail in July '08. For lower abundance species (Figure 19b), congolli abundance peaked during October in '06 and '08 but increased and remained relatively high between July '07 and March '08. Tamar goby abundance peaked in spring each year following the flow period, as did the blue-spot goby in '06 and '07. There was a spike in black bream abundance during low flows in March '08 whilst they remained relatively low at other times in the Myponga estuary.

In the middle Myponga site, common galaxias, small-mouth hardyhead and flat-tail mullet were highly abundant (Figure 19c). Both estuarine species; hardyhead and mullet peaked in abundance during no flow in summer (Dec) '07, whilst the diadromous common galaxias was generally abundant across sampling trips, peaking in spring '07. Comparatively lower in abundance, congolli maintained reasonable numbers throughout the survey period excluding July '06. Yelloweye mullet were abundant throughout '07, declining somewhat after winter '08 (Figure 19d). Conversely, there were distinct peaks in blue-spot goby (Dec '07) and black bream (March '08), whilst yellowfin whiting appeared only in July '07 during a king tide associated with a storm surge.

The freshwater site at Myponga had only two abundant species out a total of three (Figure 19e), with common galaxias peaking in abundance during October each year following the flow season. They also showed a peak in abundance during July '08 and were reasonably abundant at other times. Congolli abundance increased gradually to December '07 before gradually declining again.

Site 1- Estuary (High abundance) (19a)




Site 1- Estuary (Low abundance) (19b)

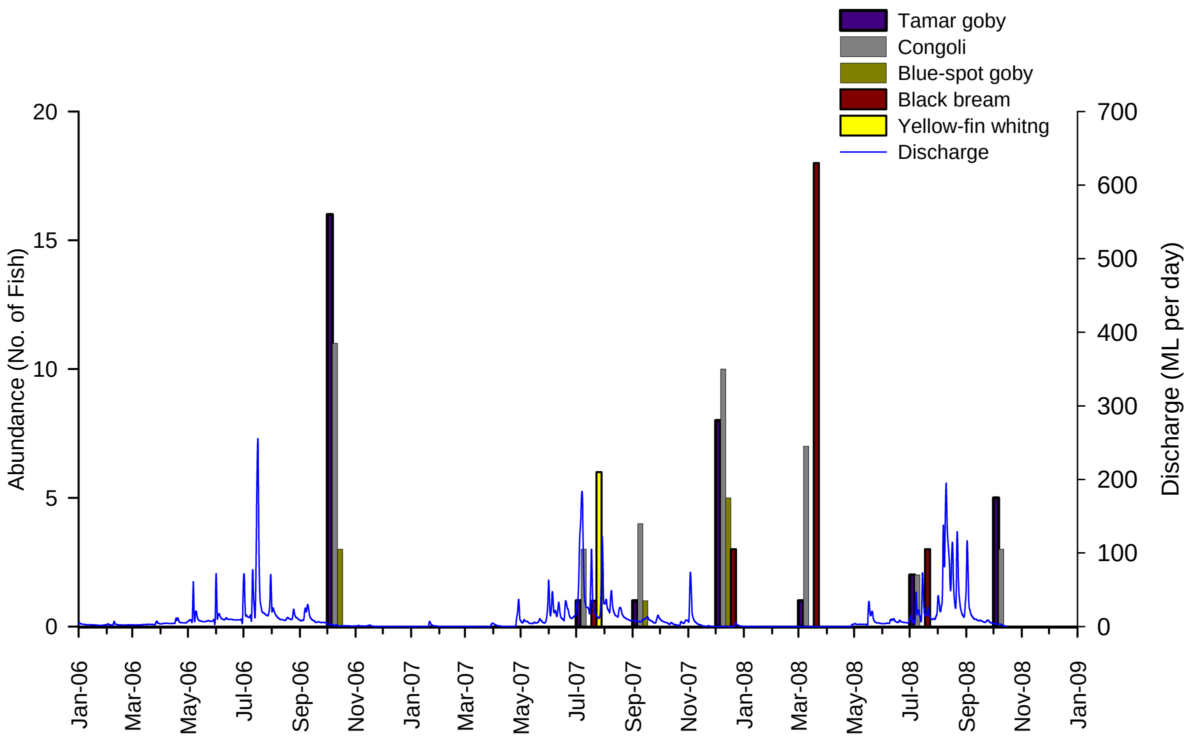
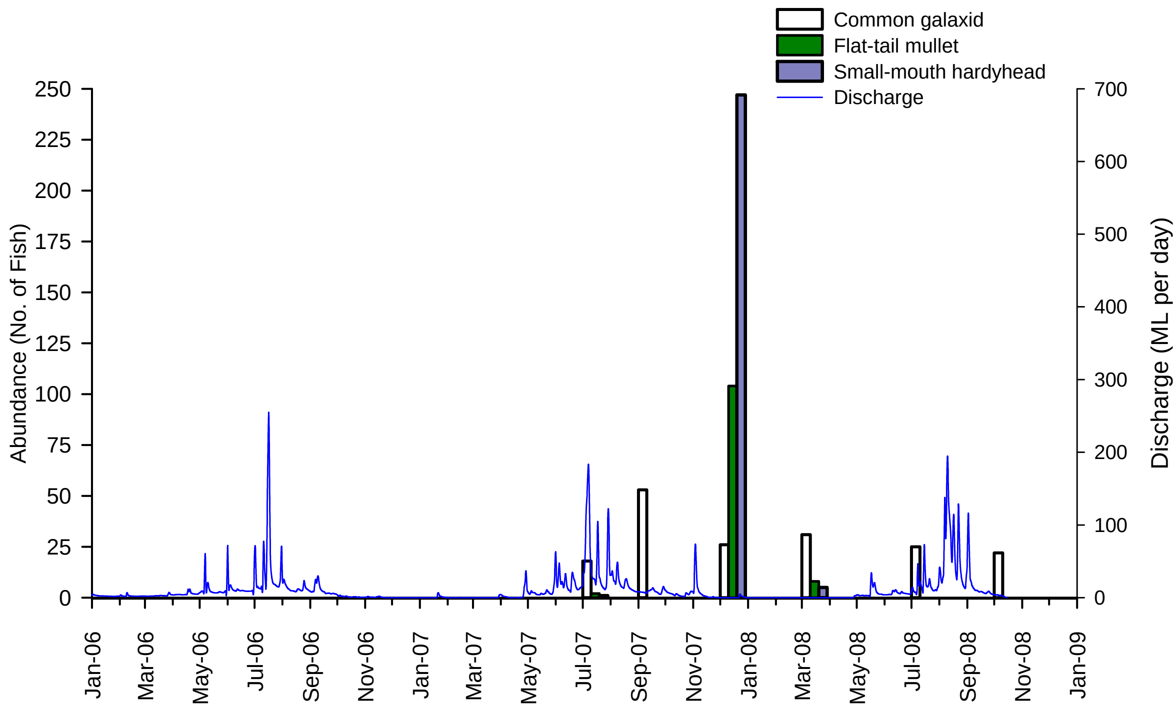



Figure 19 a-b. The abundance of fish species in the Myponga Estuary site for a: highly abundant species and b: low abundance species in relation to surface water flow rates.

Site 2- Brackish (High abundance) (19c)




Site 2- Brackish (Low abundance) (19d)

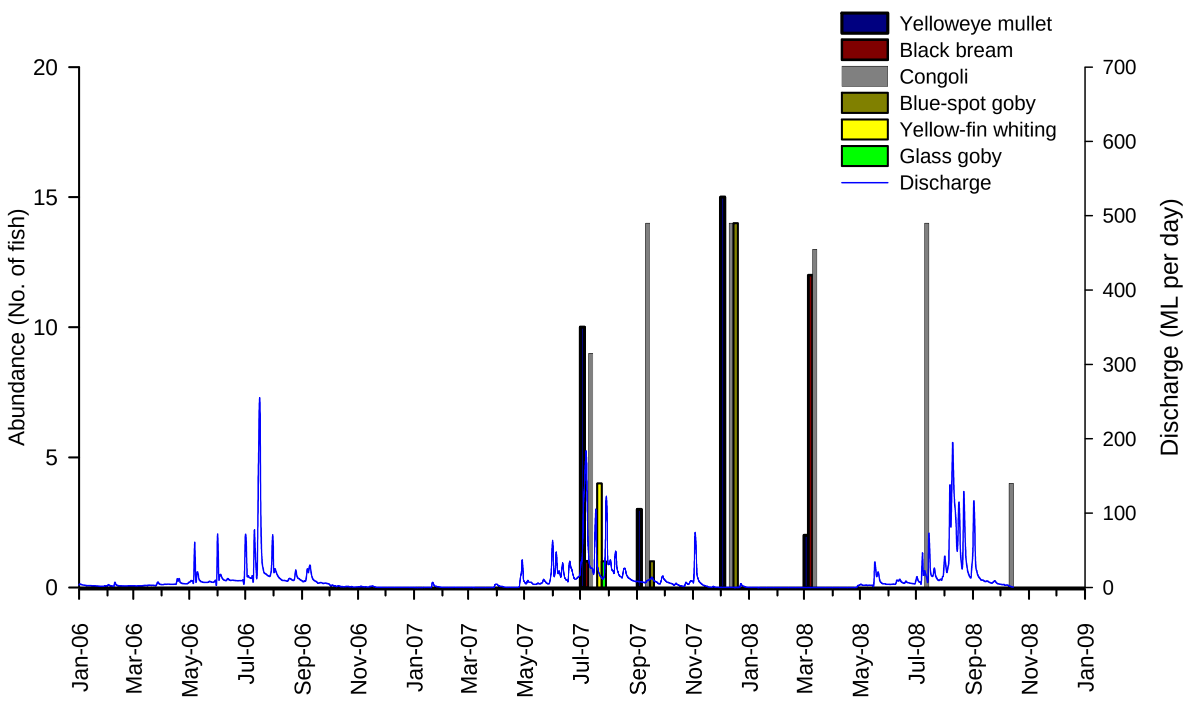


Figure 19c-d. The abundance of fish species in the Middle Myponga site for c: highly abundant species, and d: low abundance species in relation to surface water flow rates.

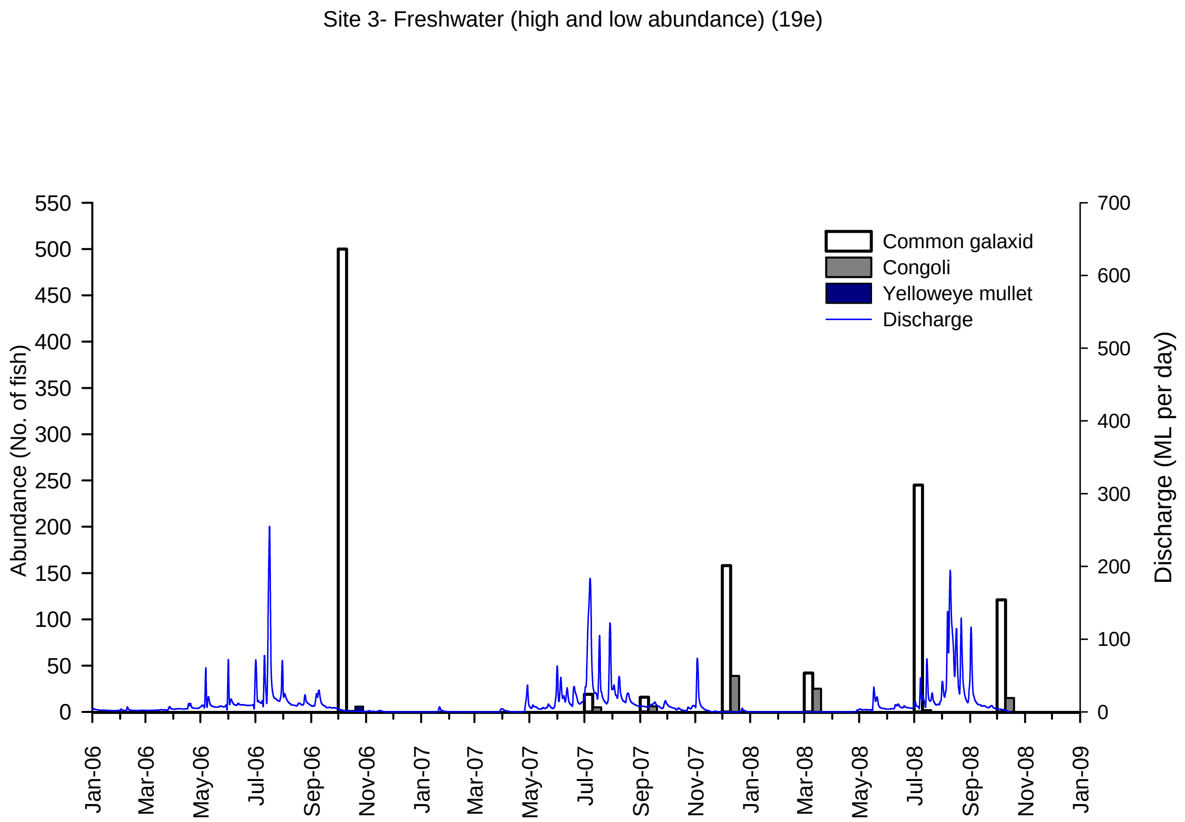



Figure 19 e. The abundance of fish species in the Freshwater Myponga site for all species in relation to surface water flow rates.

### 3.2.3 Recruitment and adult survival

Detailed length frequency relationships are presented for each net and species at each site in Appendix A (Onkaparinga) and Appendix B (Myponga). Analysis of these figures provides details regarding periods of recruitment as well as the direction of any migration related to those periods relative to other species caught at the same time. We have attempted to summarize this information by separately presenting patterns of juvenile and adult abundance for the most abundant species. This section therefore outlines the trends in the abundance of new recruits (juvenile) and of older breeding-age individuals separately in relation to flow variability. Individuals were split on the basis of size at reproductive age provided for each species in McDowall (1996) and Lintermans (2007). Common galaxias were split at 60mm, congolli at 80mm and larger bodied species such as bream and mullet at 110mm.

## Onkaparinga recruitment & adult abundance

In the Onkaparinga River, common galaxias recruitment peaked in December '07 at all sites (Figure 20a) and was directly preceded by a rise in the abundance of adults in all sites during July and September of that year, during peak flows (Figure 20b). These patterns were strongest upstream in freshwater and weakest in the estuary site. A second peak in adult abundance during the flow season in July '08 was again followed by a rise in recruitment during declining flows in the following October, although recruitment was highest in the middle reach at this time. Coincident with the rise in juvenile abundance, adult abundance declined in the estuary and middle site, but remained high in the freshwater site suggesting this provided reasonable adult habitat.

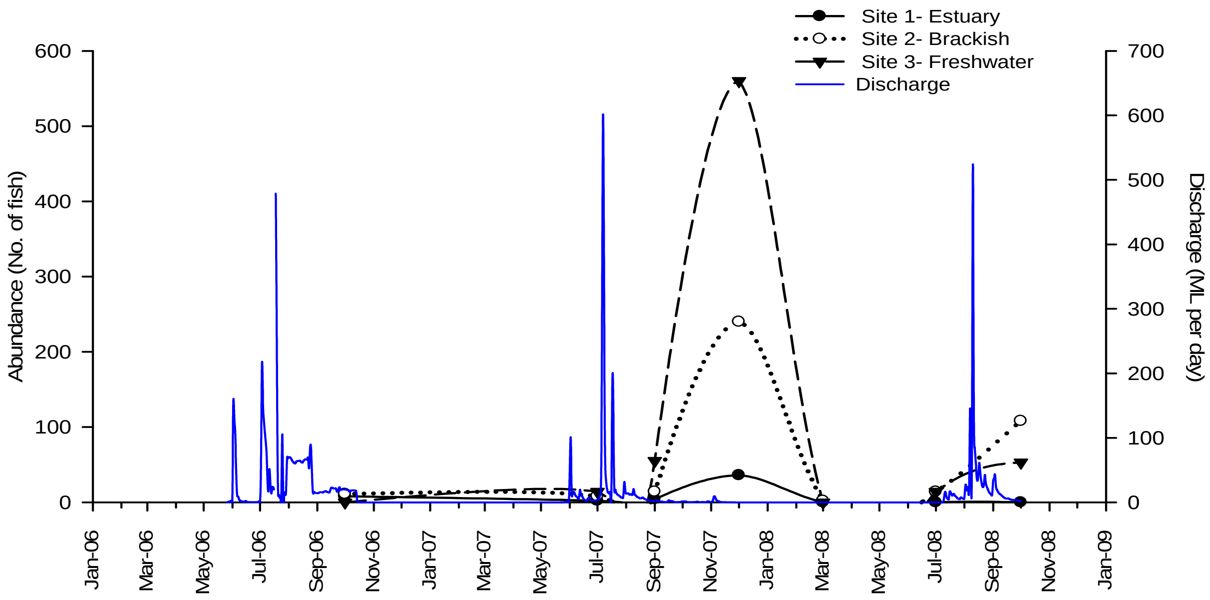
Congolli in the Onkaparinga showed a similar pattern of rising adult abundances during July and September as river flows begin (Figure 20c), followed closely by a sharp rise in juvenile abundances during late spring to early summer (Figure 20d). Adult congolli show a constant pattern of higher upstream abundance, declining towards the estuary except in March '08 during zero flow when estuarine abundance was higher.

The juvenile abundances of congolli in '07 and '08 reveal a more complex pattern, however, with juvenile abundance in July predominantly confined to the freshwater site, switching in September/October to be higher in the middle and estuarine sites. In '07, juvenile abundance was once more higher in the freshwater site by December, but this data was not available for '08.

Black bream in the Onkaparinga estuary showed two clear peaks in juvenile abundance, one in December '07 and another in July'08 suggesting both spring and autumn spawning events driving twice yearly recruitment (Figure 20e). These peaks are mimicked in the middle site to a lower degree. This pattern was also reflected in the adult abundance patterns with peaks in adult abundance directly preceding both juvenile peaks (Figure 20f). Juvenile black bream were largely confined to the estuarine and middle sites with no apparent recruitment to freshwater habitats.

Flat-tail mullet in the Onkaparinga showed a distinct peak in juvenile abundance under flowing conditions during spring and summer '07, predominantly in the estuary, and increased in the middle site later in summer (Figure 20g). This was followed in March '08 with a peak in adult abundance within the estuarine site under low flow conditions (Figure 20h). This may reflect the successful recruitment of the spring '07 age class into the local adult population. Yelloweye mullet showed a peak in juvenile abundance under flowing conditions in early spring '07 (Figure 20i), concurrent with a smaller peak in adult abundance (Figure 20j).

Common Galaxias (juvenile) (20a)




Common Galaxias (Adults) (20b)

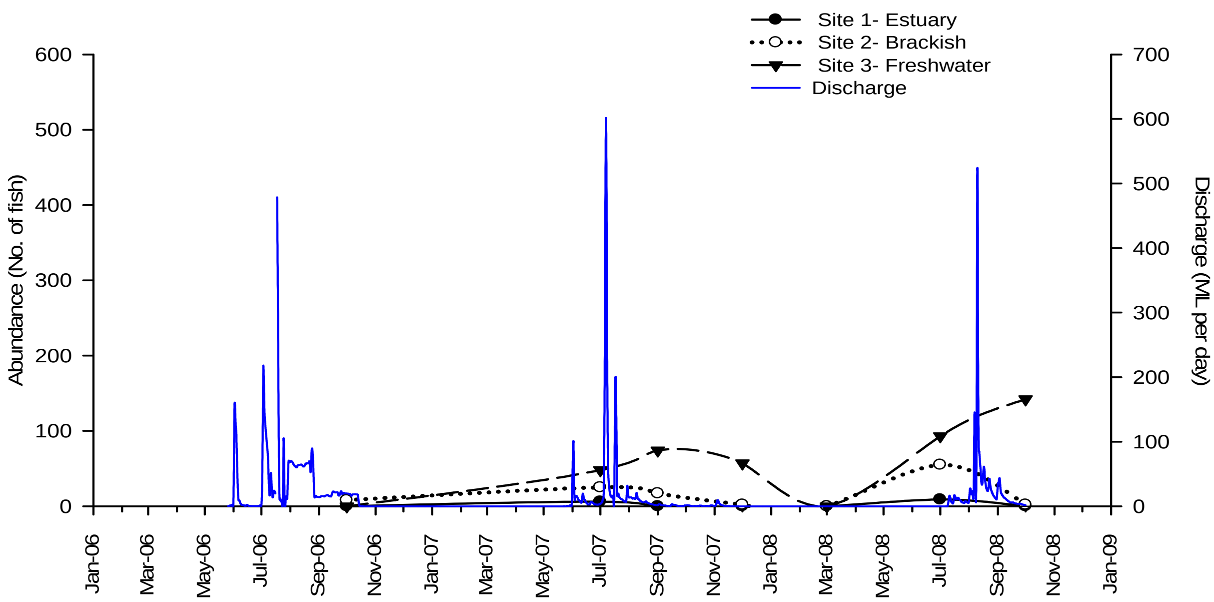
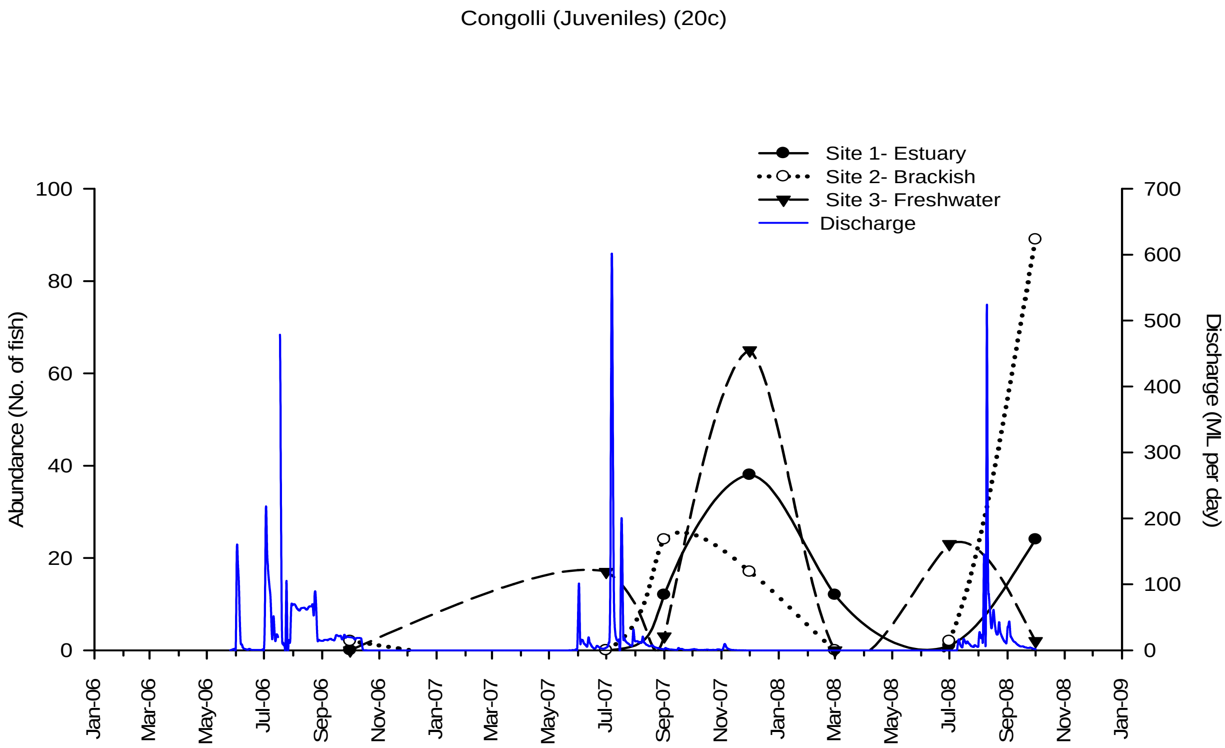



Figure 20a-b. Abundances of a: juvenile and b: adult common galaxias in the lower Onkaparinga River in relation to catchment flows over the course of the study.



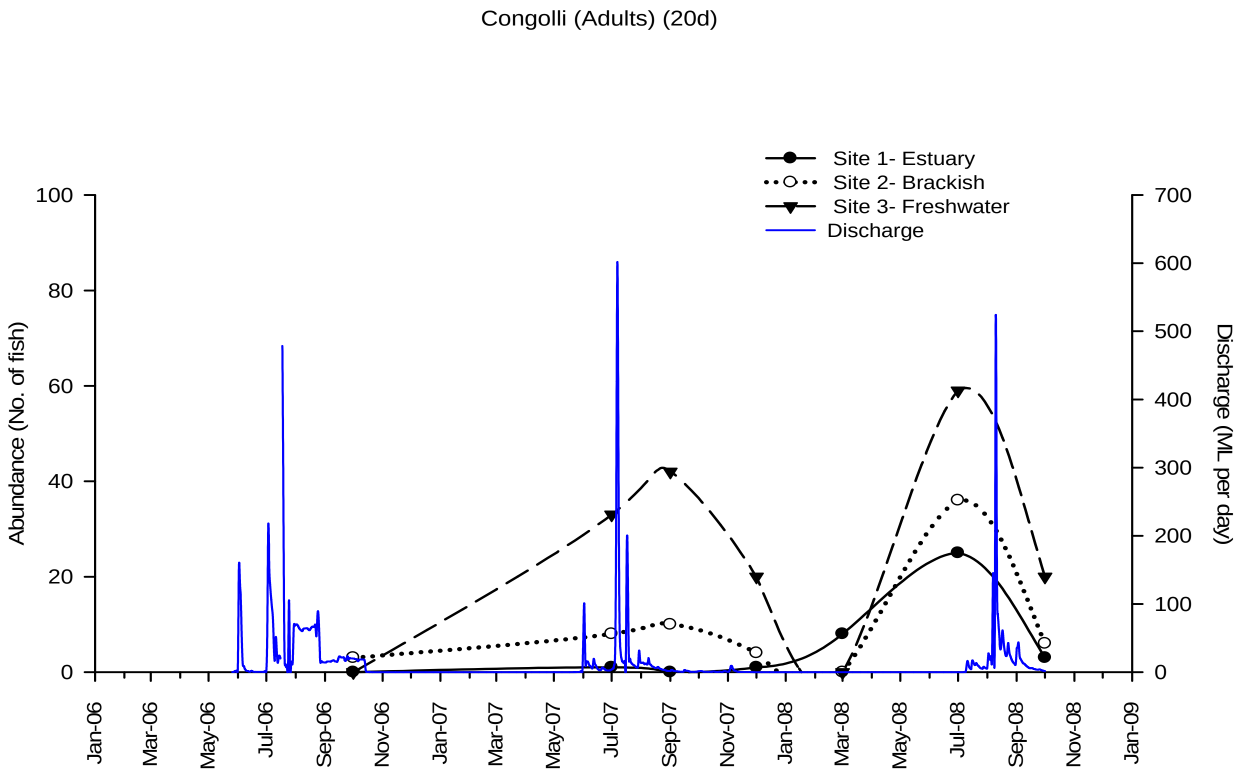
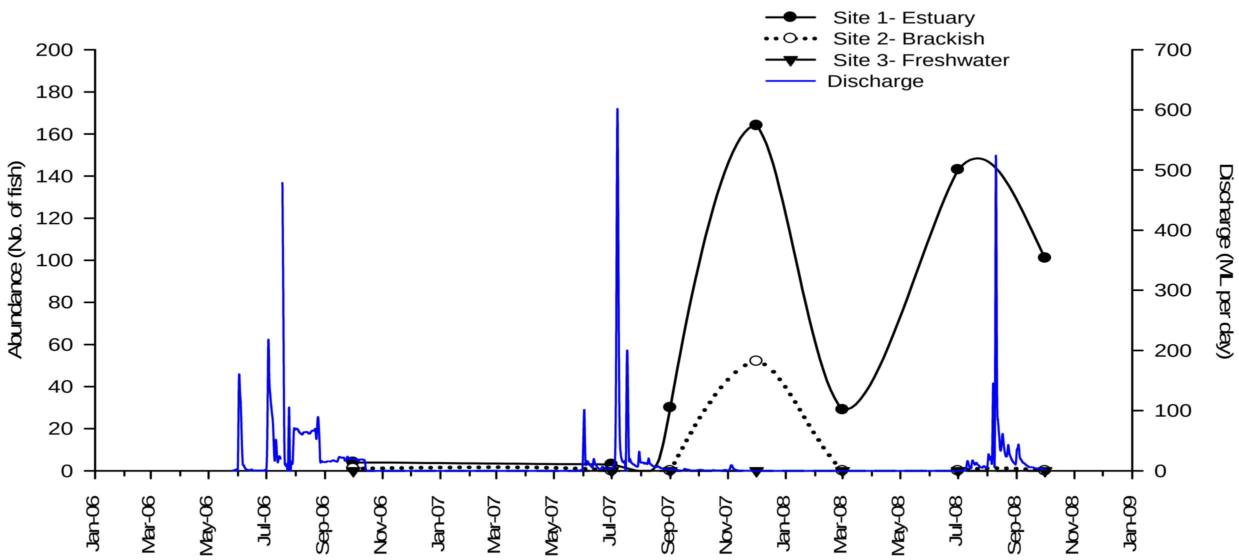




Figure 20 c-d. Abundances of c: juvenile and d: adult congolli in the lower Onkaparinga River in relation to catchment flows over the course of the study.

Black bream (Juveniles) (20e)




Black bream (Adults) (20f)

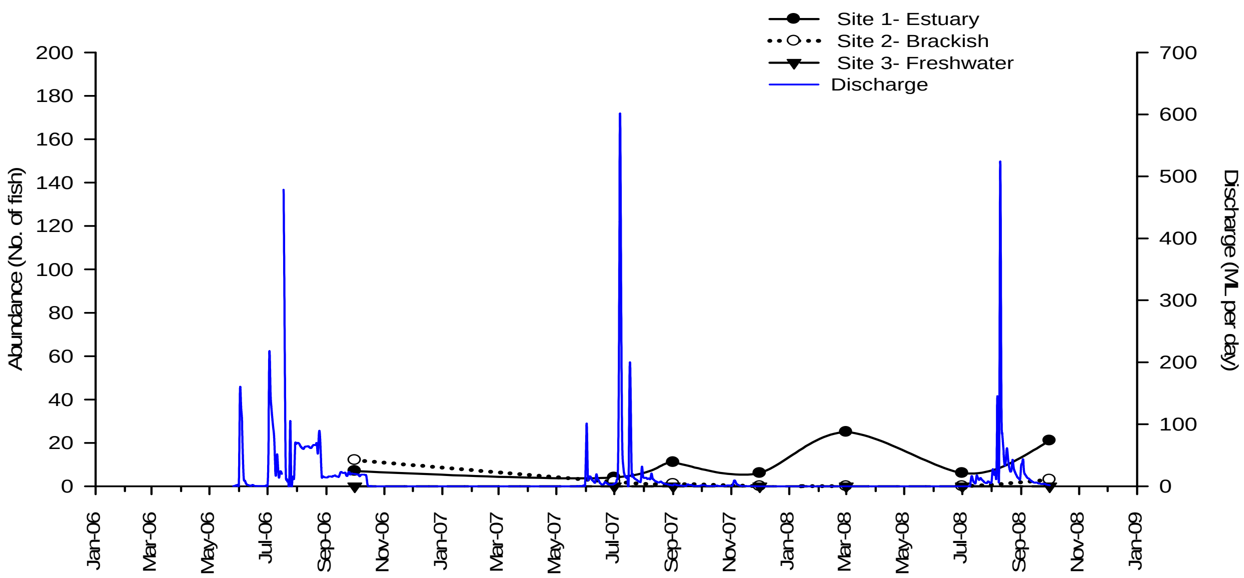
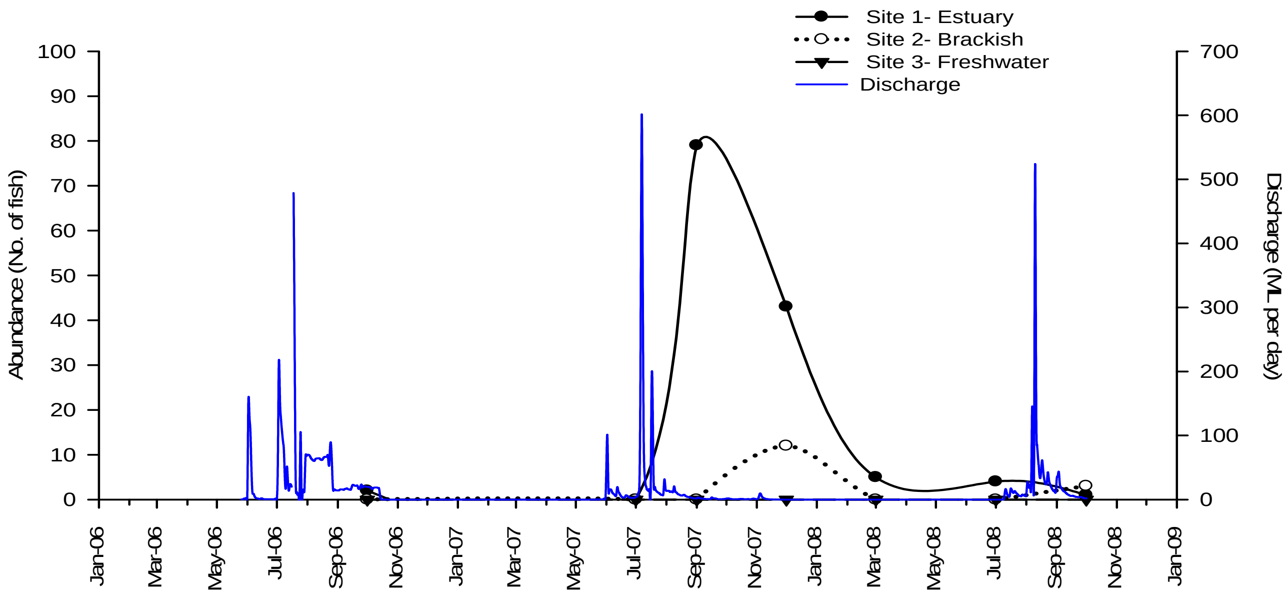



Figure 20e-f. Abundances of e: juvenile and f: adult black bream in the lower Onkaparinga River in relation to catchment flows over the course of the study.

Flat-tail mullet (Juveniles) (20g)




Flat-tail mullet (Adults) (20h)

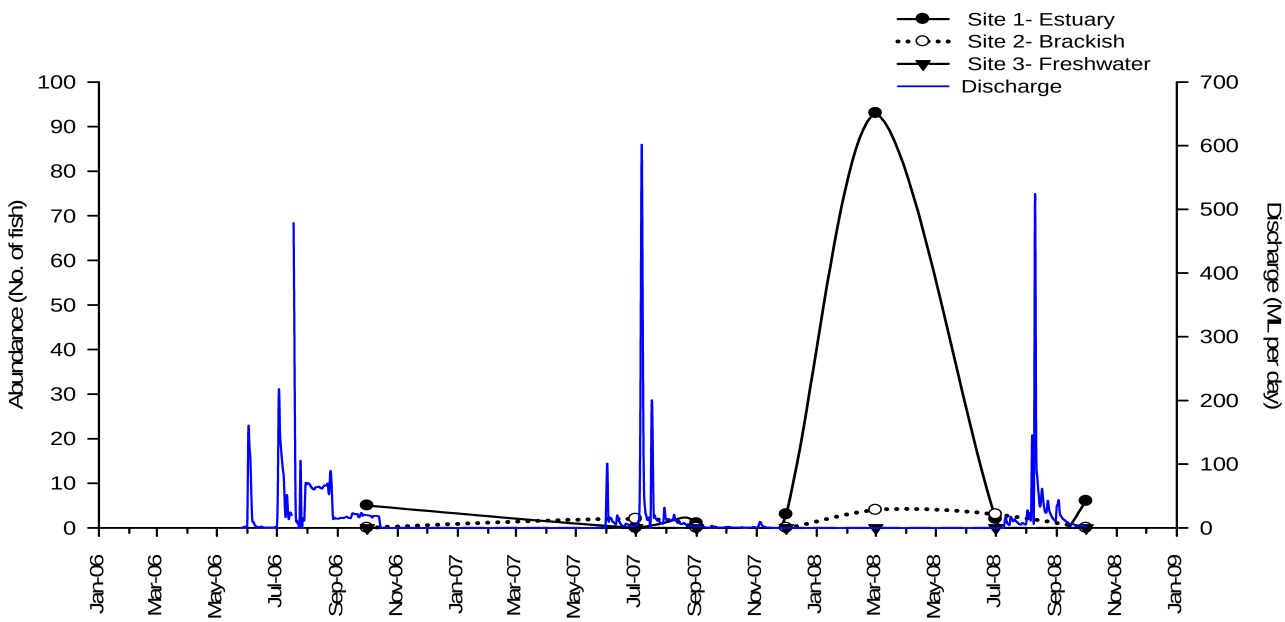
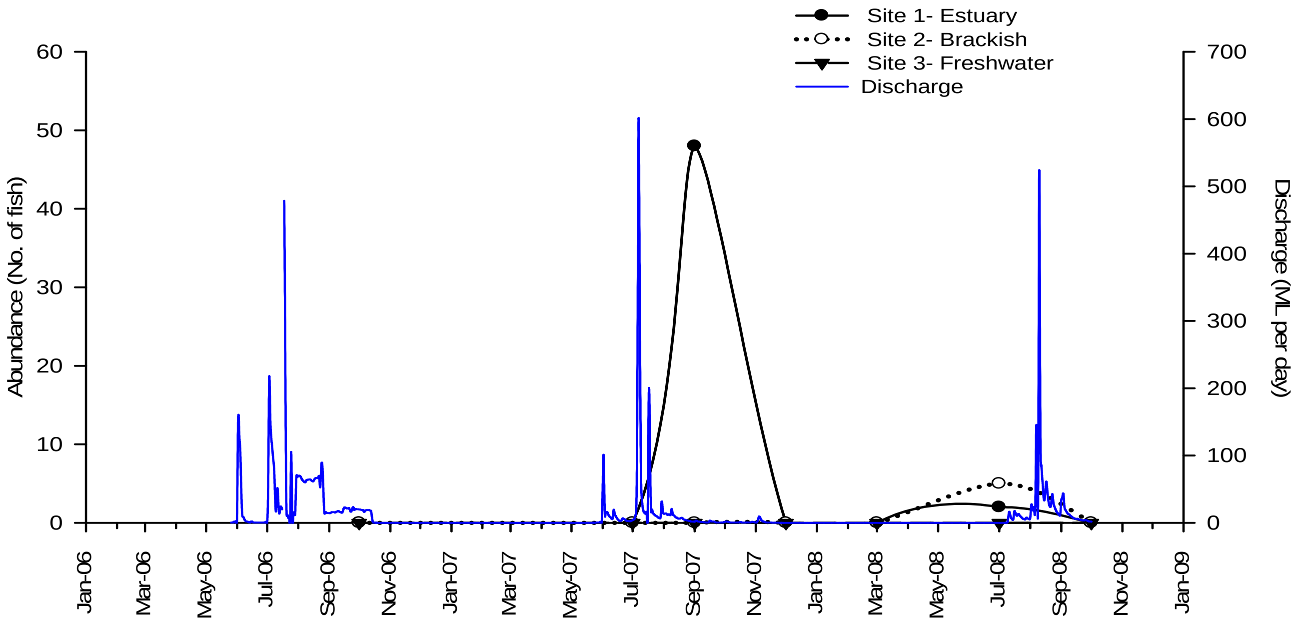



Figure 20g-h. Abundances of g: juvenile and h: adult flat-tail mullet in the lower Onkaparinga River in relation to catchment flows over the course of the study.

Yelloweye mullet (Juveniles) (20i)




Yelloweye mullet (Adults) (20j)

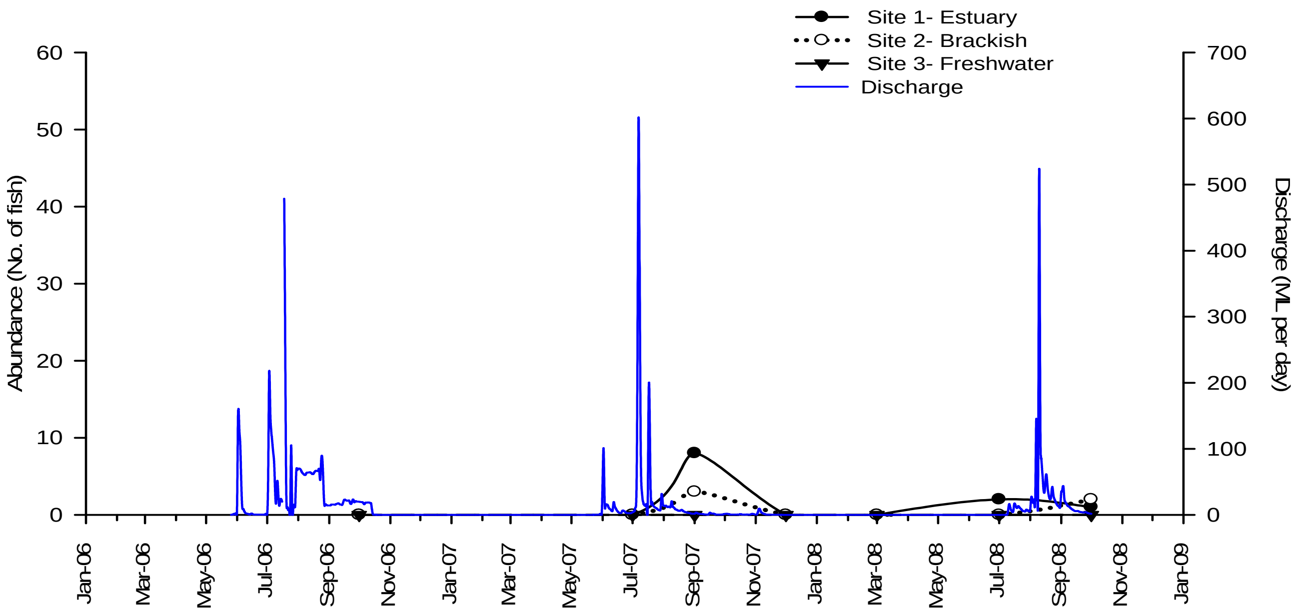



Figure 20i-j. Abundances of i: juvenile and j: adult yellow-eye mullet in the lower Onkaparinga River in relation to catchment flows over the course of the study.

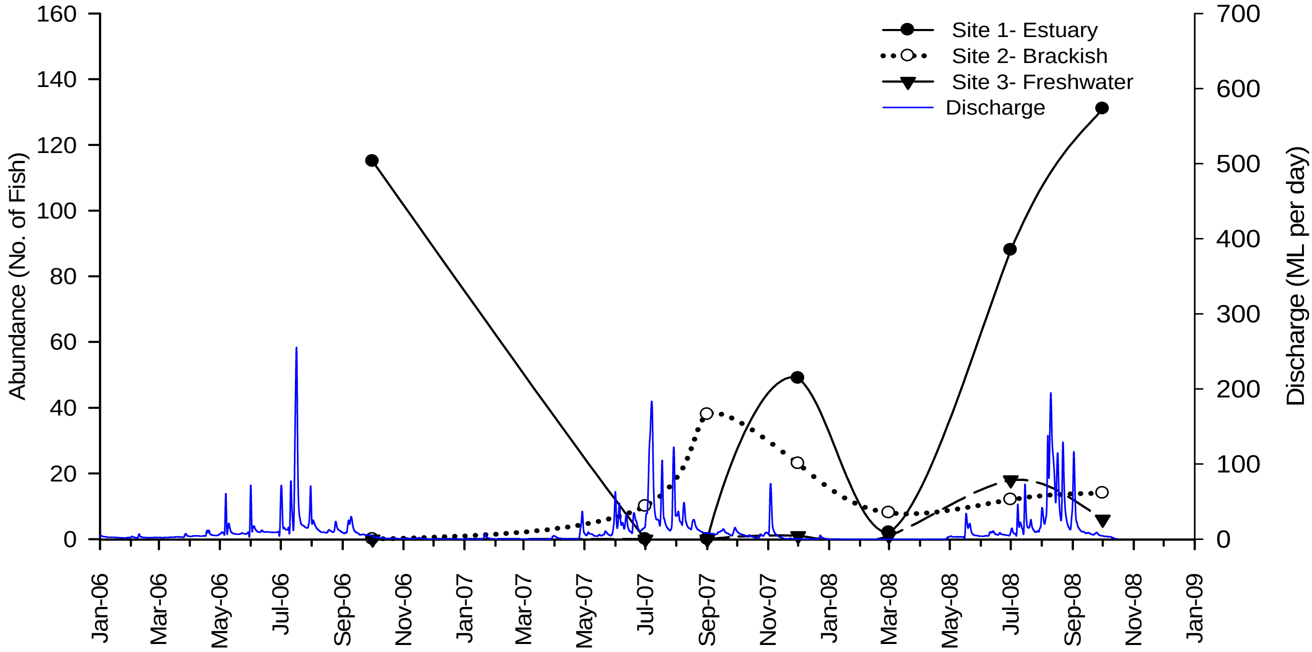
## Myponga Recruitment & adult abundance

Juvenile abundances of common galaxias peaked each year during spring/early summer, with highest catches in the estuary and middle reaches (Figure 21a). Curiously, juvenile common galaxias abundance remained high throughout 2007/08 in the middle site suggesting a possible stranding of recruits at the estuarine/freshwater interface. Adult abundances increase dramatically in the freshwater site over the course of the study, peaking in winter and spring each year (Figure 21b). The estuarine site fluctuated differently with small peaks in adult abundance during winter and spring, whilst the adults in the middle site increased gradually over '07 and declined gradually over '08.

Juvenile congolli showed relatively low abundances with small peaks in spring each year following the peak flow season (Figure 21c). Adult abundance however, showed switching between sites with winter peaks in July each year predominantly located at the middle site. This pattern reversed in late spring, with adult abundances again concentrated in the freshwater site associated with an overall peak in adult abundance at all sites. The following July; however, adult abundance peak again moved to the middle site (Figure 21d). This may be related to spawning movements of congolli between freshwater and estuarine habitats as running ripe congolli were recorded during July when adult abundance peaks in the upper estuary. As with juvenile common galaxias, adult congolli numbers in the middle site remained high throughout summer '07 and all of '08.

Black bream juvenile abundance peaked in March '08 (Figure 21e), directly after a rise in adult abundance in Dec '07 and March '08 (Figure 21f) but only in middle and estuarine sites. This possibly represents spawning aggregation of adults and subsequent appearance of juveniles in the area. Flat-tail mullet had very high juvenile abundances across much of the study duration, with peaks in July '07 and '08 and another in December '07 suggesting multiple spawning or recruitment events for this species, predominantly in estuary and middle sites (Figure 21g). Adult flat-tail mullet abundance also rose in July each year (early spring in '06) coinciding with the winter peaks in juvenile abundance (Figure 21h). Yellow-eye mullet juvenile abundance peaked in spring each year but also rose in July '07 suggesting an earlier spawning event in that year (Figure 21i). A large peak in juvenile abundance occurred between spring '07 and autumn '08. This is matched by a rise in adult abundances each spring, with numbers remaining high throughout spring and summer '07 until autumn '08 (Figure 21j).

Common galaxias (Juveniles) (21a)




Common galaxias (Adults) (21b)

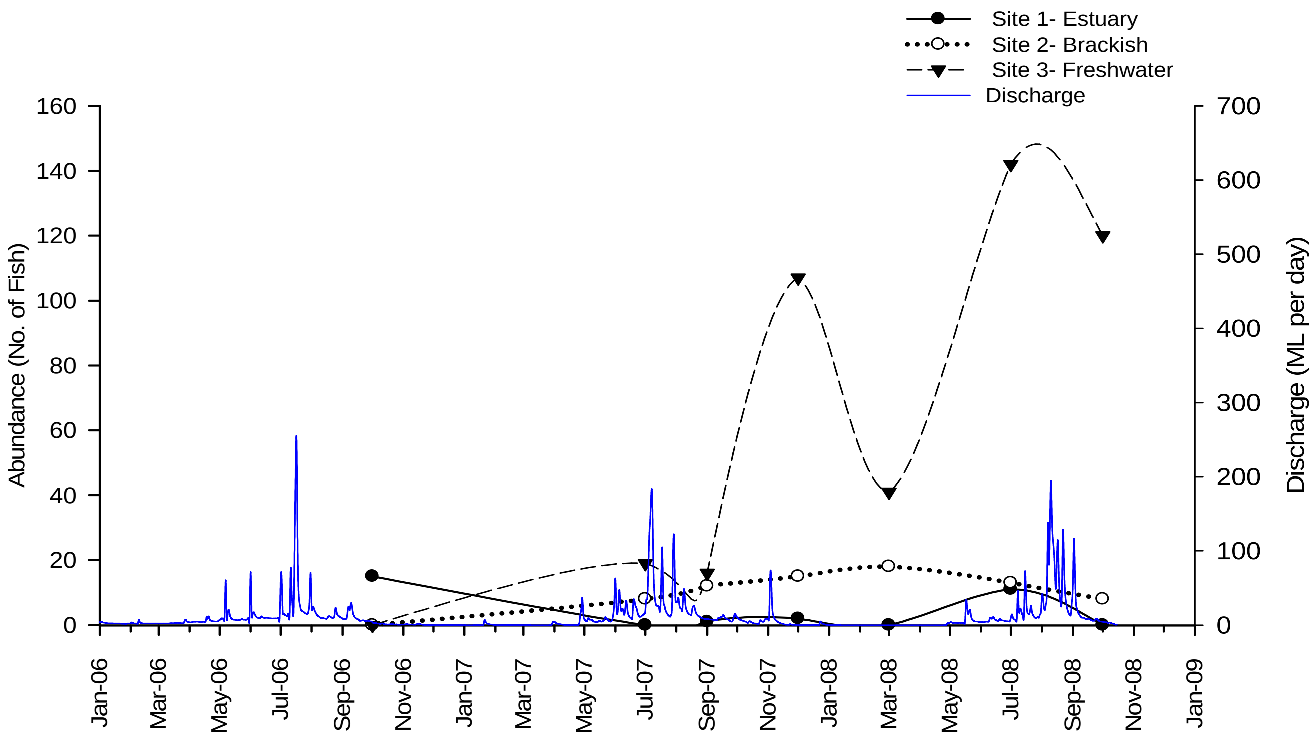
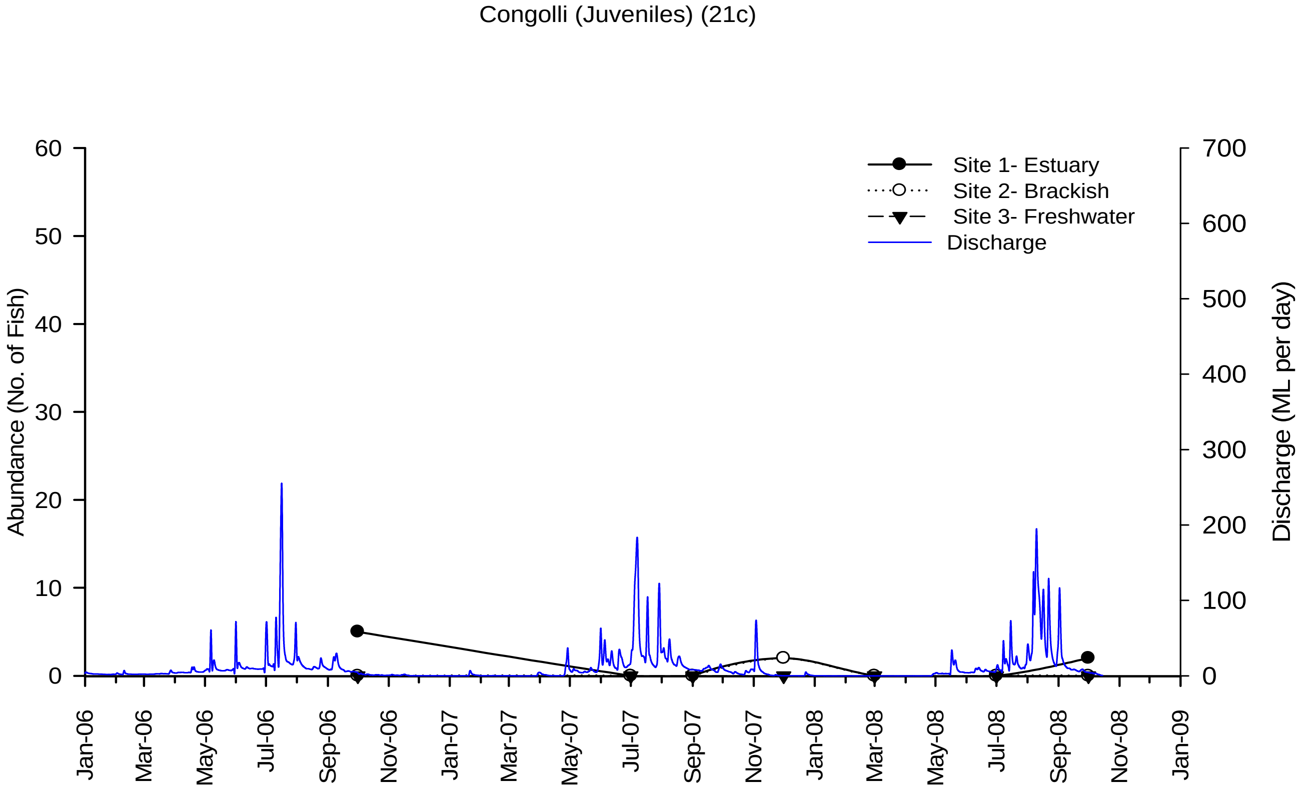



Figure 21a-b. Abundances of a: juvenile and b: adult common galaxias in the lower Myponga River in relation to catchment flows over the course of the study.



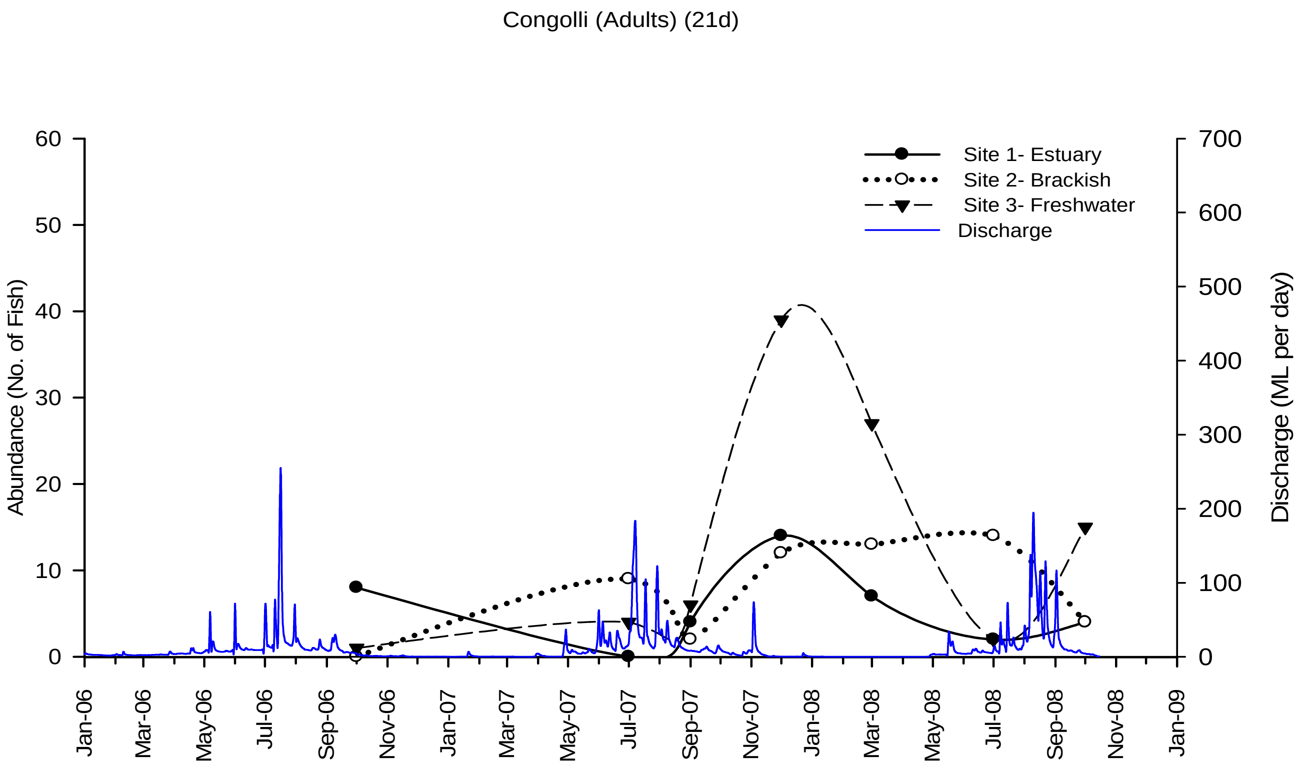
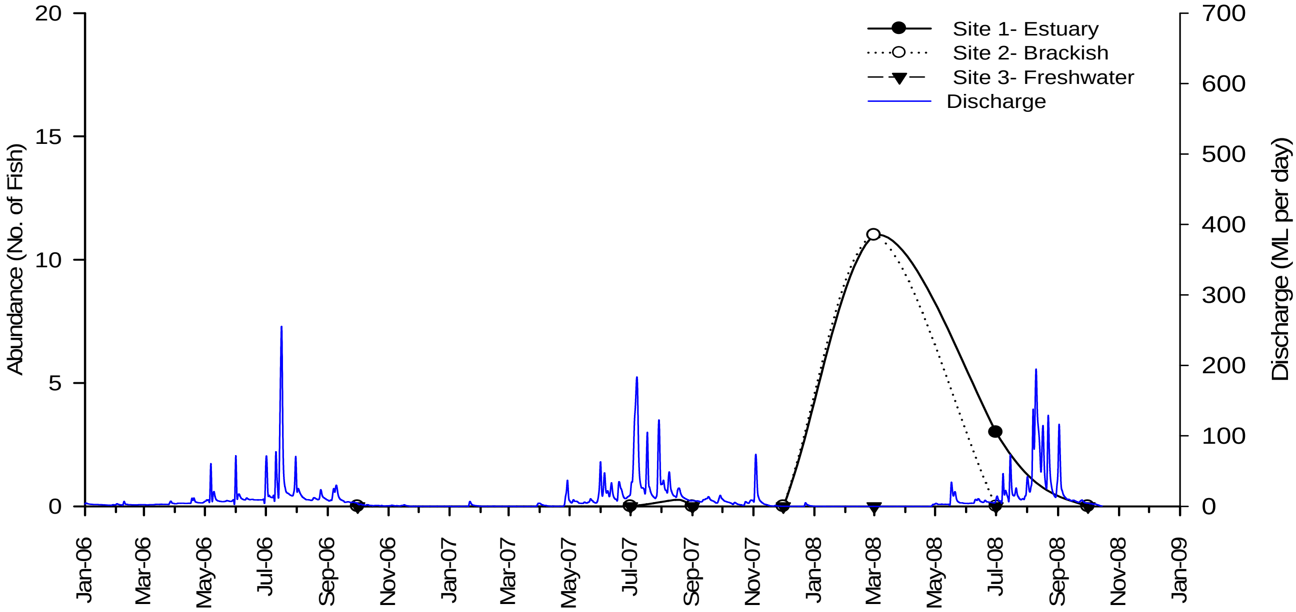




Figure 21c-d. Abundances of c: juvenile and d: adult congolli in the lower Myponga River in relation to catchment flows over the course of the study.

Black bream (Juveniles) (21e)




Black bream (Adults) (21f)

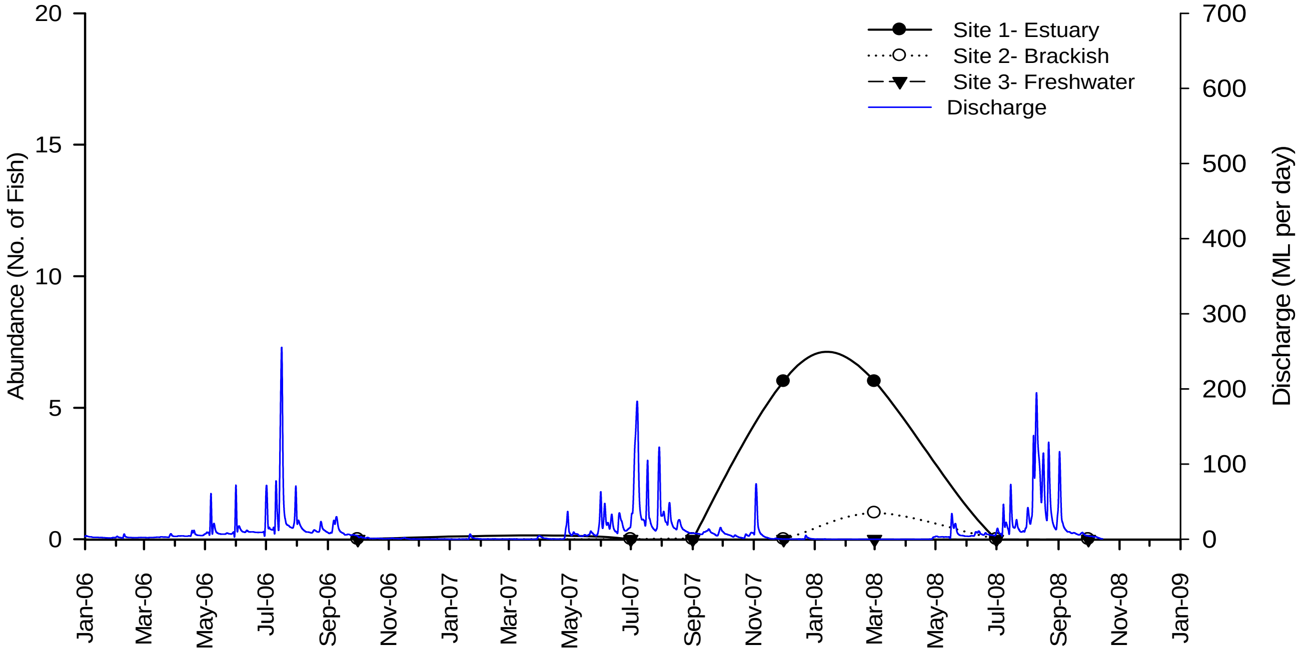
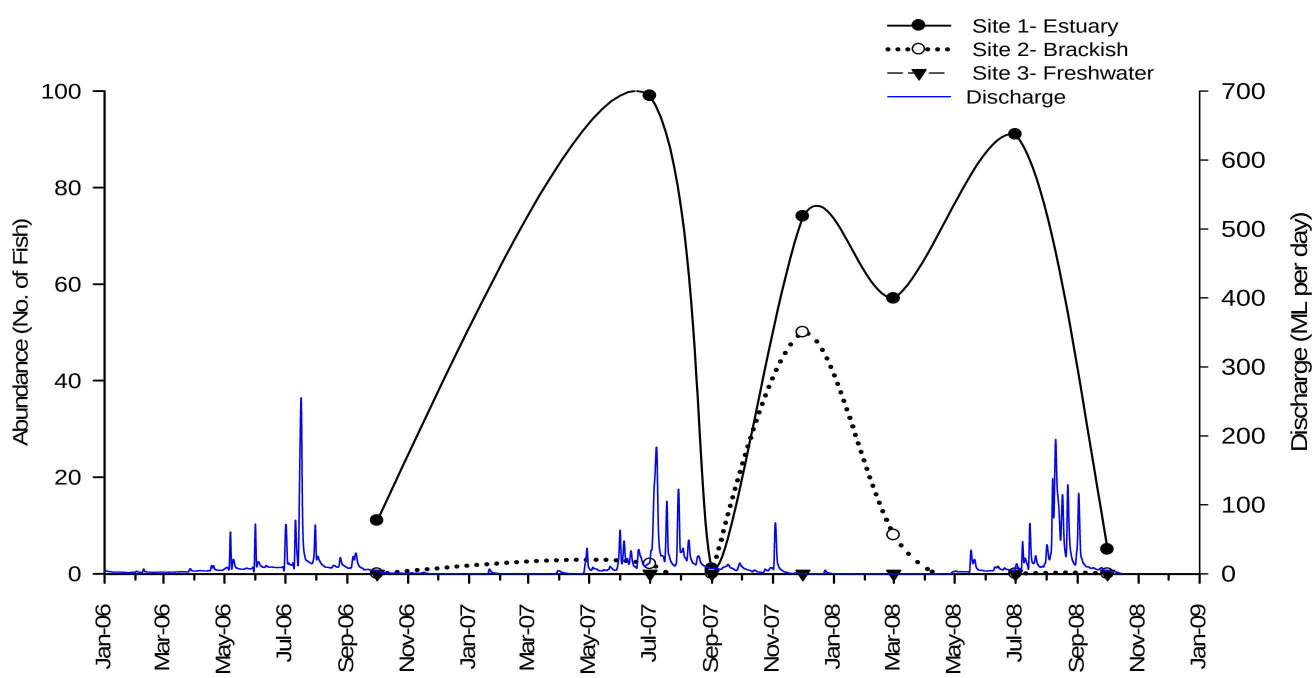



Figure 21e-f. Abundances of e: juvenile and f: adult black bream in the lower Myponga River in relation to catchment flows over the course of the study.

Flat-tail mullet (Juveniles) (21g)




Flat-tail mullet (Adults) (21h)

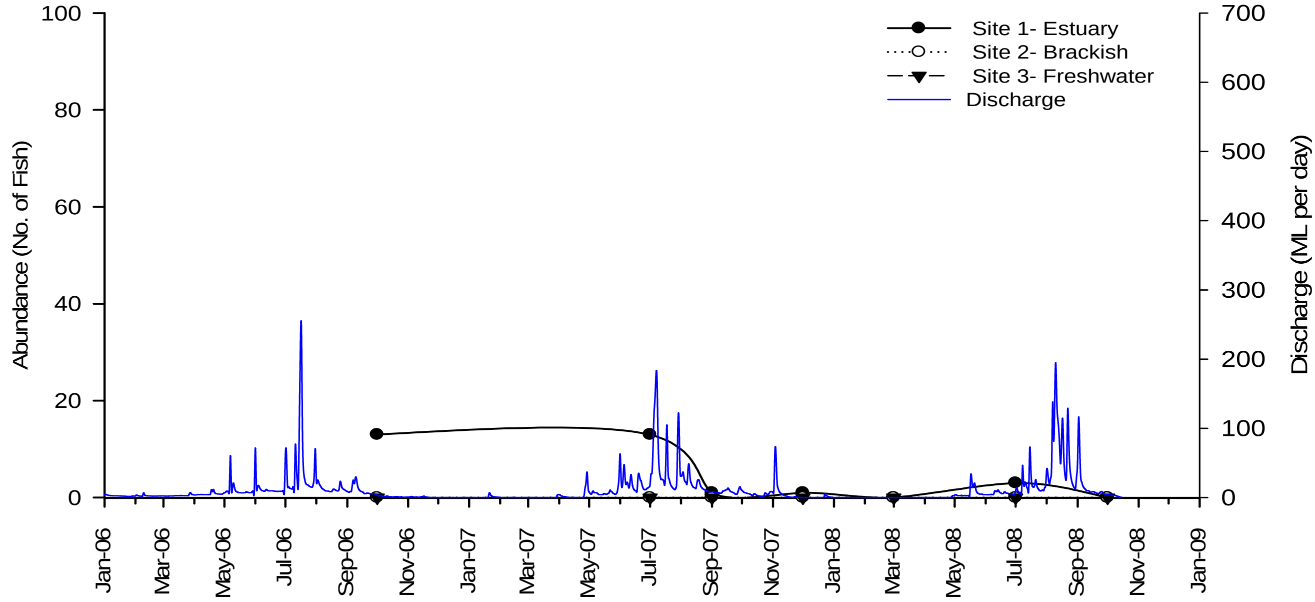
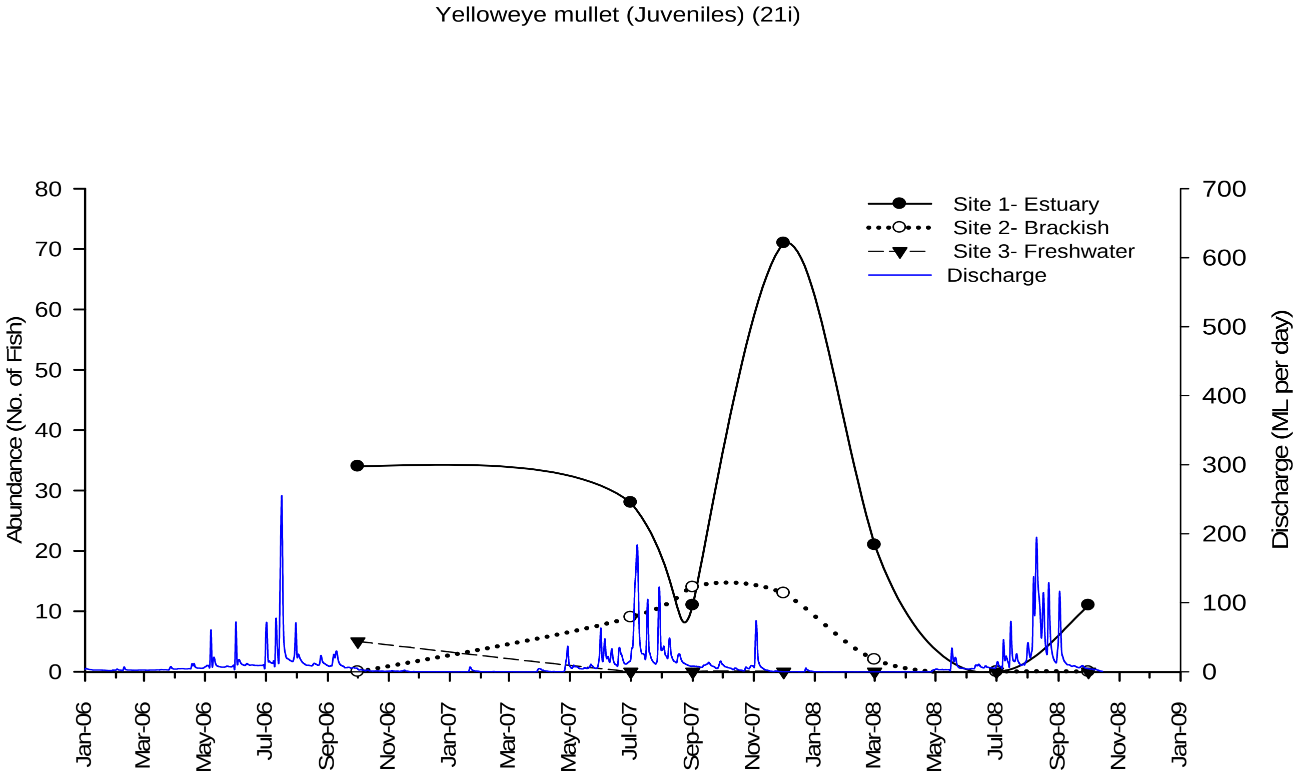



Figure 21g-h. Abundances of g: juvenile and h: adult flat-tail mullet in the lower Myponga River in relation to catchment flows over the course of the study.



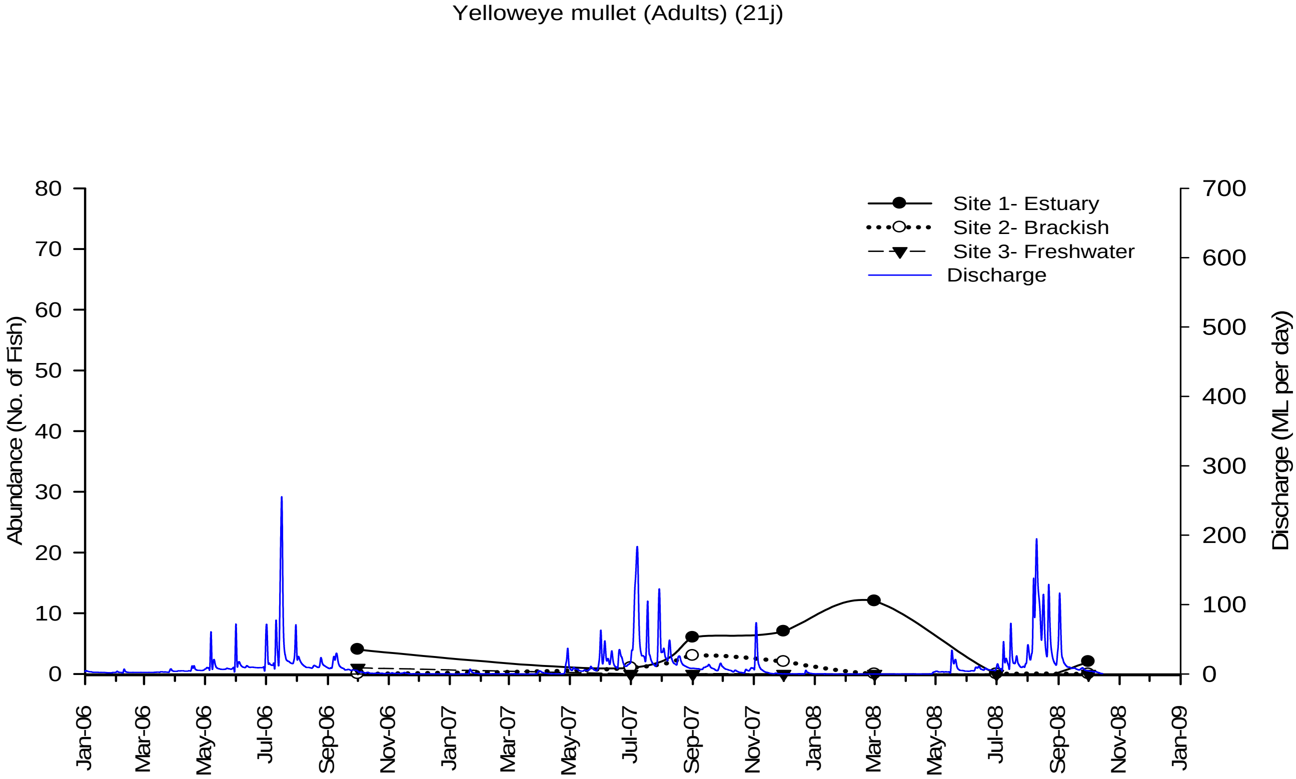




Figure 21i-j. Abundances of i: juvenile and j: adult yellow-eye mullet in the lower Myponga River in relation to catchment flows over the course of the study.

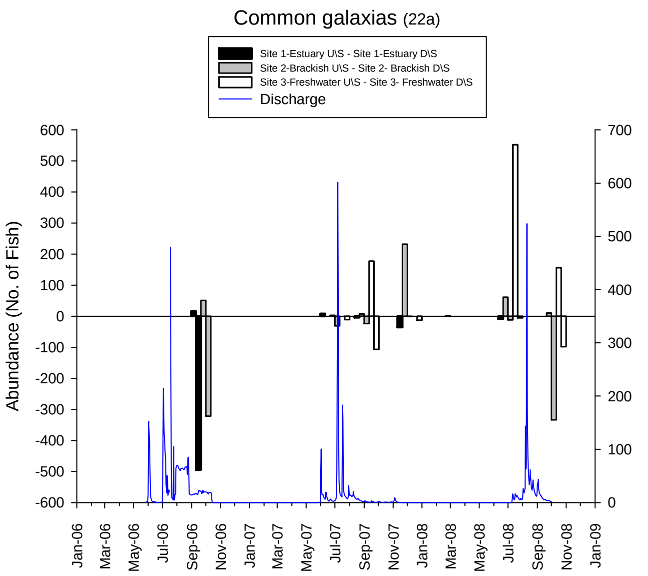
### 3.4 Directional fish migration

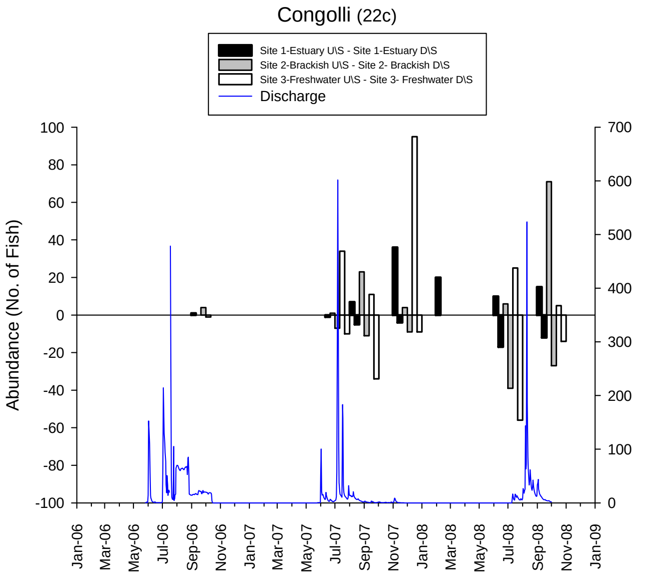
Directional migrations were assessed by comparing upstream and downstream facing nets at each site. The resulting data is presented as either positive (upstream movement) or negative (downstream movement) values for each species at each site over the course of the study (Figure 22). This assessment was carried out only for highly abundant species, namely, common galaxias, congolli, black bream, yelloweye mullet and flat-tail mullet. All species showed mixed movements and clear unidirectional patterns were few with high catches represented in both upstream and downstream nets, or varying spatially and temporally between sites and sampling trips. This makes the summary of directional movements complicated and a longer sampling period encapsulating several seasons is probably required to tease out movement patterns.

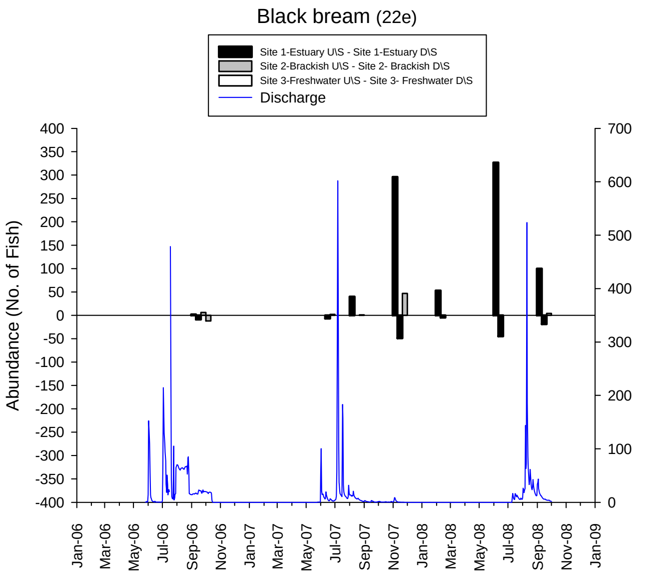
Common galaxias displayed downstream movements in both catchments during October '06 and '08, and upstream movements in December '07 and only in the Onkaparinga in July '08 (Figure 22a & b). All movements coincide with peaks in juvenile abundance (Figure 20a and 21a), although to a lesser degree in the Onkaparinga in '06. Congolli in the Onkaparinga appeared to make upstream movements in late spring in '07 and '08, preceded by mixed or downstream movement earlier in the flow season (Figure 22c). Congolli movement patterns in the Myponga were not clear and were mostly in a downstream direction (Figure 22d).

Black bream showed upstream migrations in the Onkaparinga estuary during October '07 and May and August '08 (Figure 22e), all of which coincide with peaks in juvenile abundance (Figure 20e) suggesting upstream recruitment of juvenile bream into the upper estuary at these times. Movement patterns of this species at Myponga were unclear (Figure 22f). Yelloweye mullet moved downstream in the Onkaparinga during August '07 (Figure 22g) and in the Myponga in August '06 (Figure 22h), both coinciding with peaks in juvenile abundance at these sites (Figures 20i and 21i). In the Onkaparinga they also moved upstream in July and October '08 (Figure 22g) although this was not associated with any peaks in juvenile or adult abundance. Flat-tail mullet in the Onkaparinga moved downstream in July '07 and upstream in November '07 and July and October '08 (Figure 22i), all of which coincide with peaks in juvenile abundance (Figure 20g). In the Myponga River, flat-tail mullet moved upstream in October '06, December '07 and July '08 (Figure 22j), all of which also match peaks in juvenile abundance (Figure 21g).

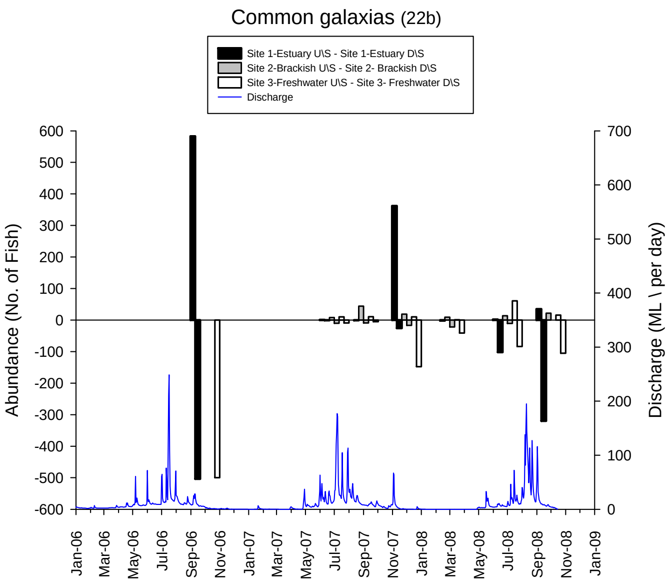
## ONKAPARINGA

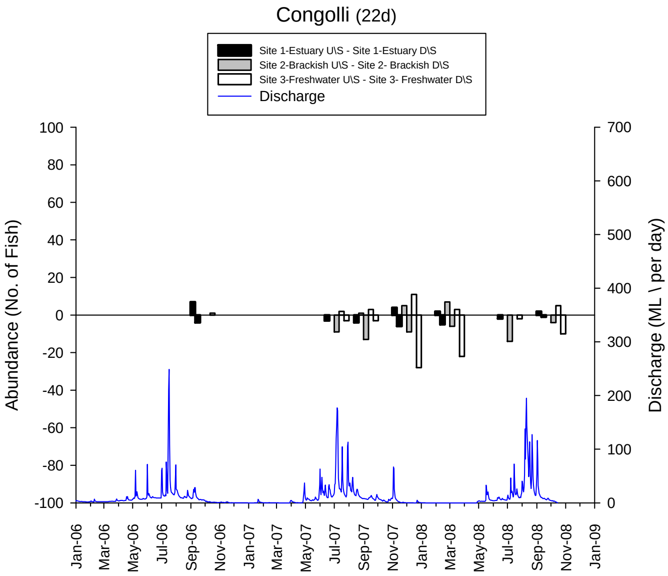


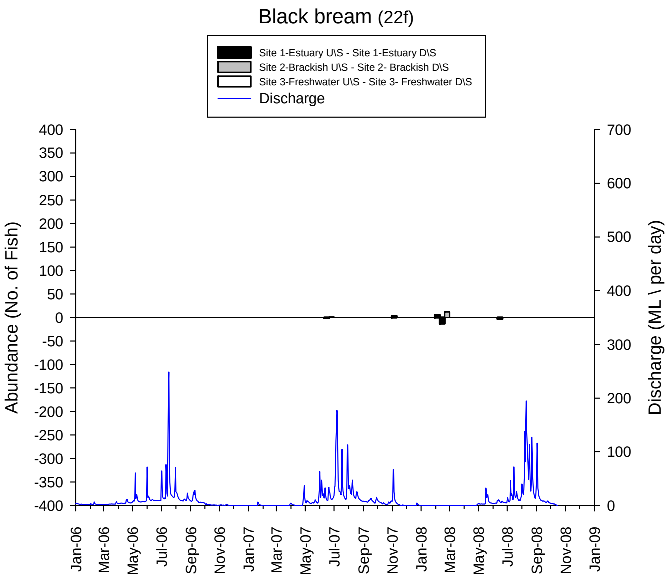



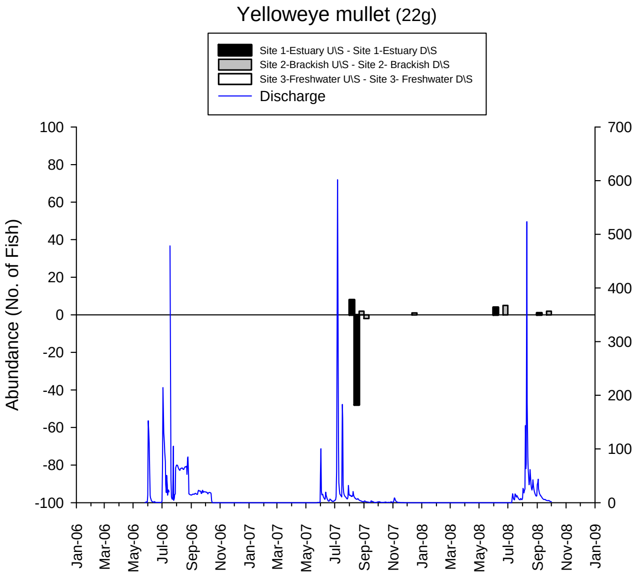

## MYPONGA

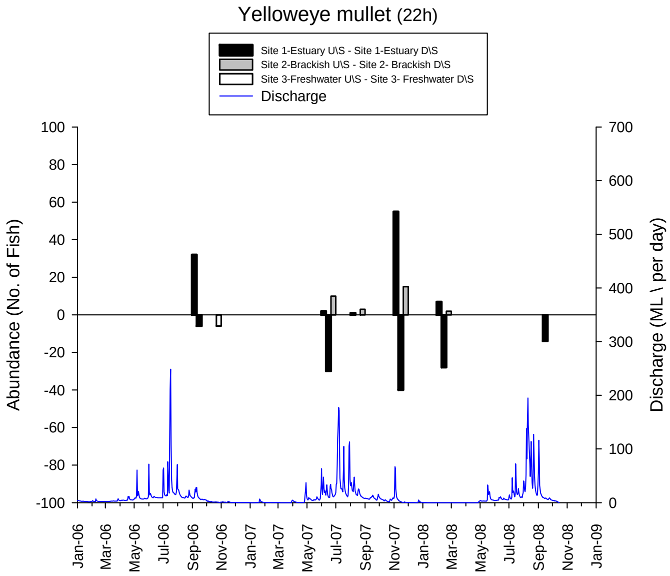


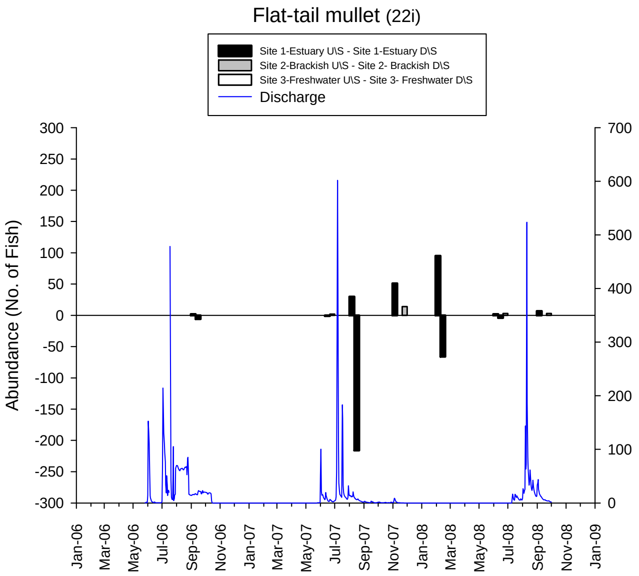



**ONKAPARINGA** **MYPONGA**



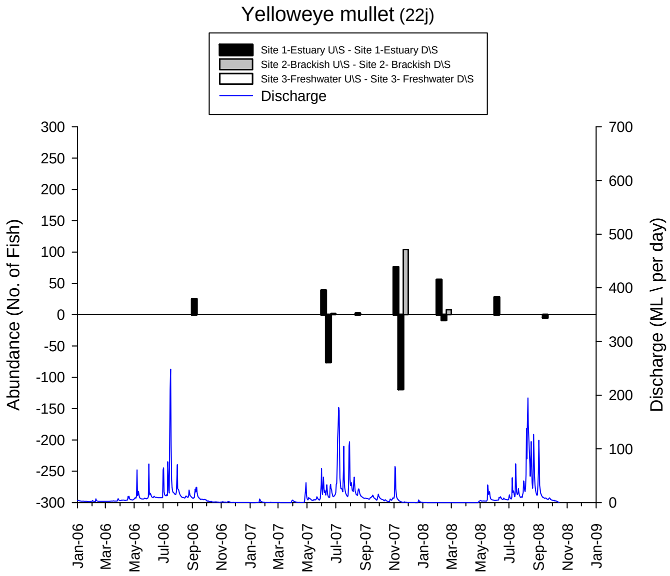
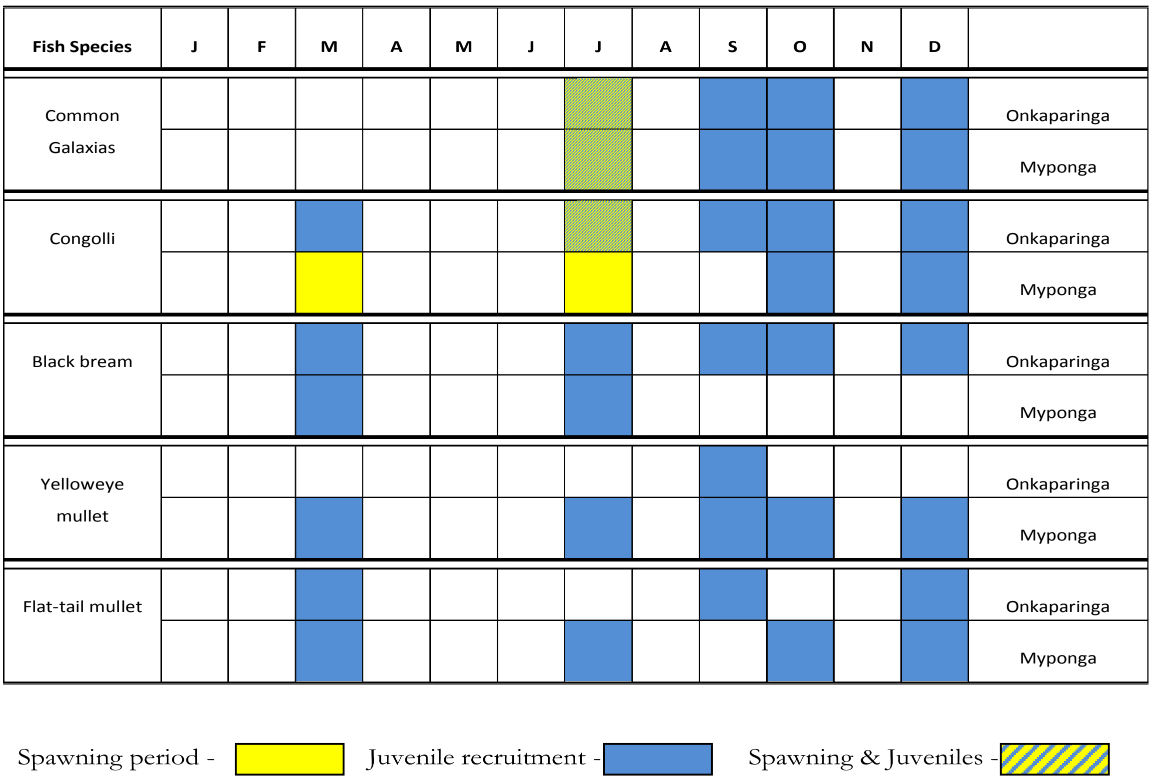




Figure 22a-j. Upstream versus downstream movement from pairs of directional fyke nets over the course of the survey. Data is for common galaxias a: in the Onkaparinga and b: in the Myponga; congolli c: in the Onkaparinga and d: in the Myponga; black bream e: in the Onkaparinga and f: in the Myponga; yellow-eye mullet g: in the Onkaparinga and h: in the Myponga; and flat-tail mullet i: in the Onkaparinga and j: in the Myponga, shown in relation to river flows. (Note: data is presented as either positive (upstream movement) or negative (downstream movement).

### 3.5 Spawning and juvenile recruitment calendar

Five fish species common to both catchments exhibited clear patterns of spawning and juvenile recruitment over the course of the study. A calendar indicating the months where spawning and recruitment events were observed is presented below in Figure 23. Common galaxias were found to be ripe and/or producing milt in July within both catchments, with juvenile recruitment occurring throughout spring and early summer in both catchments (Figure 23). Spawning (ripe adults present) for Congolli also occurred in July in both catchments, but also occurred in March in the Myponga catchment. Juvenile recruitment for Congolli occurred in March and from Sept-Dec in the Onkaparinga and Oct-Dec in the Myponga River. No spawning period was recorded for black bream; however, juvenile recruitment occurred in both catchments in July and from Sept-Dec in the Onkaparinga catchment. Yellow-eye mullet juvenile recruitment occurred in September in the Onkaparinga, but was recorded in March, July, September, October and December in the Myponga River. Flat-tail mullet also didn't have a spawning period recorded, but juvenile recruitment occurred in March, September and December in the Onkaparinga and March, July, October and December in the Myponga River.

Figure 23. Annual calendar indicating spawning periods and juvenile recruitment of 5 common fish species found in the Onkaparinga and Myponga Rivers between October 2006 and 2008.



### 3.6 Hypersalinity and Fish Kill: March '07

A large fish kill occurred in the Onkaparinga estuary and middle sites during the March '08 sampling trip, with hundreds of dead fish being recorded throughout both sites. Although no detailed assessment of the kill was made, black bream, flat-tail and yellow-eye mullet, congolli and *G. maculatus* were amongst the dead. Analysis of salinity levels revealed that the salinity in those sites had been steadily rising since September '07 when the last flow event occurred (Figure 24a). Salinity data revealed that these sites had salinities exceeding that of sea-water (~35ppt) for at least three months prior to the fish kill and that at the time of the kill was between 50ppt and 60ppt. This fish kill occurred during an extended period of low or zero flow and was associated with at least two events where storm surges and king tides raised the water level in the estuary above the church track ford causing sea-water incursion into the lower freshwater reaches of the lower Onkaparinga.

The freshwater site however was beyond the reach of these incursions and experienced no fish kill. Similarly, salinity levels in the Myponga estuary and middle site varied consistently across the study period peaking each winter below 20ppt, whilst the freshwater site peaked at a lower (~11ppt) salinity following flow events (Figure 24b). This suggests that the fish kill was the result of hypersaline conditions occurring within normally brackish habitats that were caused both by sea-water intrusion as well of a lack of freshwater flows that should normally have occurred during those storm events. However, it must be noted that the fish kill may have resulted in hypoxia or other water quality factors and not directly as a result of intolerance to hypersaline conditions per-se.

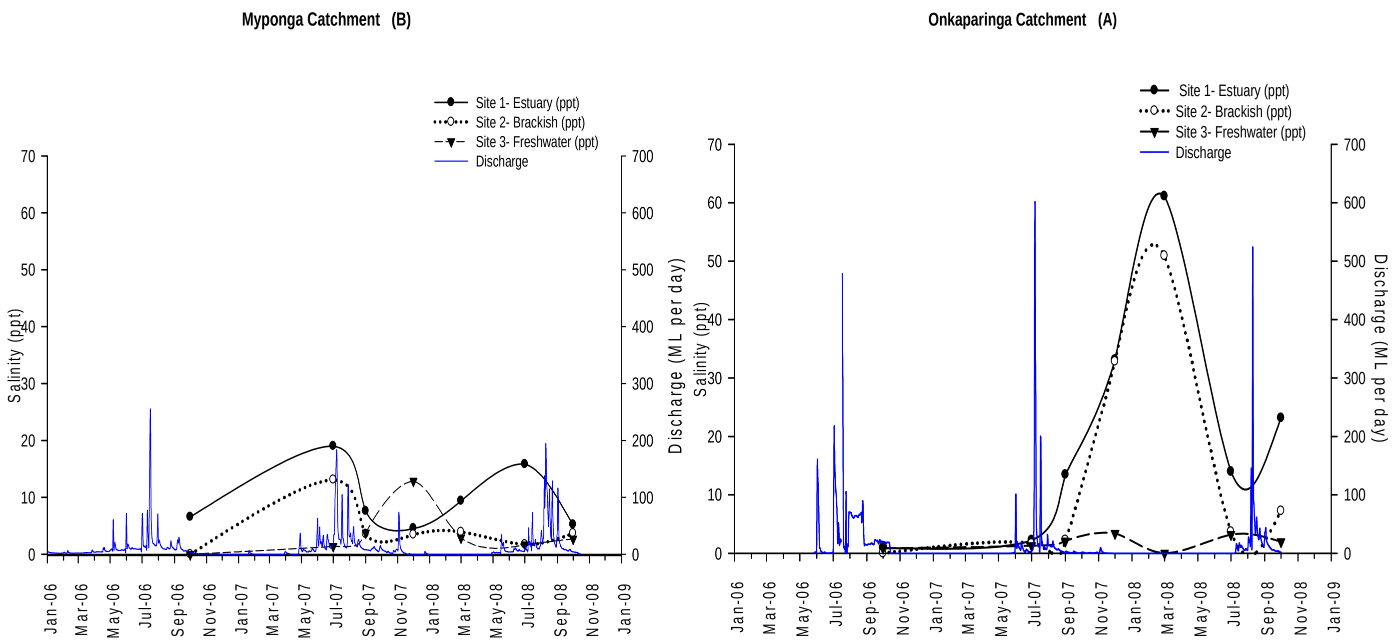



Figure 24. Fluctuating salinity levels for all sites in both catchments in response to environmental flows.

Figure 25. Dead estuarine fishes including black bream and mullet following the Onkaparinga estuary fish kill in March 2008.

# 4. Discussion

Although a relatively short term investigation of coastal fish ecology in the Onkaparinga and Myponga Rivers, this study provides the most significant ecological study of these fish communities to date and has provided some important knowledge regarding the general biology of resident fishes as well as some insight into the linkages between the biological processes of flow regime and marine/freshwater connectivity. The study revealed that the lower Onkaparinga River still possesses a range of native fish species that are reliant on freshwater/estuarine linkages. The study also revealed; however, the absence and potential local extinction of a number of diadromous species from the Onkaparinga and Myponga catchments.

Of particular note was the failure to detect pouched or short headed lamprey, two anadromous species historically recorded from the Onkaparinga and other catchments on the Adelaide coast (McNeil and Hammer 2007). Both species require access from the sea to upper catchment habitats in order to spawn and undergo juvenile development (Potter 1970). Lampreys require mud or silt habitats along river edges for juvenile habitat (Potter 1970). As a result of the dominance of rocky gorge sections (with bedrock and cobbled substrate) in the coastal freshwater reaches of both rivers, it is likely that lamprey would historically have travelled long distances upstream to find appropriate sediments within which to spawn and develop. The construction of the Myponga and Mount Bold reservoirs and the Clarendon Weir, has resulted in the fragmentation of the Onkaparinga and Myponga catchments, and represent barriers to fish movement, limiting access to freshwater spawning and juvenile habitats further upstream. Such barriers are known to restrict upstream movement of lampreys elsewhere, although populations can persist if appropriate spawning and juvenile habitats are available downstream of the obstruction

(Almeida *et al.* 2000, Quintella *et al.* 2003). Such downstream habitats appear to be absent from the Onkaparinga and Myponga Rivers. Thus, for populations of lamprey species to be re-established in these catchments it is likely that fish passage between the coast and upper sections of coastal catchments must be restored. Recent catches of both species of lamprey at the Torrens River mouth suggest that remnant adult populations may still be available to restore catchment populations, although there is no evidence that lamprey are currently attempting to recolonise the Onkaparinga or Myponga Rivers, perhaps due to a high degree of home river fidelity with adults returning largely to nursery sites.

The climbing or broad finned galaxias (*Galaxias brevipinnis*) was also absent from the lower Onkaparinga and Myponga River catches despite being recorded from both catchments in the past (McNeil and Hammer 2007). Adults of this diadromous species typically reside in freshwater, migrating to coastal freshwater habitats to spawn in autumn and winter (McDowall 1995, Koehn and O'Connor 1998), followed by a corresponding upstream migration of whitebait that should return from marine larval habitats (McDowall *et al.* 1975) in large shoals during spring (Rowe *et al.* 1992, McDowall 1995). Two juvenile *G. brevipinnis* have been recently collected within the Onkaparinga Gorge during fish surveys under the fish sustainability component of the MLR e-flows project, which implies that adult populations and appropriate spawning habitats may exist within the coastal section of that river. It is possible, however, that these juveniles may have come from landlocked populations within tributary catchments such as Kangarilla Ck, and have washed downstream from those habitats, rather than migrated from the sea (or indeed from outside the catchment). The use of diadromy in these populations appears to have been lost and may represent a significant impact of anthropogenic influences such as barriers or the presence of introduced predators such as redfin perch (*Perca fluviatilis*), which may intercept and/or prevent downstream adult migrations for spawning diadromous stages. In the main channel of the Onkaparinga, the loss of riparian forest and spawning habitats may have contributed to the decline of diadromous *G. brevipinnis* (Eikaas *et al.* 2005). There may; however, be an alternative explanation to the loss of diadromous *G. brevipinnis* that relates to flow regime in coastal areas. Koehn and O'Connor (1998) found that Victorian coastal populations of this species lay their eggs on riparian substrates during high flow pulses during autumn. These eggs are stranded out of the water but survive on damp substrates and subsequently hatch upon reinundation during subsequent flow pulses to be washed to sea. The loss of smaller flow pulses relating to autumn and winter rainfall is a major component of the modern hydrograph resulting from the regulation provided by Myponga, Clarendon and Mount Bold reservoirs. The evolution of spawning behaviours so closely linked with subtle aspects of river flow regime may lead to dramatic collapses of these diadromous populations following the loss of these critical hydrological components. This is likely to have occurred in the Onkaparinga and to a lesser degree in the Myponga River, and may have restricted this species to landlocked populations in tributary streams above migrational barriers.

A further diadromous native fish the short finned eel (*Anguilla australis*) was recently discovered near Clarendon in the Onkaparinga River (McNeil *et al.* 2009a) although it is not known whether this individual was translocated by humans into the catchment from elsewhere, or if a naturally occurring diadromous population of eels actually exists in the Onkaparinga River. Coastal rivers of the Gulf St. Vincent are on the western boundary of known natural distributions for this species and similar discoveries and anecdotal reports from the Lower River Torrens, Kangaroo Island and the Fleurieu Peninsula increase the likelihood that diadromous eel populations may exist on the Adelaide coast (McNeil and Hammer 2007, McNeil *et al.* 2009a). These rivers may only be colonised in years where oceanic currents are strong enough to push returning elvers westward into the Gulf. The present study; however, found no indication of juvenile eels entering the catchment during spring /summer or movement of adults to the sea. If eels are part of the natural population, it appears that recruitment may be sporadic and irregular and adults found in the Gulf St. Vincent are likely to be remnants from rare recruitment years or have been introduced manually by the surrounding community.

Only a single diadromous species was found to be abundant and flourishing in coastal habitats during the study. The common galaxias was found to be developing spawning condition in both rivers during July and there was evidence of regular recruitment events as well as the persistence of good populations of adults to maintain reproductive potential and support population viability. Whilst movement data was less than clear, there was an overall pattern of adults moving through freshwater and estuarine habitats during the winter spawning season, which was followed in spring and early summer by large abundance peaks of juvenile fish returning from marine larval habitats (McDowall *et al.* 1975). There was also some evidence that the volume of recruitment peaks may differ somewhat, although the duration of the trial and irregularity in early sampling precludes solid comparisons across the years.

This data reveals two critical aspects of riverine flow regime that must be protected to sustain successful spawning, larval development and recruitment of this species. The first is that winter flows are critical in providing spawning cues for adult galaxiids and for providing the connectivity required to access spawning habitats and for newly hatched larvae to be washed out to sea where they can feed and develop. This requires that winter flow rates be sustained at the highest level possible. Any development in the Onkaparinga catchment that may reduce the volume of winter flows may pose a direct threat to the survival of common galaxias through the failure of flow linked spawning requirements in this species. The low winter flows that are currently reaching the Adelaide coast appear to be sufficient for maintaining local populations but any further reduction in the volume or duration (particularly those that reduce late autumn flows) are likely to pose significant threats to the population. Autumn flows have already been reduced as a result of the impact of climate change on rainfall patterns in south eastern Australia and therefore future autumn flows may have to be provided through direct management of flow regime. In short, environmental flows may be required in autumn under developing climate change to support spawning and recruitment of common galaxias.

The second aspect of flow regime crucial for this species is the maintenance of spring and early summer flows to provide access for whitebait into freshwater habitats. Under natural flow regime, high winter rainfall would move more gradually down through catchments, providing coastal river flows long after the decline in rainfall moving into early summer. Under current management; however, these flows are captured within large water storages and spring flows are dependent on runoff from the small catchment area downstream of the Onkaparinga and Myponga storages. As a result, flows decline sharply in spring and do not continue into early summer. This scenario is likely to lead to stranding of whitebait within estuarine habitats, or lower reaches of rivers near the coast. In the Myponga estuary, whitebait persisted within the estuarine and middle sites far longer than usual during extremely low flows in spring and summer '07. The provision of spring flows is likely to have seen these whitebait move upstream into freshwater habitats. These results suggest that environmental water allocation may be required to supply the spring and early summer flows required to extend the temporal duration of flows each year and in turn provide hydrological connectivity for long enough to allow upstream migration of galaxiid whitebait into freshwater habitats with enough duration to provide access to inland habitats within the WMLR. This second aspect may also contribute to the loss of diadromous *G. brevipinnis* populations from these rivers as they generally inhabit upland streams which require longer periods of flow for juveniles to travel all the way into these higher catchments. Reductions in the duration of spring flows under river regulation are likely to preclude *G. brevipinnis* whitebait from reaching these adult habitats (Mackay *et al.* 2008).

The study found that significant populations of congolli persist within coastal reaches of the Onkaparinga and Myponga Rivers and that these populations were able to spawn and maintain viable populations within these reaches. In the Onkaparinga, peaks in adult abundance during the winter spawning season coincided with the appearance of ripe fish in spawning condition and was followed in spring and summer by peaks in juvenile abundances, suggesting successful spawning and recruitment processes are operating for this species. Traditional models of spawning behaviour for this species suggest that large females persist within freshwater reaches, with smaller adults confined to estuarine and near shore marine environments (Piddington 1964, Hortle 1978, Koehn and O'Connor 1990). Whilst this model was not explicitly tested under the current project, the data certainly revealed peaks in adult abundance related to downstream movements during the spawning period in July each year. There was also some upstream movement found early in July '07 related to adult abundance peaks. Upstream movements; however, were clearly related to peaks in juvenile abundances in spring /early summer each year. In combination, this data supports the concept of adult downstream movement during the spawning season followed by juvenile upstream migrations into freshwater habitats later in spring. However, there may be more complex movement patterns occurring, for example, upstream adult movement early in the spawning season may represent the movement of male congolli from marine habitats into freshwater habitats as both males and females have recently been found in spawning condition within freshwater reaches of the Onkaparinga further upstream of the present sampling reach (McNeil *et al.* 2009a).

In the Myponga River, there were no significant peaks in juvenile abundance, nor were there any large upstream migrations. Constant patterns of downstream movement; however, were related with a gradual build up of adult congolli in the middle sites and a decline in adult abundance in the freshwater sites. These downstream movements are largely associated with large bodied (over 120mm in length see

Appendix B) and therefore most likely female individuals (SARDI unpublished data). This directly supports the conceptual model of large female congolli moving downstream to spawn, however the continual build up of these fish in the middle site over '07 and '08 may represent females moving to estuarine spawning habitats on small spring and summer flows and becoming stranded there over the long zero flow period over summer and autumn '08. The accumulation certainly disappears once flows return in July '08, and is followed by some juvenile recruitment suggesting that they may have spawned once flows returned. Overall, congolli spawning and recruitment are closely related to the flow season in both catchment and support for the generally accepted spawning model means that, as with galaxiids, congolli require winter flows for adult movement and extended flows into spring and late summer to allow both large adults and juvenile recruits to move upstream into freshwater habitats.

A number of freshwater obligate species were recorded in the Onkaparinga River but not in the Myponga. Large populations of flathead gudgeons were found to move into estuarine habitats at times, although the study did not provide any evidence as to the nature of this pattern. The species is highly tolerant of salinities above sea-water, and are unlikely to be impacted by normal estuarine conditions, but would need to spawn within freshwater reaches due to relatively salt intolerant egg and larval stages (McNeil 2009). Dwarf flatheaded gudgeon and the introduced eastern gambusia were also collected sporadically in the Onkaparinga and primarily in the freshwater and middle sites. These species potentially move downstream with flowing waters but are not permanent residents in saline habitats. No freshwater obligates were found in the Myponga River. This reflects either the historical absence of these species in the coastal reach or may represent the disappearance of these species due to the impact of Myponga reservoir, which may have dried the coastal reach in the past, with only euryhaline, diadromous or estuarine species being able to re-colonise. This is purely hypothetical; however, and no data is available to support this contention.

The euryhaline blue spot goby was found in reasonable numbers in both catchments as were purely estuarine species such as small mouth hardyhead and Tamar, bridled and glass gobies. Other marine and estuarine species appeared rarely in estuarine catches and may be temporary and opportunistic visitors to upper estuarine habitats such as those sampled here. Species such as Australian salmon and yelloweye/flat-tail mullet are known to move in and out of estuaries on a regular basis (McDowall 1976). Yellowfin whiting are a marine species but were found at the upper extent of the estuary under storm surge and king tide conditions and may therefore have been seeking refuge within calmer estuarine habitats. They were not found at any other time.

Flat-tail mullet did not move into freshwater reaches but were abundant in upper estuaries where they were recorded in adult and juvenile aggregations. These are likely to represent local spawning and recruitment aggregations and the data suggests that these are linked with freshwater flows, with all peaks in juvenile abundance following peaks in freshwater flow at both sites, apparently regardless of season. Similarly, yellow-eye mullet showed peaks in juvenile abundance following freshwater flow peaks or flow onset. Adult yellow-eye mullet were also found within the upper estuary predominantly during periods of high flow. Black bream also exhibited peaks in juvenile abundance following small flow peaks in both spring and autumn and may move into the upper estuary to spawn in response to flow. It appears that all three of these species remain largely within estuarine habitats but respond to freshwater flow events with peaks in both adult and juvenile abundances. This data suggests that the timing of freshwater flows may not be as critical for meeting the needs of these estuarine fishes as for species that have adapted life histories with an obligate freshwater phase. It should be noted; however, that flow related peaks in juvenile abundance for all three species were linked to flows in late spring and autumn and therefore any reduction in the duration of the flow season may impact on the ecology and population structure of these species. This evidence supports the claim for providing environmental flows to extend the duration of the flow season both into late spring and summer as well as providing earlier flow resumption in autumn in line with the onset of historical rainfall trends. Overall, any process that is likely to further reduce the duration and/or volume of freshwater flows may have significant impacts on sustainability and population viability of these estuarine fish species.

Significantly, the large fish kill witnessed in the Onkaparinga Estuary caused widespread deaths predominantly in these three estuarine species along with common galaxias stranded in the estuary due to failure of spring/early summer flows. The fish kill occurred in late autumn '07 following an extended period of zero freshwater flow, caused in part by the ongoing drought but in part failure to provide environmental flow allocations as outlined under the EWP plan (Pikusa and Bald 2005). Planned environmental flows, which could have prevented these fish deaths, were cancelled at the onset of the drought. The cause of the fish kill was a gradual increase in salinity levels over a six month period made worse by storm assisted tidal seawater intrusions, combined with a lack of river flows, even though heavy rains in the upper Onkaparinga catchment should have resulted in concurrent freshwater flows that would have alleviated the condition. The capture of this rainfall in water storage reservoirs; however, resulted in almost none of this rainfall making it to the coast. This event is a classic example of the disastrous consequences of preventing freshwater flows from reaching coastal riverine habitats. Carefully planned and timed environmental flows of appropriate duration are the only mechanism by which managers can prevent such deaths under current management scenarios. Furthermore, the event reiterates the critical need to supply environmental water to rivers and streams during drought, as opposed to retracting life saving provisions at such a crucial time. It is highly recommended that special provisions be sought to supply environmental flows during drought conditions. However, these provisions need to be delivered with great care as inappropriate flow delivery during drought periods can result in blackwater events that may threaten resident fish populations (Wallace *et al.* 2008). The event underscores the dependence of estuarine fishes on freshwater inputs. Future developments in water resource storage or water savings projects that may result in less freshwater flows reaching Adelaide's estuaries are highly likely to increase the incidence of large fish kills such as seen during the present study.

# 5. Conclusions

The study revealed that most of the native diadromous fish species and populations previously recorded in the coastal rivers of the Gulf of St Vincent appear to have likely become extinct in the Onkaparinga and Myponga Rivers. This includes the pouched and short headed lampreys climbing or broad-finned galaxias and possibly short finned eel. Common galaxias remain in viable populations in both the Onkaparinga and Myponga Rivers, with adult populations persisting in coastal freshwaters and larvae washed in to marine habitats during winter to return in spring. Congolli were also found to be present in both catchments in viable populations, with regular movement between freshwater and estuarine habitats recorded for both adults and juveniles. The study has revealed that these species are highly dependent on freshwater flows to provide access from freshwater to the sea, usually in late autumn/winter, and to provide access from marine and estuarine habitats upstream into freshwater for recruiting juveniles and returning adults, predominantly in spring and early summer.

These results have strong implications for flow management in the coastal rivers of Gulf St Vincent, in that environmental flows are required to provide autumn and spring flows, which have largely been stopped as a result of river regulation. Duration of flows must be long enough to provide access for diadromous fishes to migrate long distance into the catchment and tributary habitats. Furthermore, lack of transparency in flows that reflect broader catchment rainfall patterns are likely to have resulted in the loss of diadromous populations of climbing galaxias in both study catchments. A primary impact of flow management is the construction of large water storages within river channels such as the Myponga and Mount Bold reservoirs and the Clarendon weir. These large weirs act as barriers that appear to have prevented some native diadromous fish from reaching spawning and juvenile habitats in the upper catchment. This is believed to have resulted in the possible local extinction of both pouched and short head lampreys in these catchments. Populations of these diadromous species may be restored if fish passage is facilitated on the aforementioned regulatory structures and for similar barriers along the Adelaide coast such as Woodlands Weir on the Sth Para River. It may also pertinent to address the status of diadromous fishes in other coastal streams of the MLR and Fleurieu peninsula to ensure that these populations do not become extinct across the drainage. Management actions to bolster diadromous fish populations may be better directed towards catchments where viable populations are currently surviving although the location of such sites remains unknown (McNeil and Hammer 2007).

The study also revealed a strong relationship between freshwater flows and some estuarine and marine fish species which move into freshwater habitats, or upper estuarine habitat for spawning, juvenile recruitment, or to seek refuge during disturbances such as storms. In particular, black bream and mullet species appear to utilise freshwater flow events for spawning and recruitment with juvenile abundances in particular apparently driven by flow events in spring and autumn. Finally, estuarine fish species are dependent on freshwater flows to maintain salinity gradients throughout estuaries and to counteract large saline water intrusions during large tidal and storm events. Particularly during drought periods, freshwater flows are crucial for preventing estuarine hypersalinity events which were found to have directly caused large fish kills in the Onkaparinga estuary during the study.

In general, the study has shown that freshwater flows are essential drivers of a wide range of survival and life history strategies that maintain viable and sustainable populations of coastal native fishes. Under river regulation, both the volume of coastal flows and the temporal duration of the flow season (and subsequent duration of connectivity) have become dramatically reduced. Environmental flow provisions are urgently required to restore flows in late autumn and critically in spring and early summer to support sustainable native fish populations and to protect critical biological requirements of fishes. Lastly, the study has shown that environmental flows are also required to limit the duration of zero flow periods, particularly during drought or dry summers, to prevent fish deaths resulting from deteriorating water quality. These aspects of flow management must be integrated into existing water allocation plans and guidelines currently being developed within South Australia, and incorporated into planned environmental water trials.

The study has provided a good level of baseline knowledge and data that can be used to identify any possible responses of the Onkaparinga ecosystem to planned environmental flows. With similar species composition and fish abundances, the Myponga River provides a good control river from which trajectories of change may be assessed once the outcomes of flow provisions take effect. In particular, improvement in the species composition or abundances of native fish and the effectiveness of spawning and recruitment events and the successful migration of diadromous fishes throughout the catchment and tributary systems that result from environmental flows should be detected in the Onkaparinga but not in the Myponga River. As a result, future assessments of the effectiveness of environmental flows should utilise the current data as an indication of 'baseline' condition and future monitoring and assessment of environmental flows in the Onkaparinga should continue to include comparisons against the Myponga River as a control catchment.

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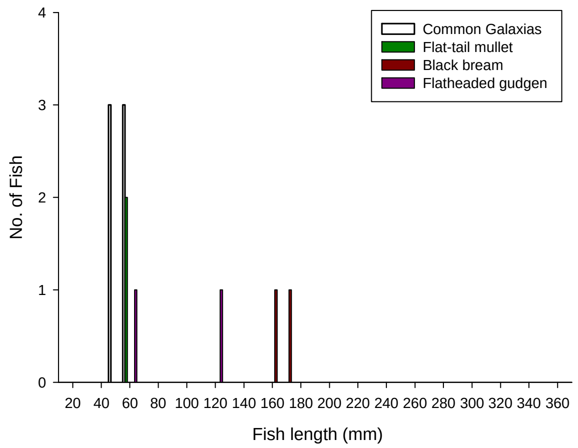
# 7. Appendices

## Appendix A. Length Frequency of fish species in the Onkaparinga catchment

Site 1- Estuary U\S (1/10/06)

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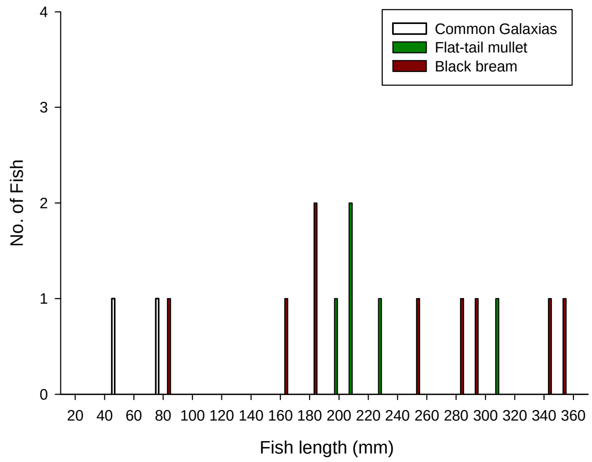


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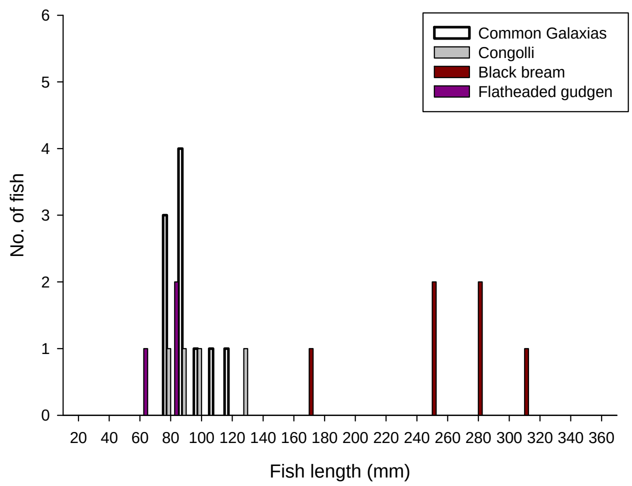


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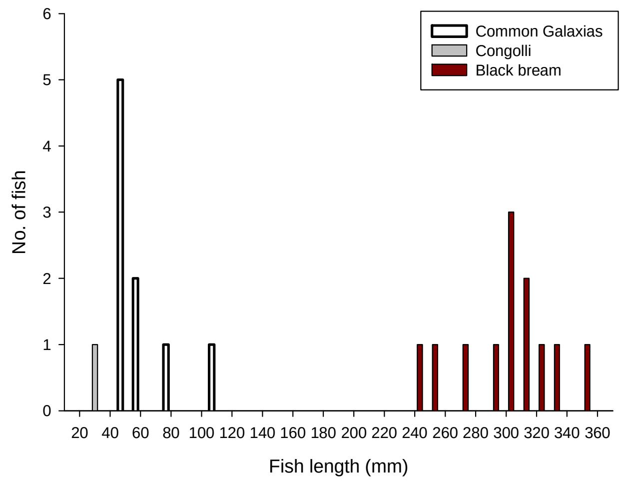


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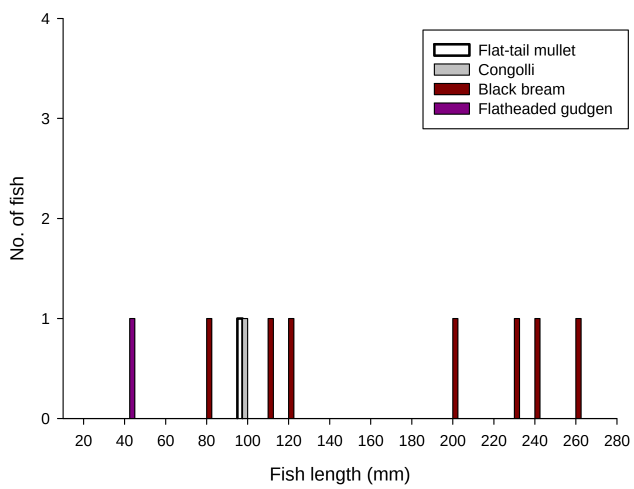


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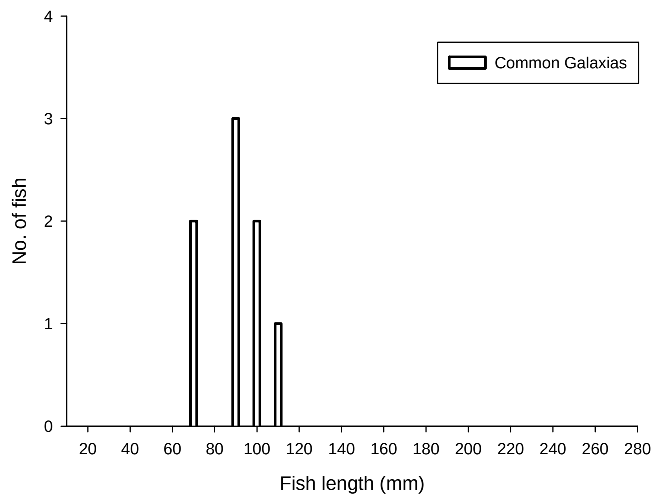
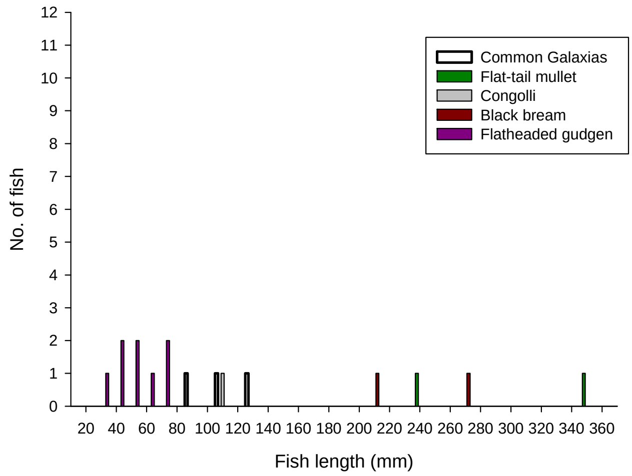


Site 2- Brackish (U\S) (1/7/07)

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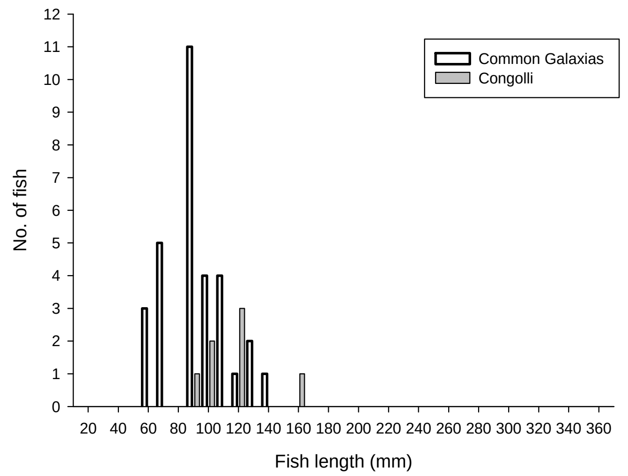


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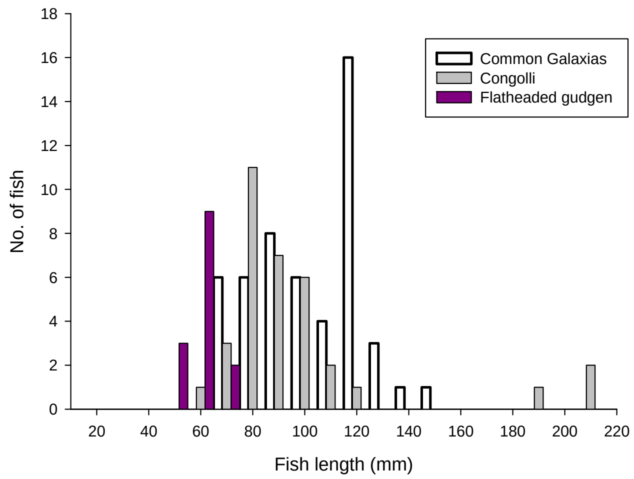


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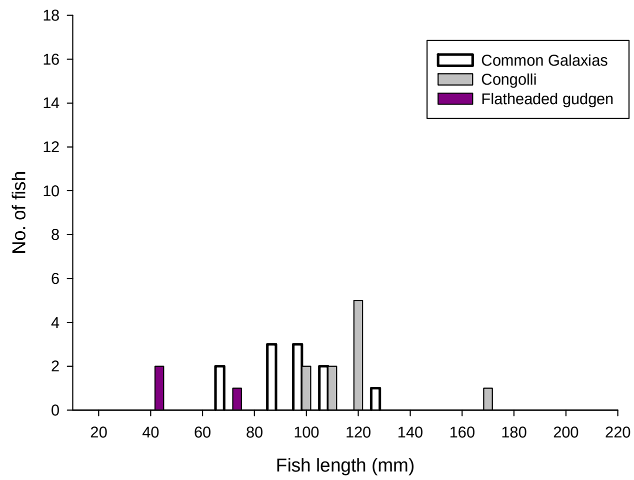
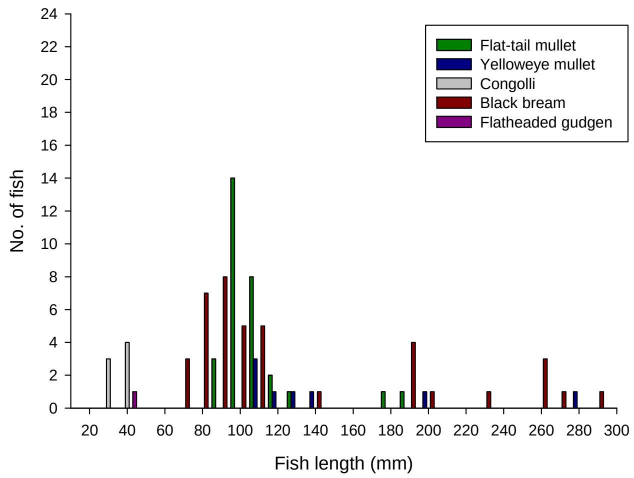



Site 1- Estuary (U\S) (1/9/07)

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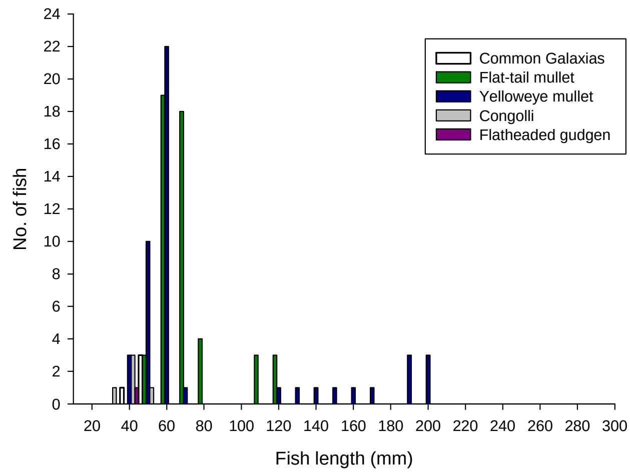
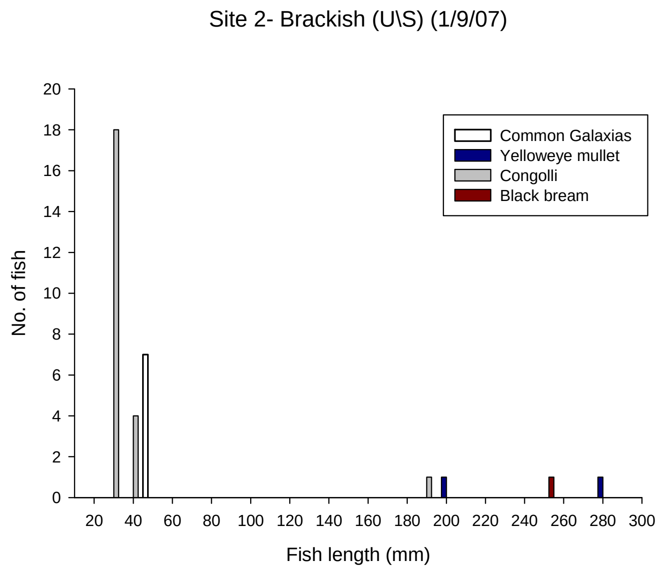
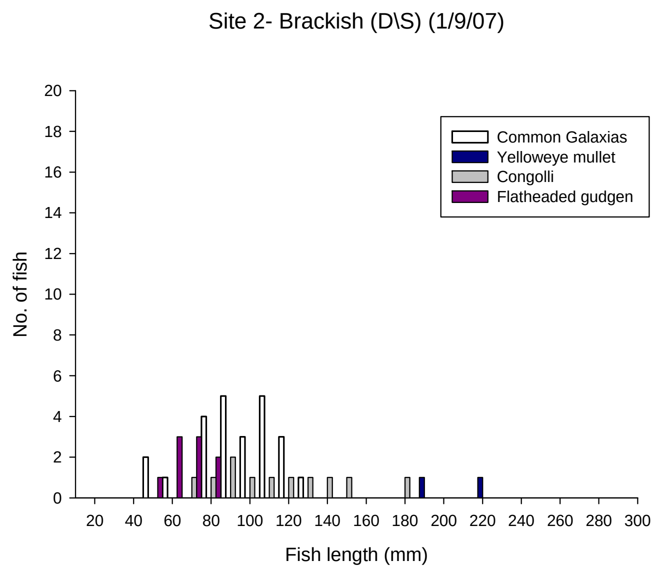
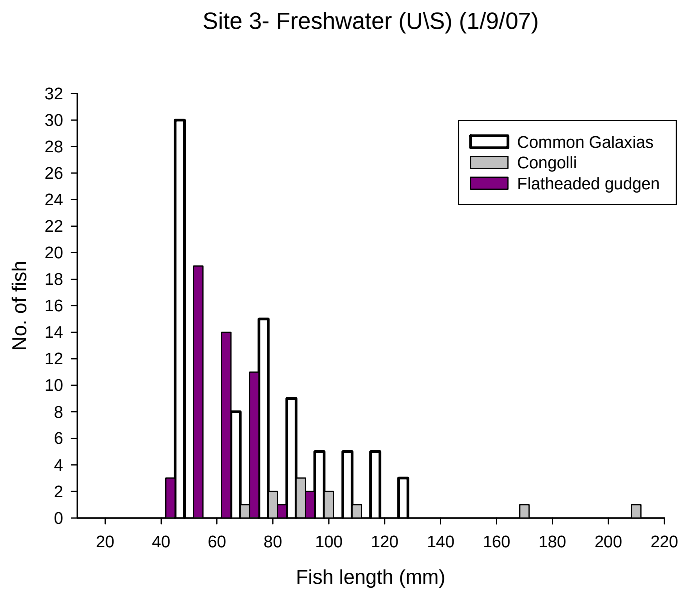
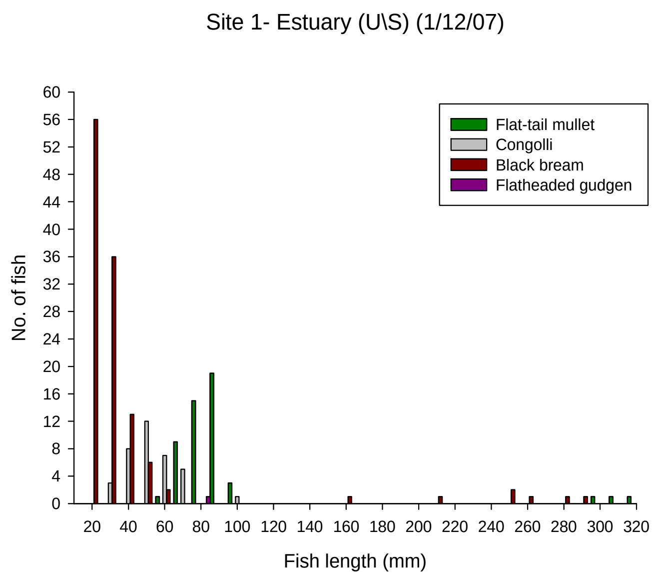
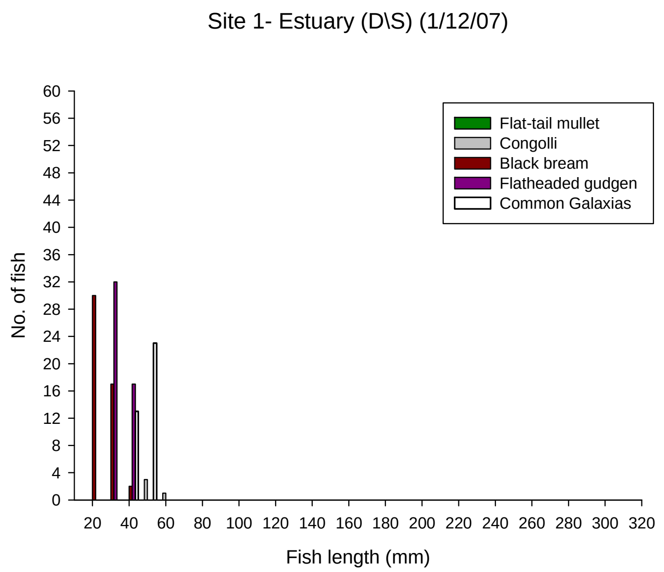



Site 2- Brackish (U\S) (1/9/07)
No. of fish
Fish length (mm)
Common Galaxias
Yelloweye mullet
Congolli
Black bream

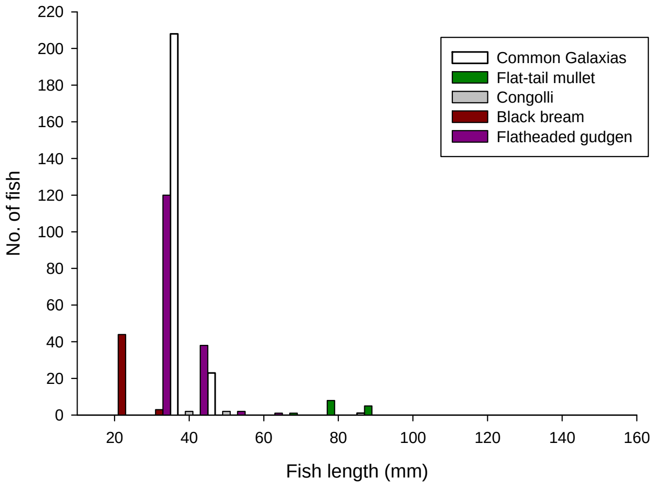

Site 2- Brackish (D\S) (1/9/07)
No. of fish
Fish length (mm)
Common Galaxias
Yelloweye mullet
Congolli
Flatheaded gudgen


Site 3- Freshwater (U\S) (1/9/07)
No. of fish
Fish length (mm)
Common Galaxias
Congolli
Flatheaded gudgen


Site 1- Estuary (U\S) (1/12/07)
No. of fish
Fish length (mm)
Flat-tail mullet
Congolli
Black bream
Flatheaded gudgen


Site 1- Estuary (D\S) (1/12/07)
No. of fish
Fish length (mm)
Flat-tail mullet
Congolli
Black bream
Flatheaded gudgen
Common Galaxias

Site 2- Brackish (U\S) (1/12/07)

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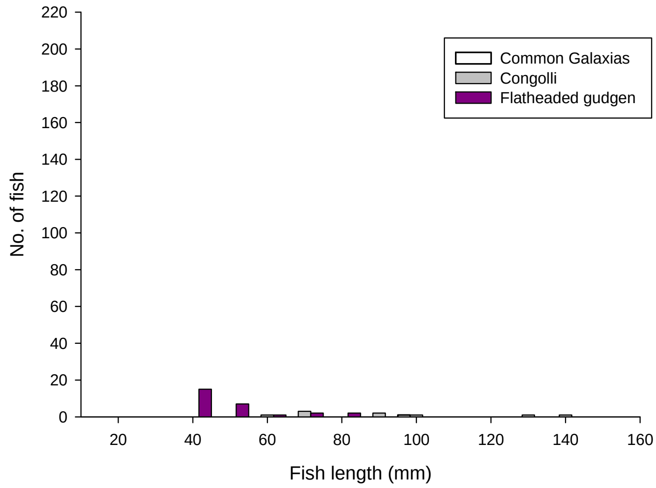


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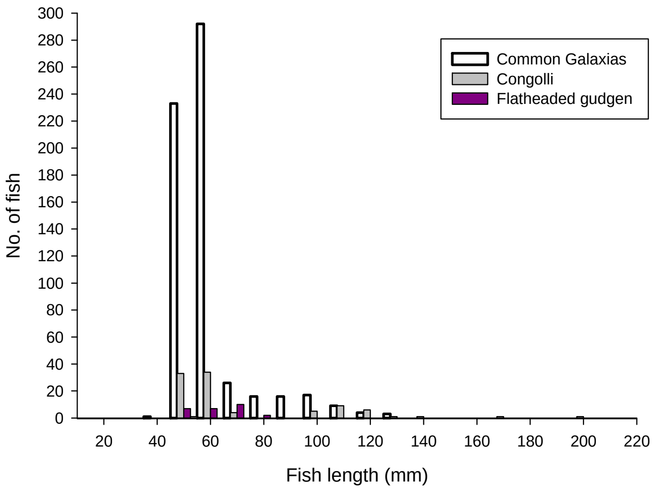


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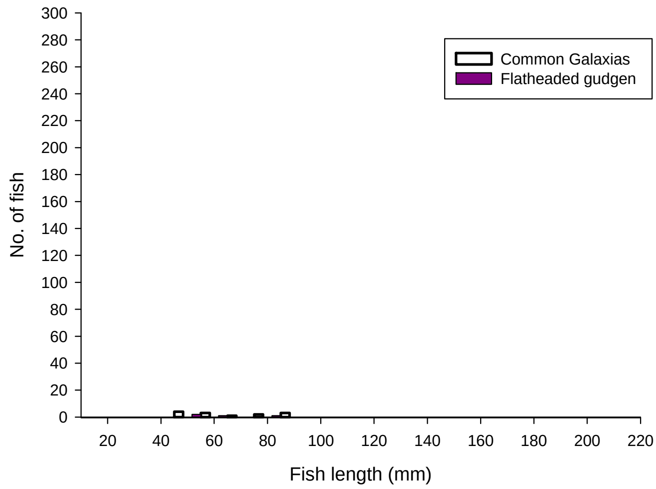
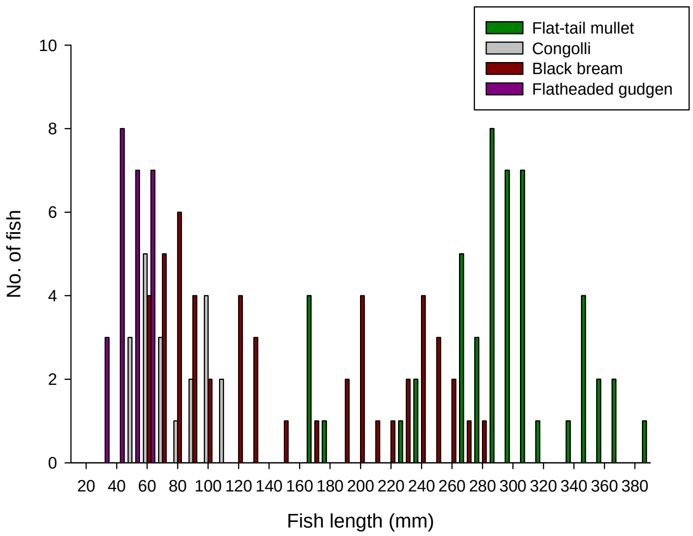



Site 1-Estuary (U\S) (1/3/08)

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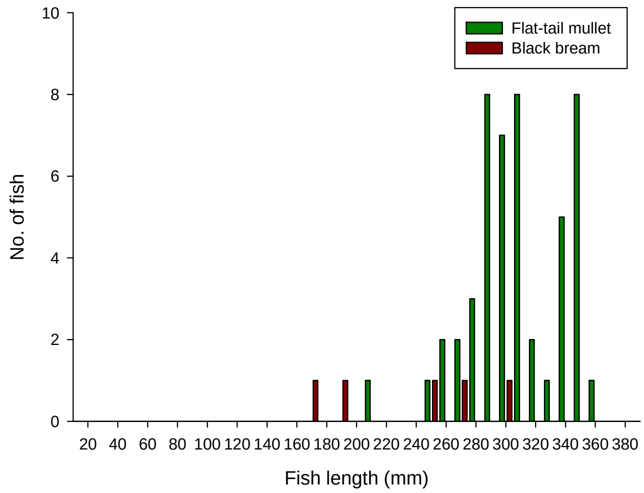

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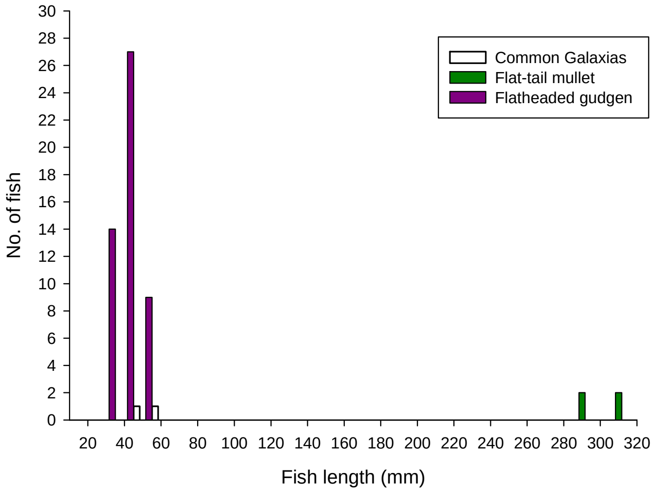


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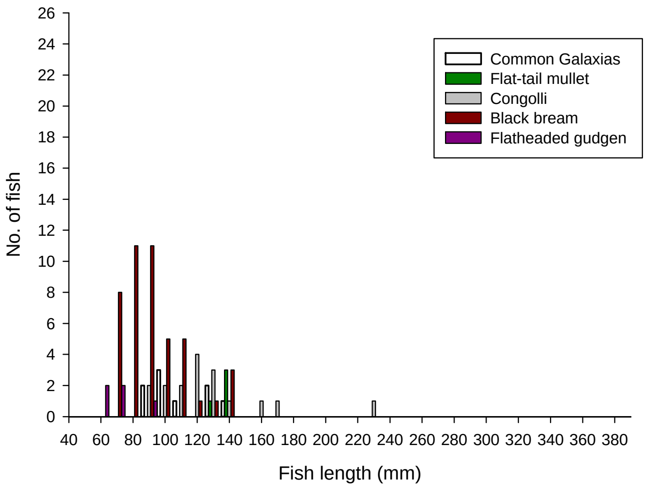


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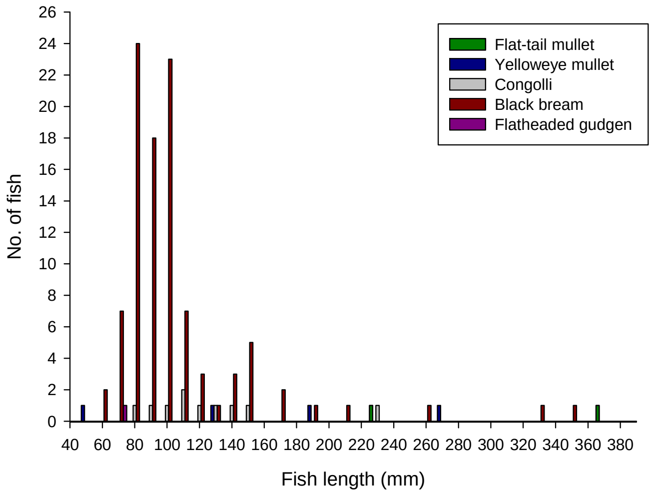


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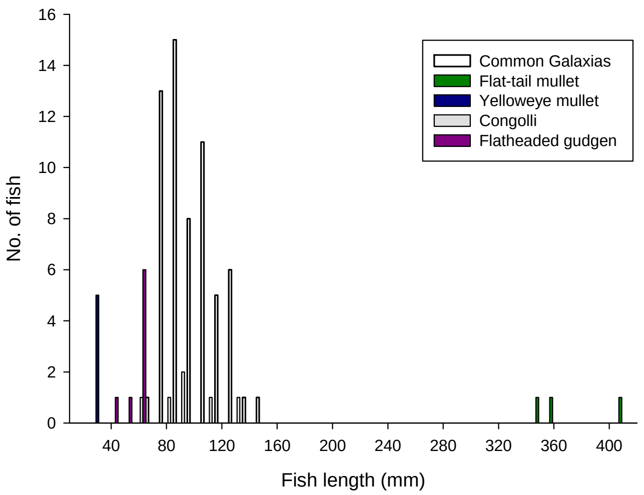


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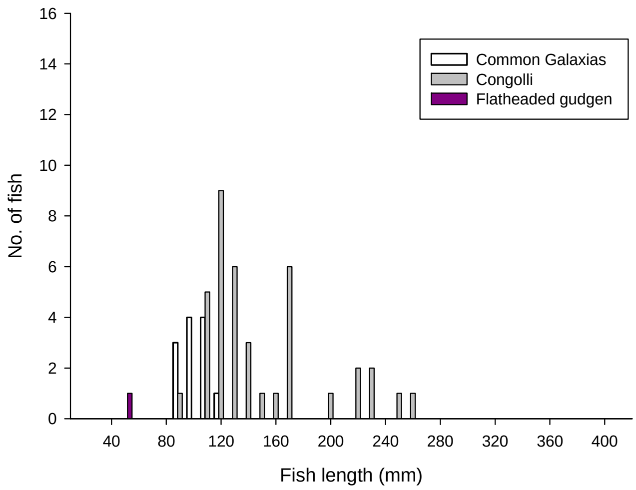

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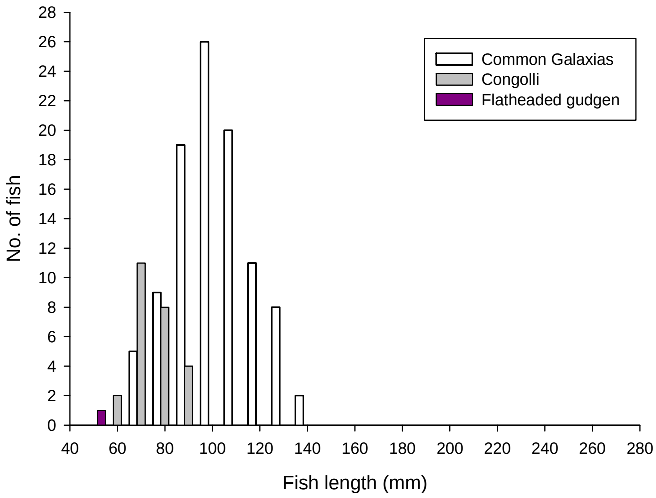
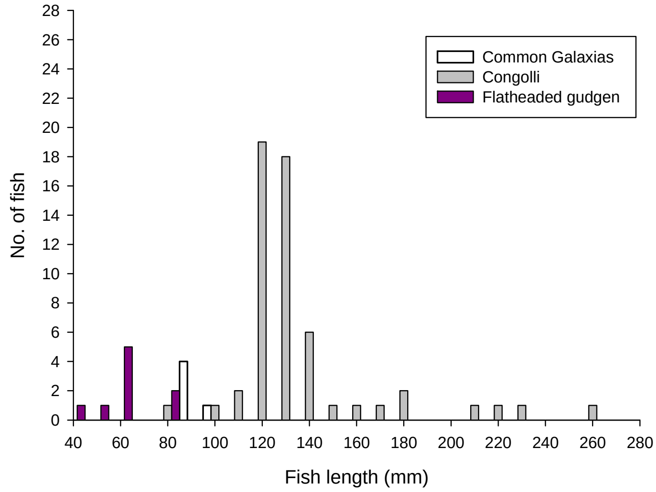
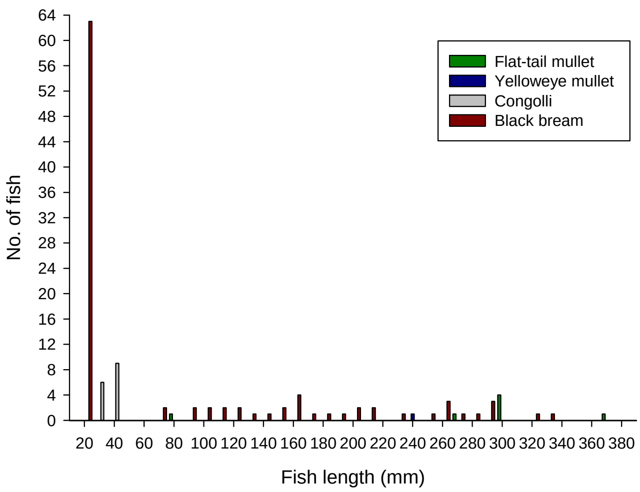



Site 3-Freshwater (D\S) (1/7/08)




Site 1-Estuary (U\S) (1/10/08)

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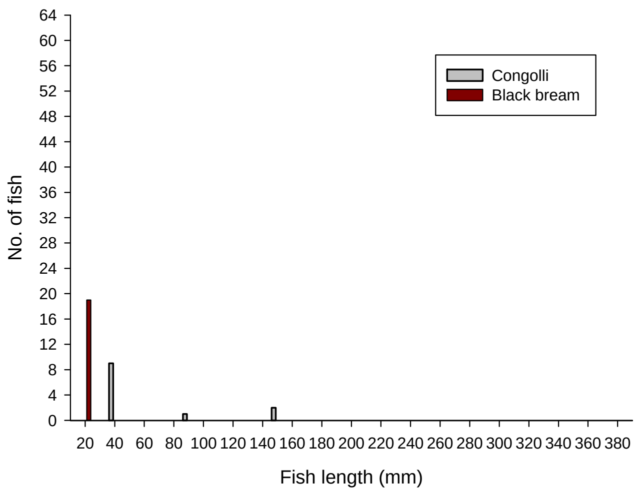


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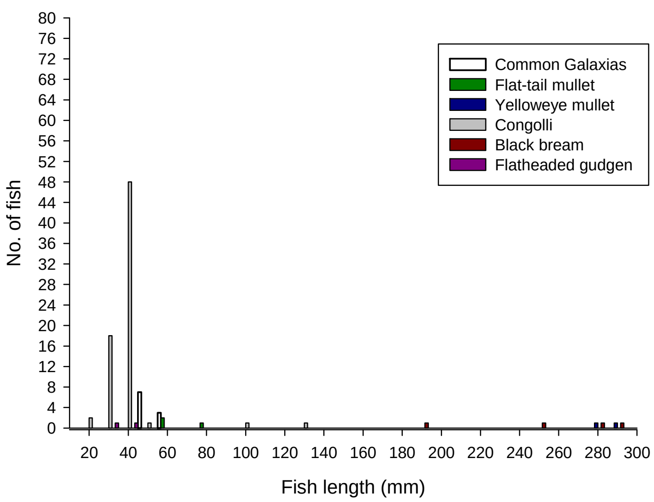
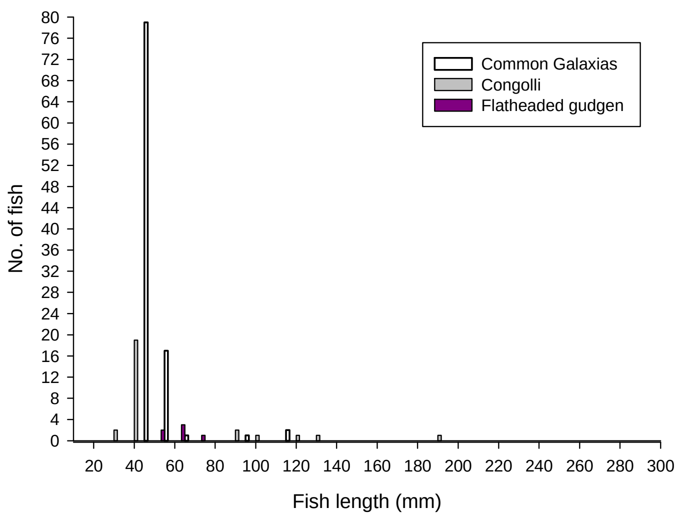
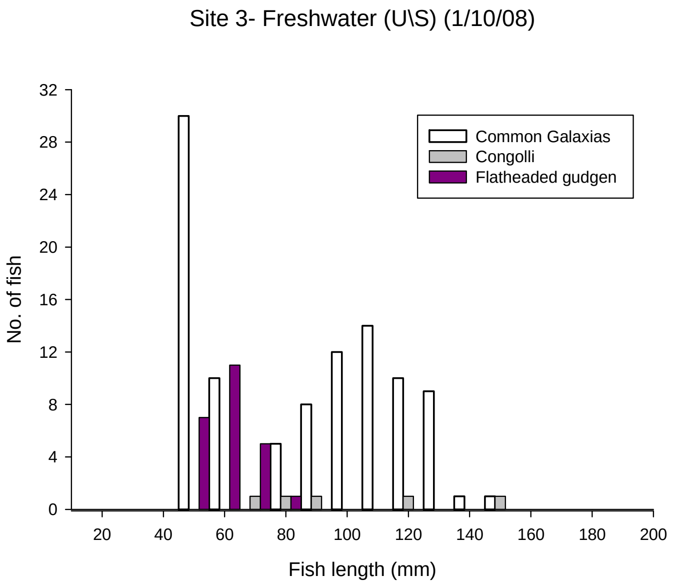
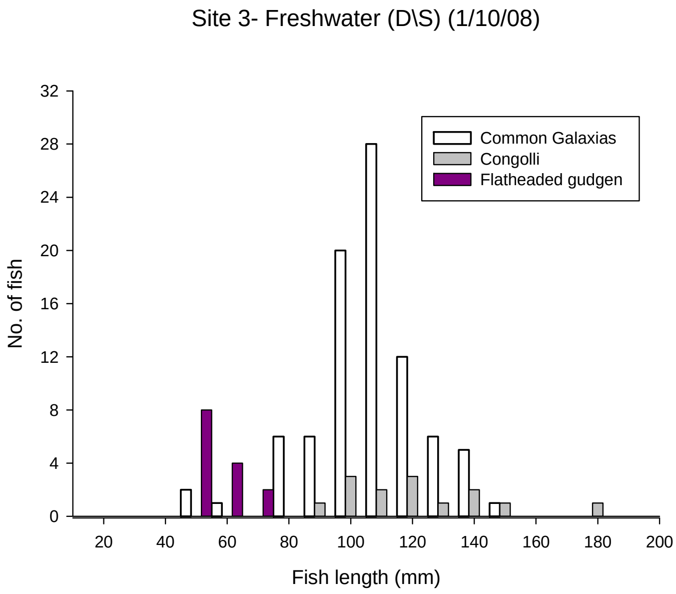



Site 2- Brackish (D\S) (1/10/08)

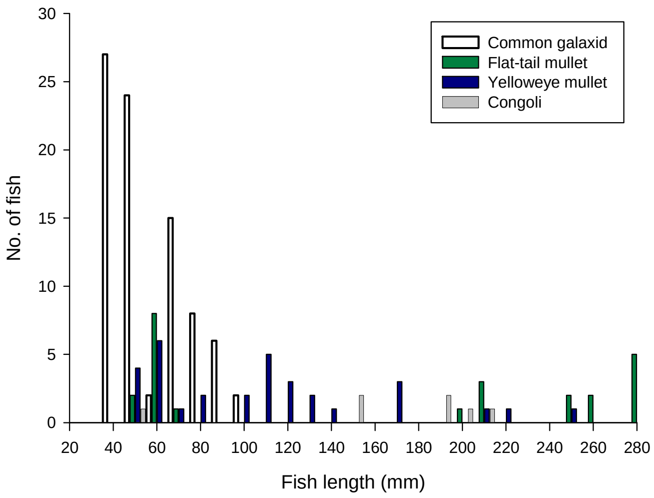



Site 3- Freshwater (U\S) (1/10/08)
No. of fish
Fish length (mm)
Common Galaxias
Congolli
Flatheaded gudgen
0
4
8
12
16
20
24
28
32
20
40
60
80
100
120
140
160
180
200

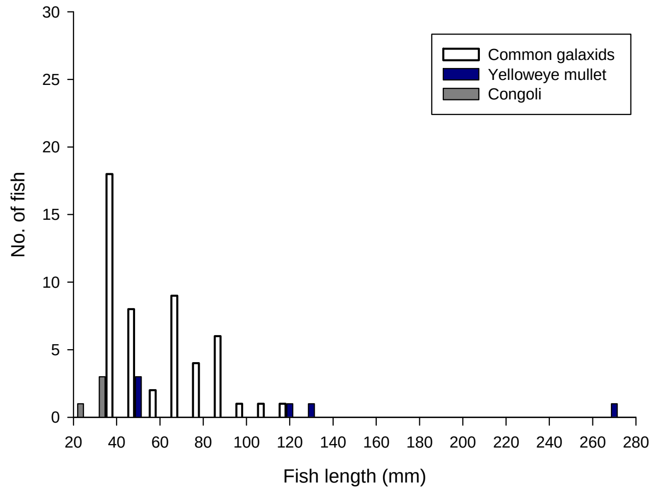

Site 3- Freshwater (D\S) (1/10/08)
No. of fish
Fish length (mm)
Common Galaxias
Congolli
Flatheaded gudgen
0
4
8
12
16
20
24
28
32
20
40
60
80
100
120
140
160
180
200

## Appendix B. Length Frequency of fish species in the Myponga catchment

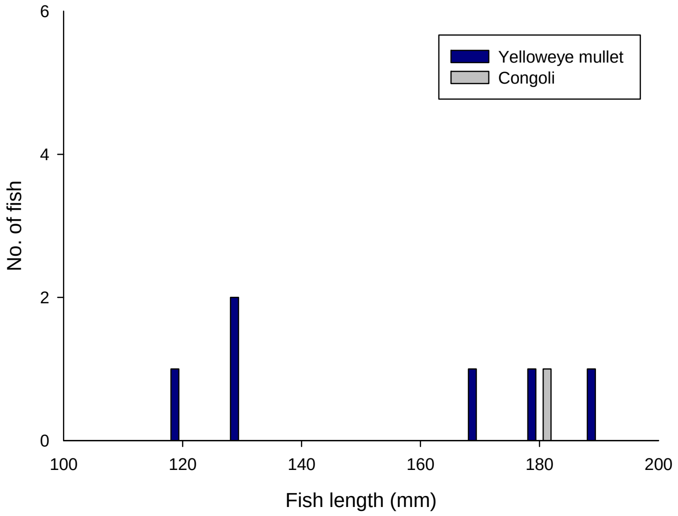
Site 1- Estuary (U\S) (1/10/2006)



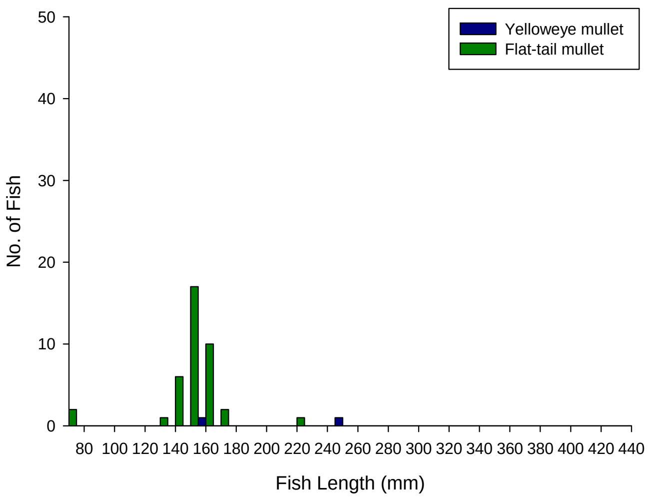

Site 1- Estuary (D\S) (1/10/2006)



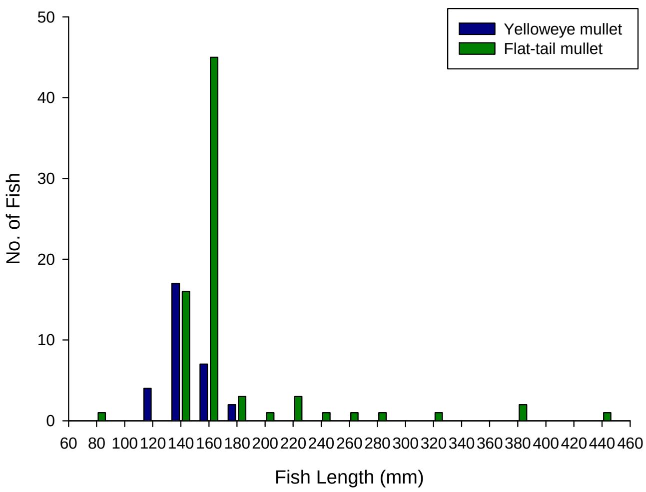

Site 3- Freshwater (D\S) (1/10/2006)



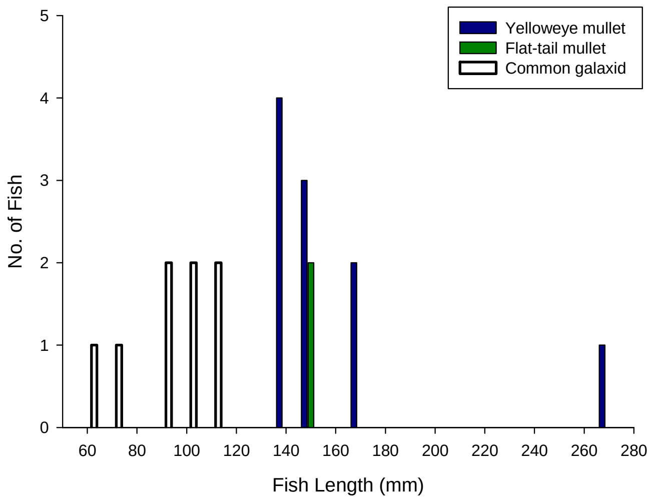

Site 1- Estuary (U\S) (1/7/2007)



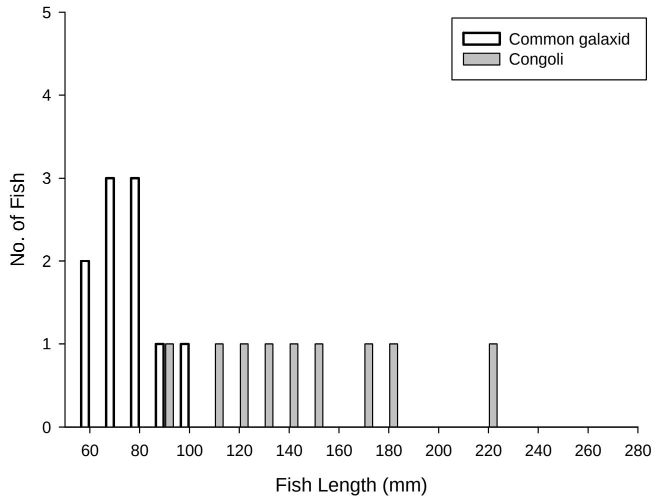

Site 1- Estuary (D\S) (1/7/2007)



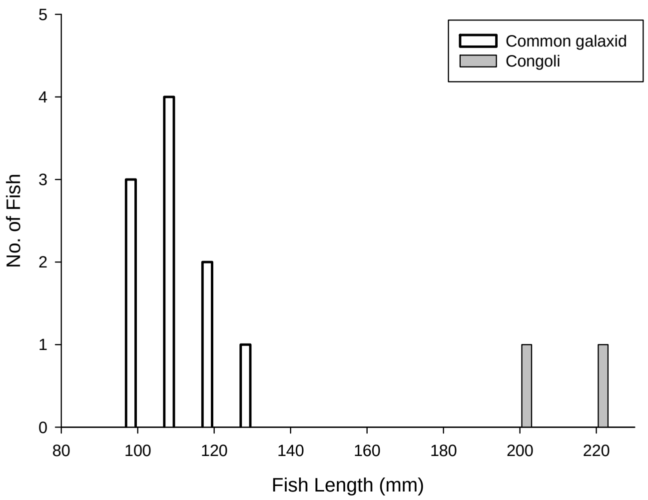
Site 2- Brackish (U\S) (1/7/2007)



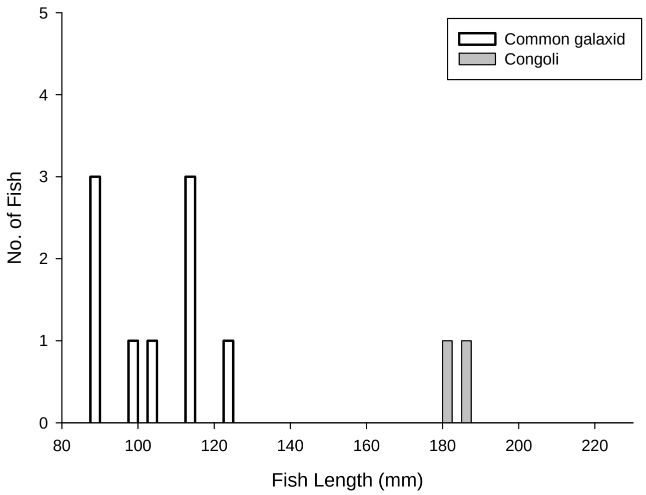

Site 2- Brackish (D\S) (1/7/2007)



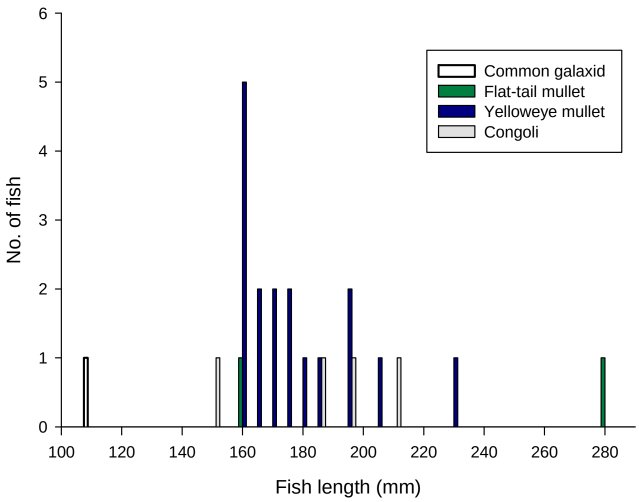

Site 3- Freshwater (U\S) (1/7/2007)



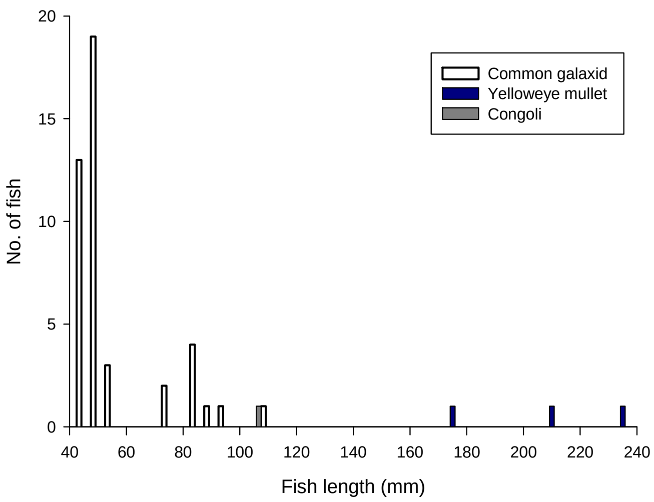

Site 3- Freshwater (D\S) (1/7/2007)



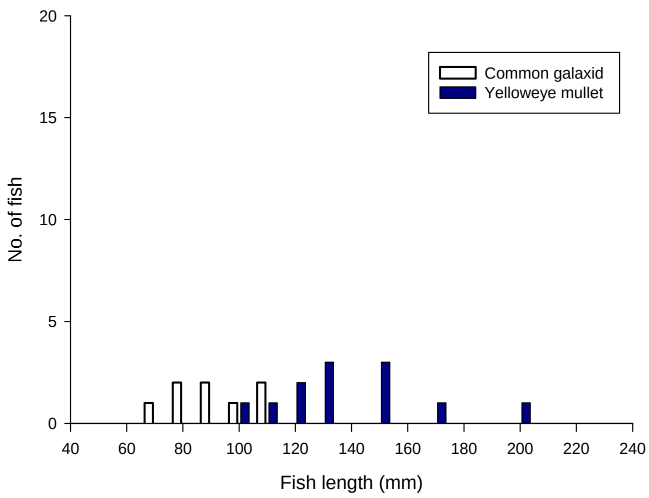

Site 1- Estuary (D\S) (1/9/2007)



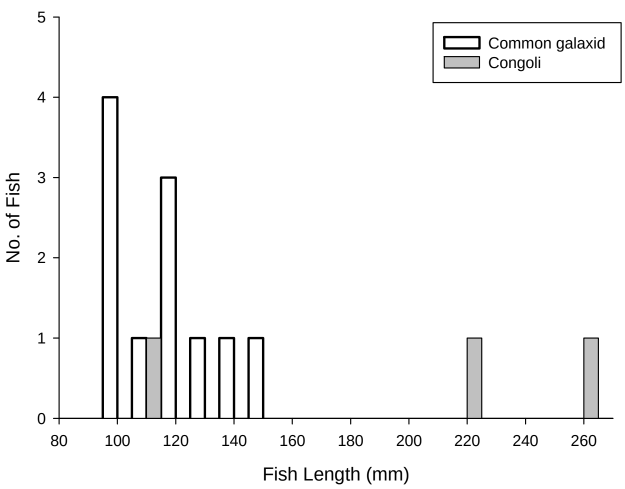
Site 2- Brackish (U\S) (1/9/2007)



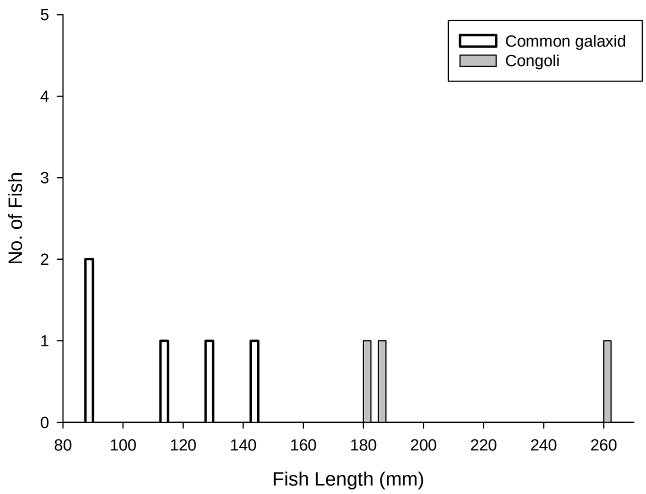

Site 2- Brackish (D\S) (1/9/2007)



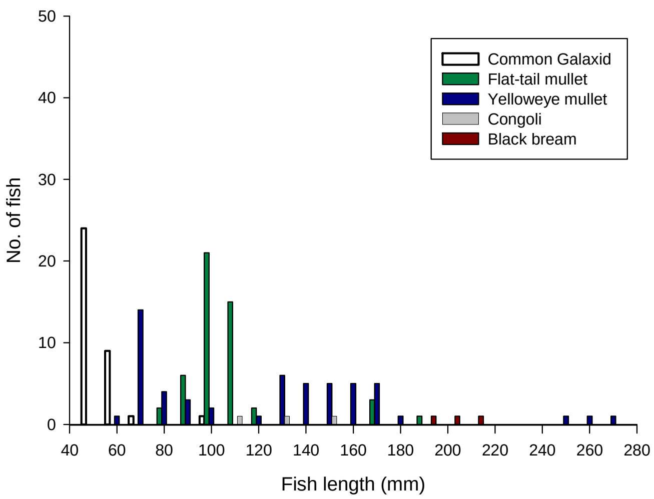

Site 3- Freshwater (U\S) (1/9/2007)



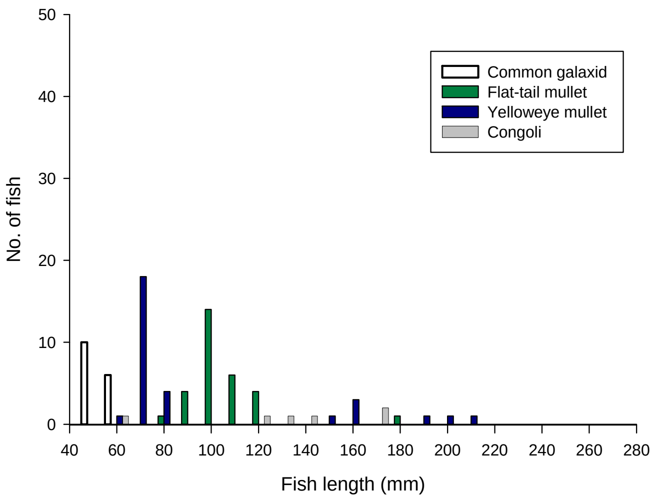

Site 3- Freshwater (D\S) (1/9/2007)



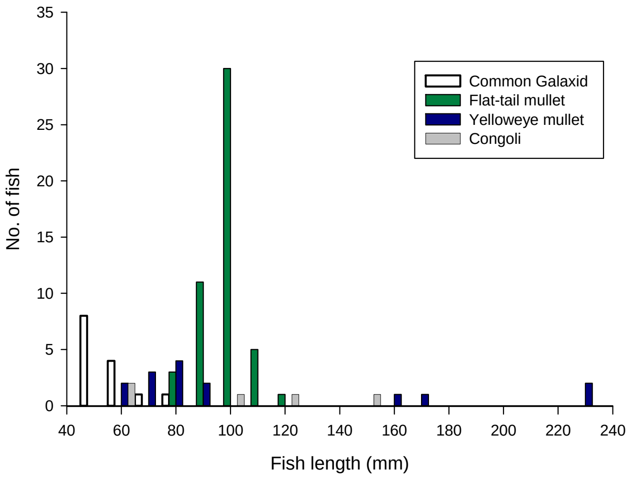

Site 1- Estuary (U\S) (1/12/2007)



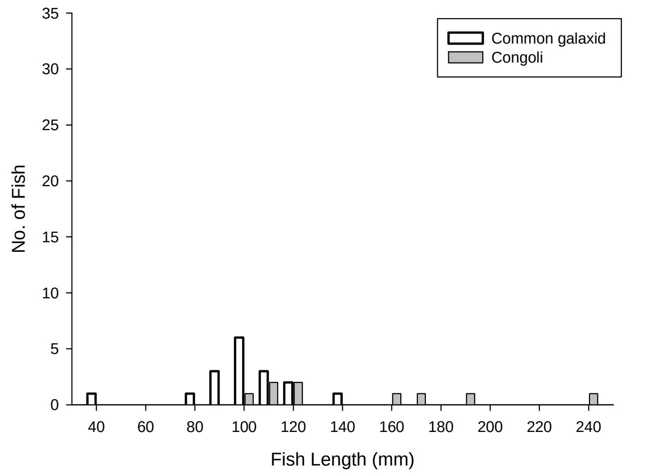

Site 1- Estuary (D\S) (1/12/2007)



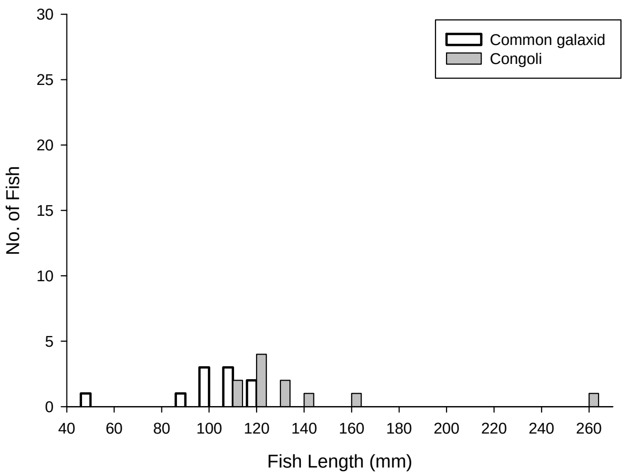
Site 2- Brackish (U\S) (1/12/2007)



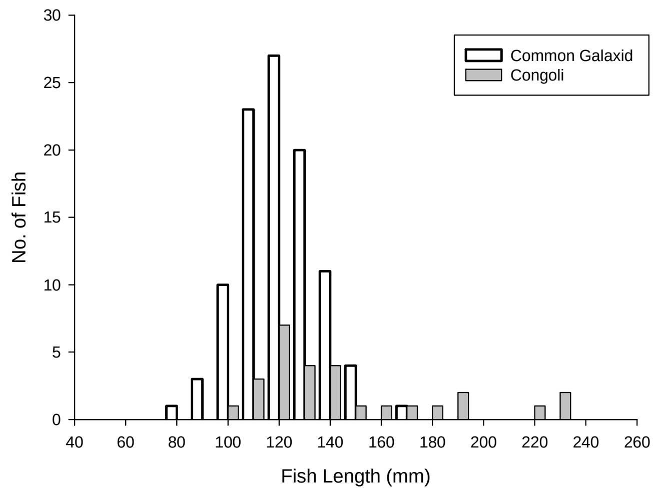

Site 2- Brackish (D\S) (1/12/2007)



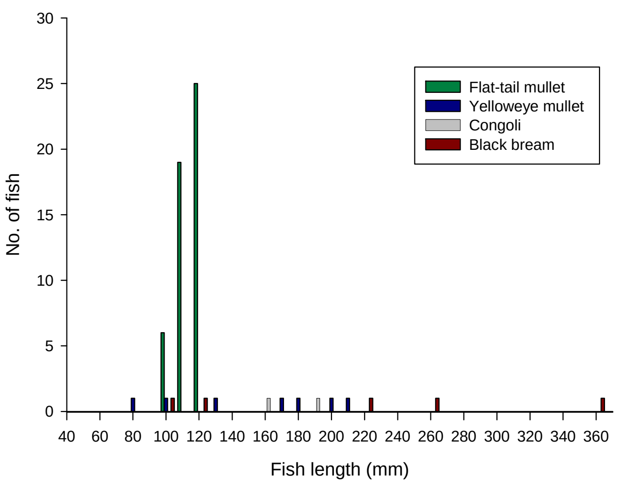

Site 3- Freshwater (U\S) (1/12/2007)



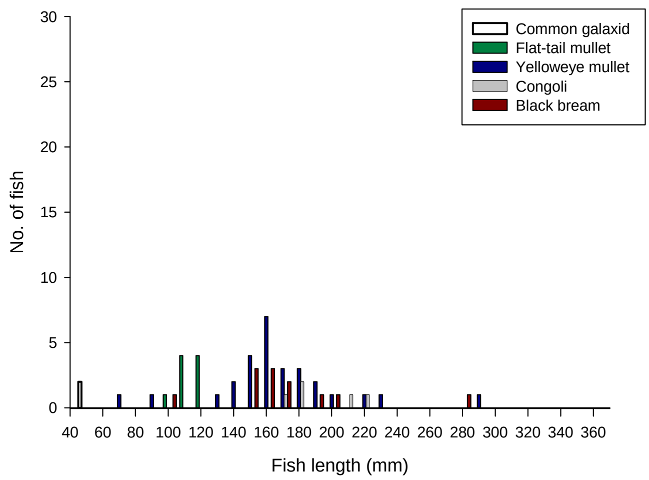

Site 3- Freshwater (D\S) (1/12/2007)

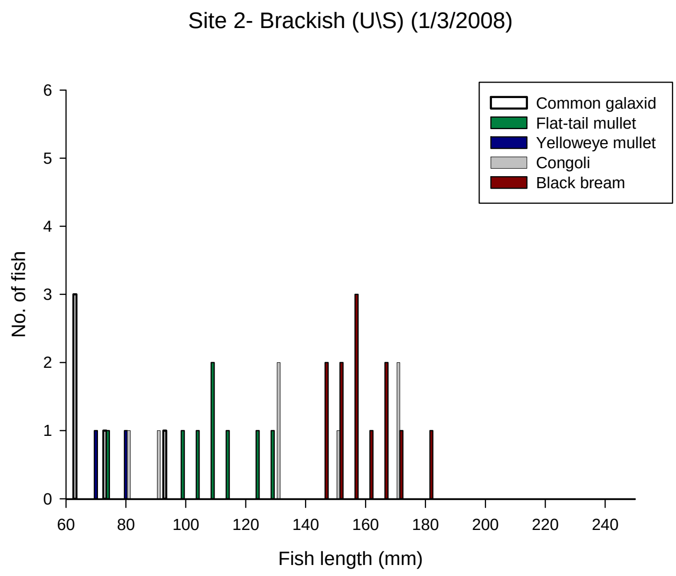


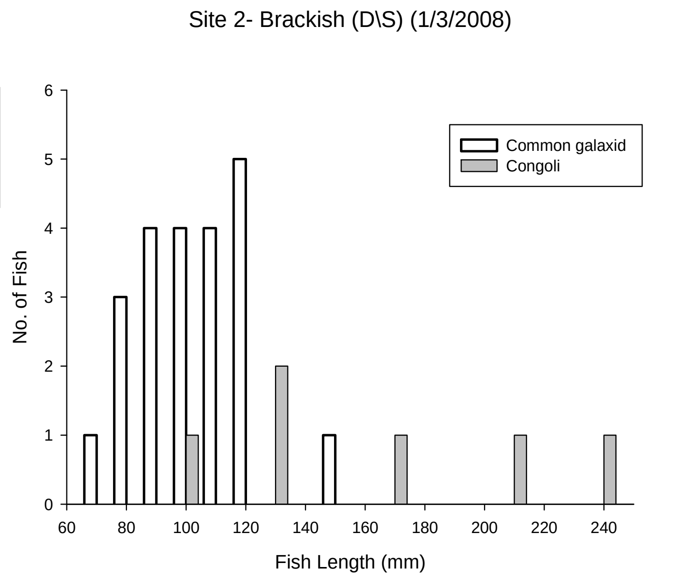

Site 1- Estuary (U\S) (1/3/2008)

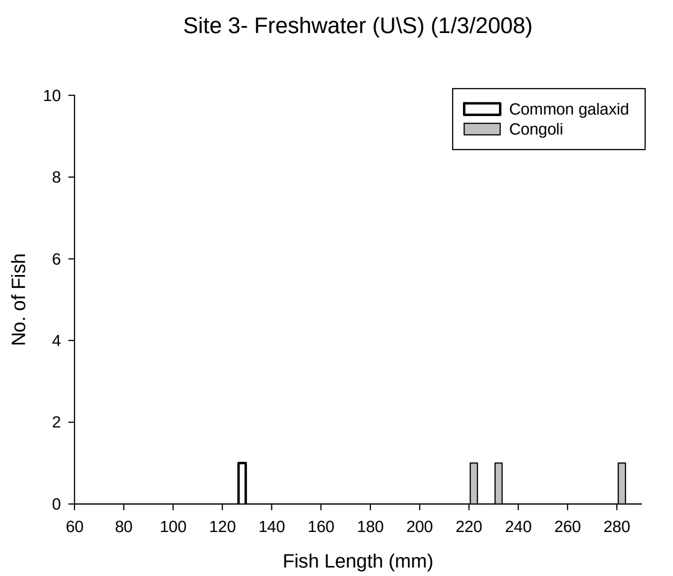


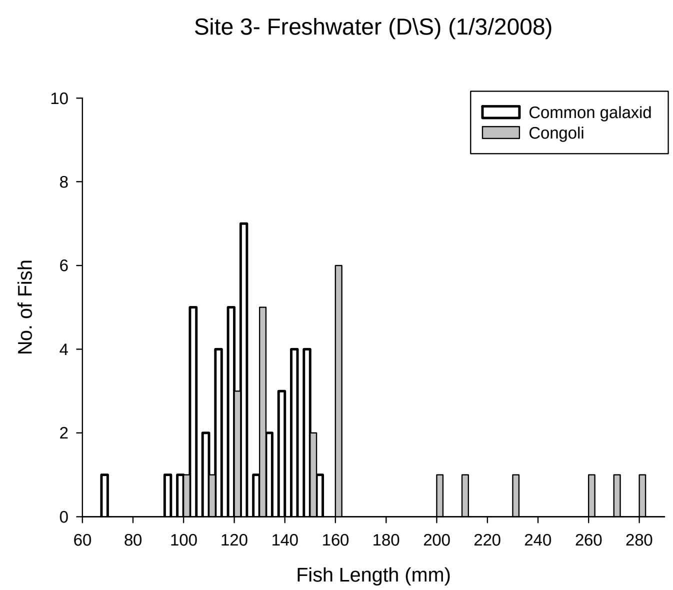

Site 1- Estuary (D\S) (1/3/2008)

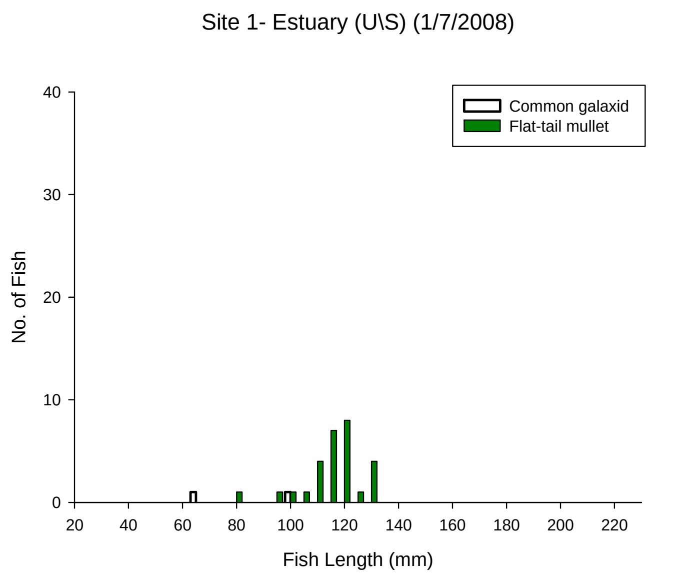


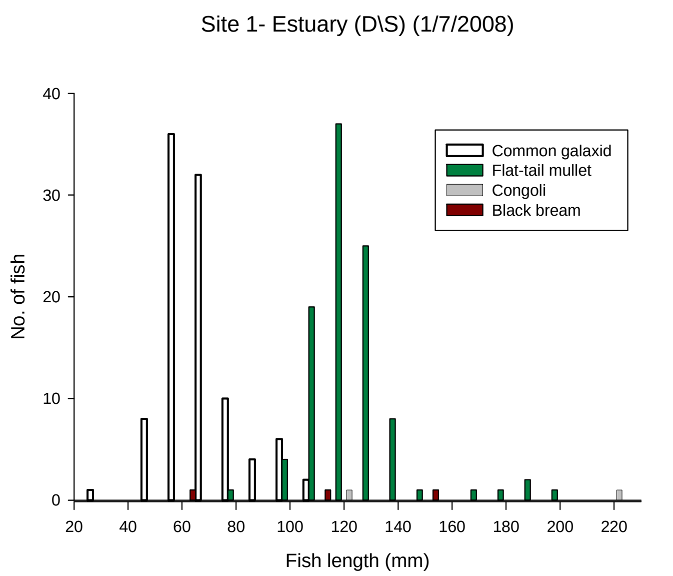

Site 2- Brackish (U\S) (1/3/2008)
Common galaxid
Flat-tail mullet
Yelloweye mullet
Congoli
Black bream
No. of fish
Fish length (mm)


Site 2- Brackish (D\S) (1/3/2008)
Common galaxid
Congoli
No. of Fish
Fish Length (mm)

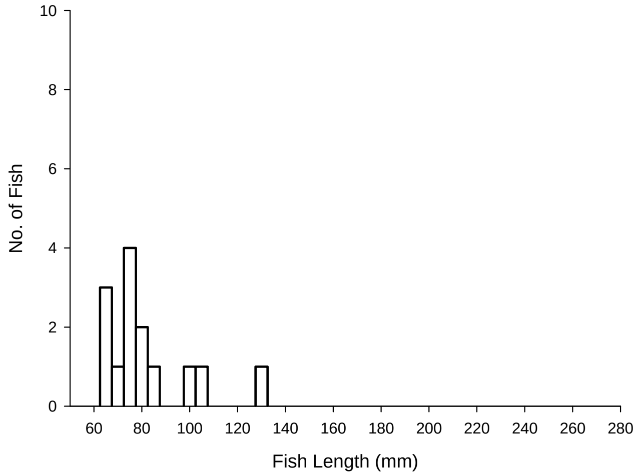

Site 3- Freshwater (U\S) (1/3/2008)
Common galaxid
Congoli
No. of Fish
Fish Length (mm)


Site 3- Freshwater (D\S) (1/3/2008)
Common galaxid
Congoli
No. of Fish
Fish Length (mm)

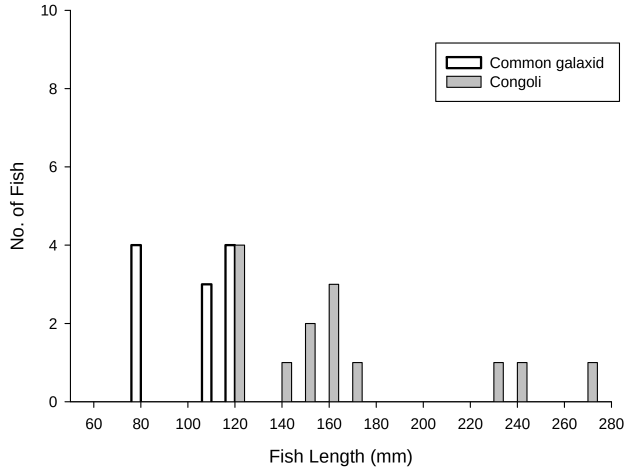

Site 1- Estuary (U\S) (1/7/2008)
Common galaxid
Flat-tail mullet
No. of Fish
Fish Length (mm)


Site 1- Estuary (D\S) (1/7/2008)
Common galaxid
Flat-tail mullet
Congoli
Black bream
No. of fish
Fish length (mm)

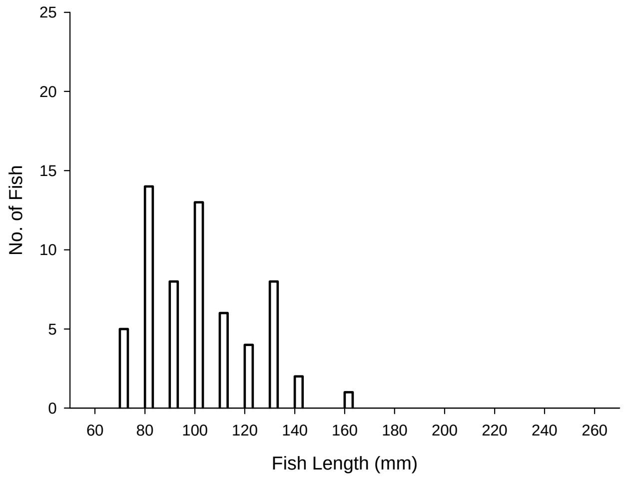
Site 2- Brackish (U\S) (1/7/2008)



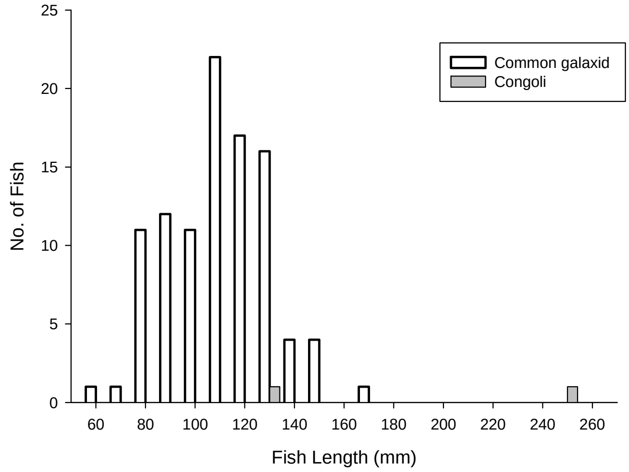

Site 2- Brackish (D\S) (1/7/2008)



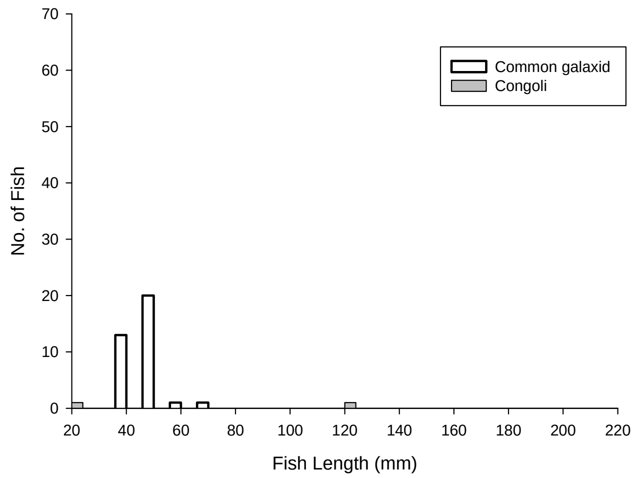

Site 3- Freshwater (U\S) (1/7/2008)



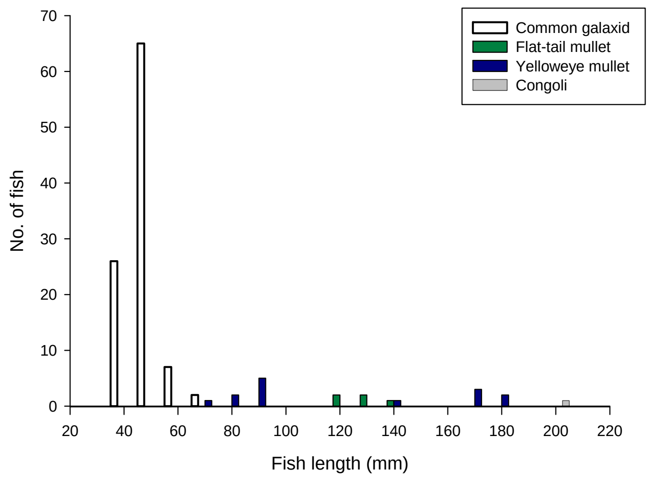

Site 3- Freshwater (D\S) (1/7/2008)

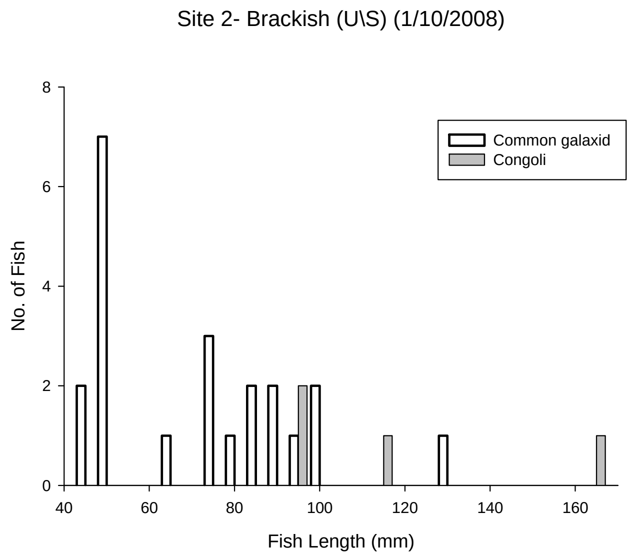


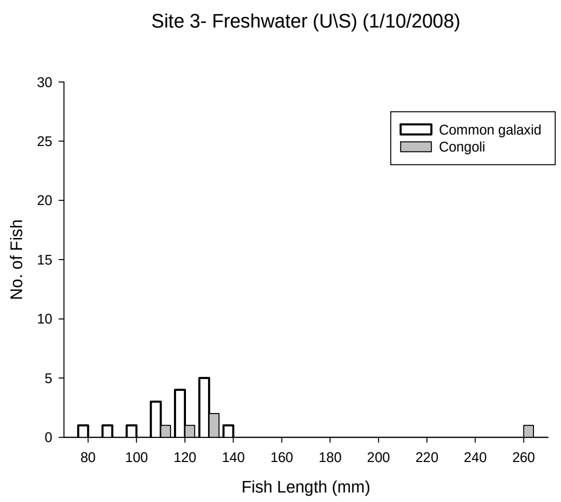

Site 1- Estuary (U\S) (1/10/2008)

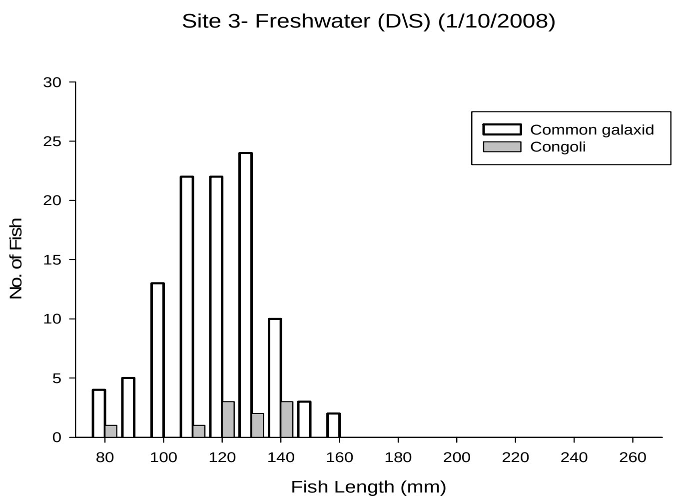



Site 1- Estuary (D\S) (1/10/2008)

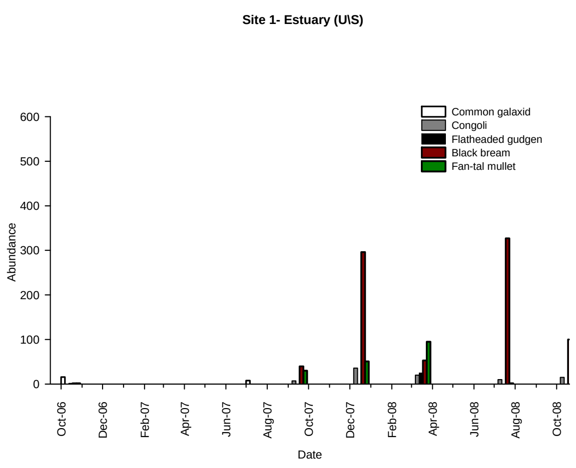


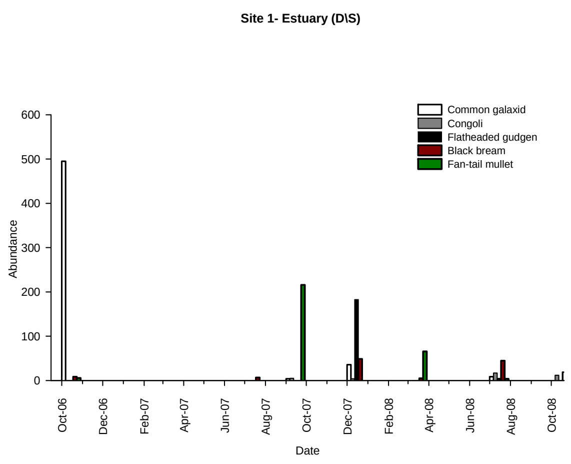


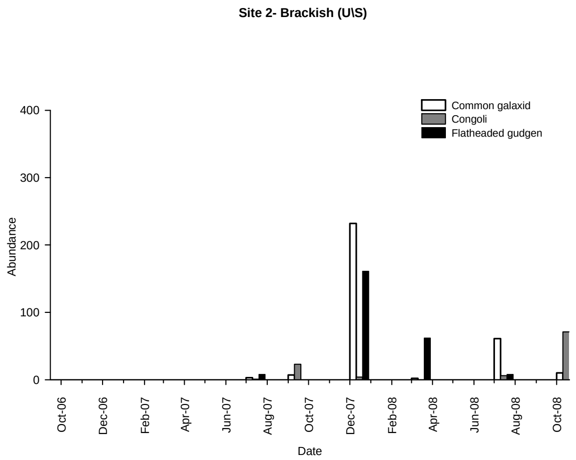



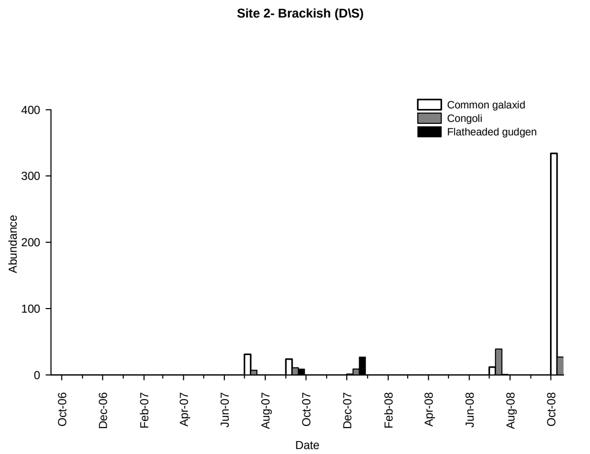



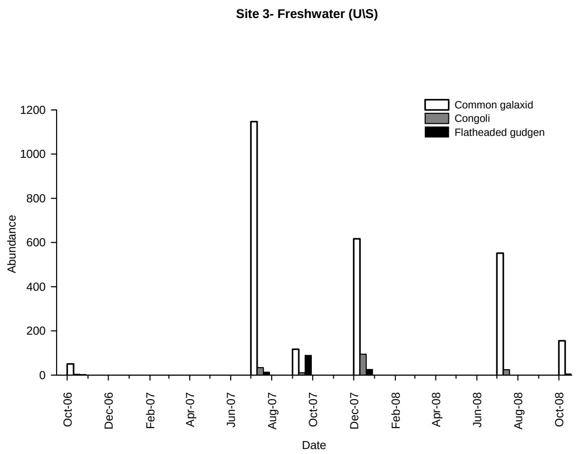

# Appendix C. Upstream and Downstream migration (Onkaparinga)

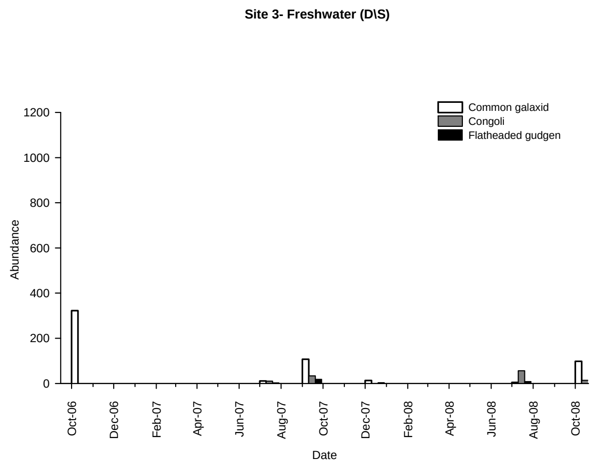


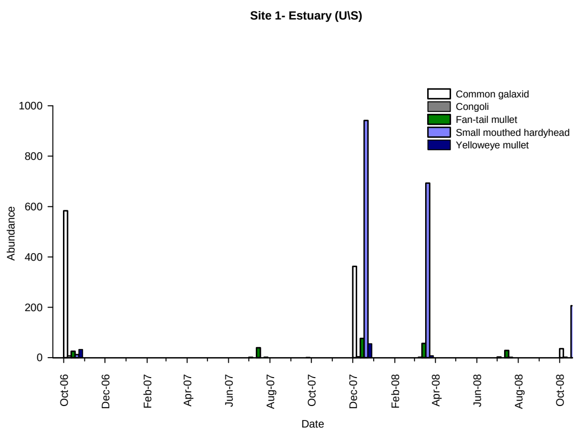


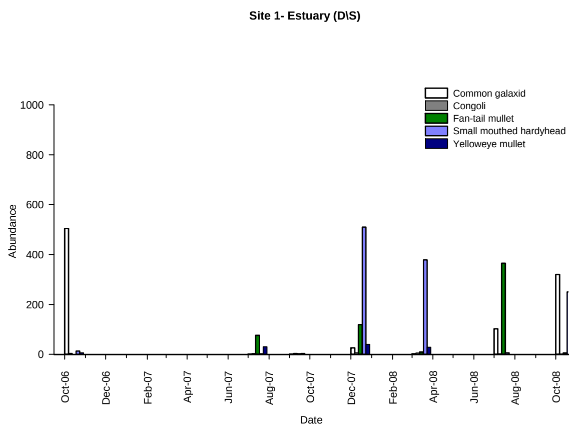



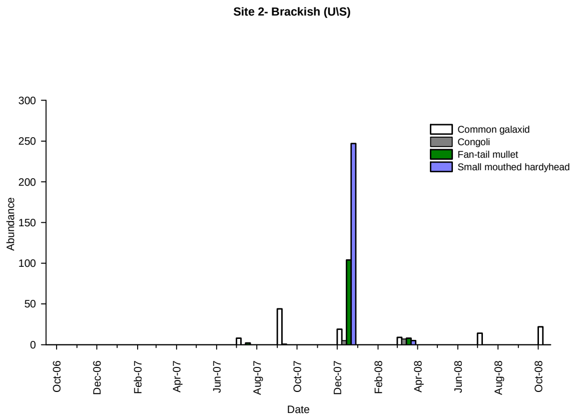



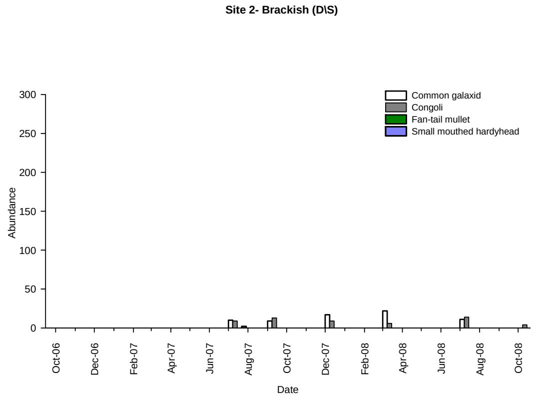



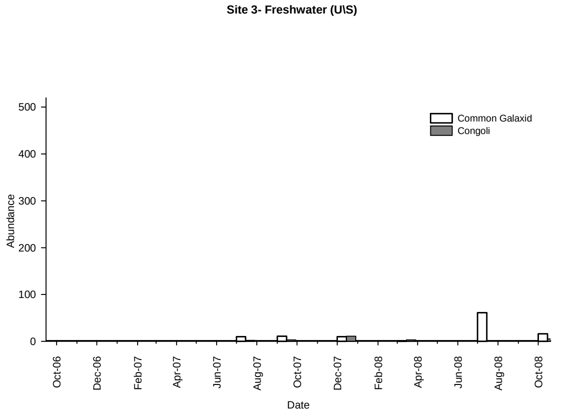

# Appendix D. Upstream and Downstream migration (Myponga)

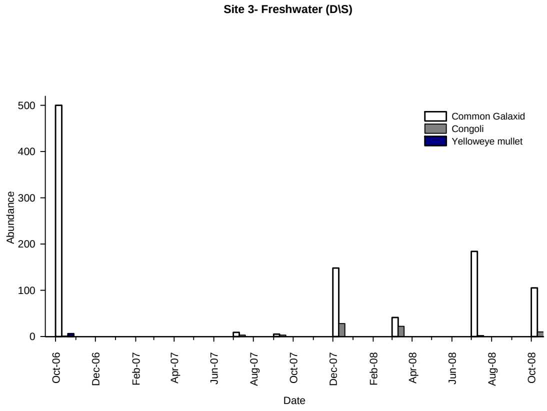



Site 2- Brackish (U\S)
Common galaxid
Congoli
Fan-tail mullet
Small mouthed hardyhead
Abundance
Date
Oct-06
Dec-06
Feb-07
Apr-07
Jun-07
Aug-07
Oct-07
Dec-07
Feb-08
Apr-08
Jun-08
Aug-08
Oct-08


Site 2- Brackish (D\S)
Common galaxid
Congoli
Fan-tail mullet
Small mouthed hardyhead
Abundance
Date


Site 3- Freshwater (U\S)
Common Galaxid
Congoli
Abundance
Date


Site 3- Freshwater (D\S)
Common Galaxid
Congoli
Yelloweye mullet
Abundance
Date