Fish and Aquatic Macrophyte Communities in the Chowilla Anabranch System, South Australia

A report on investigations from 2004 – 2007

B. P. Zampatti, S. J. Leigh and J. M. Nicol

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To anyone we may have neglected to mention we sincerely apologise.

Executive Summary

The Chowilla Anabranch and Floodplain system is the largest remaining area of undeveloped floodplain habitat in the lower Murray River. In 1987 it was listed as a *Wetland of International Importance* under the Ramsar Convention, recognising its unique birdlife and the extent of river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*) woodlands. The floodplain in this region is 5 – 10 km wide and characterised by a complex of perennial and ephemeral water bodies; consisting of creeks, backwaters, billabongs and lakes.

Due to the head differential (~ 3 m) created by Lock and Weir No. 6 on the Murray River, the Chowilla system exhibits permanent lotic habitats in what previously would have been a combination of perennial and ephemeral streams. Lotic habitats are now uncommon in the South Australian section of the Murray River, as the construction of locks and weirs has generally created a series of lentic (still water) habitats. The uniqueness of the Chowilla system has been recognised by numerous studies and the lotic environments are considered to maintain remnant populations of endangered flora and fauna that are uncommon or extinct elsewhere in the lower Murray. Nevertheless, few documented investigations have been undertaken on the aquatic flora and fauna of the area.

The overarching objective of this project was to undertake a range of investigations to assist in determining the current status and ecological requirements of native fish and aquatic macrophytes in the Chowilla system. The outputs of the project were to be used primarily in the development of management strategies for achieving the ecological targets specified in the Chowilla Asset and Environmental Plan (AEMP) (DWLBC 2006).

The specific aims of the project were to:

1. Determine the distribution and community structure of native fish assemblages in the Chowilla Anabranch system.
2. Determine the distribution and community structure of aquatic macrophyte assemblages in the Chowilla Anabranch system.
3. Investigate the ecology of native fish, particularly Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua ambigua*) in the Chowilla Anabranch system.
4. Assess the impacts to fish passage caused by barriers identified in the “structure assessment project”.
5. Facilitate knowledge transfer to inform operation and modification of existing and new flow regulation structures.

Investigations from 2004 – 2007 have shown that the Chowilla system is characterised by a diverse freshwater fish assemblage and that the distinct aquatic mesohabitats of the system support significantly different fish assemblages. Regulating structures, however, impede the movement of fish between mesohabitats, particularly between Slaney and Pipeclay Creek and the Murray River.

In the case of high conservation value species, such as Murray cod, the fast-flowing aquatic mesohabitats of the Chowilla system are characterised by significantly higher relative abundances of Murray cod than other available mesohabitats in the lower Murray River. The broad size range of Murray cod, compared to that captured from the main channel of the Murray River, indicates that the Chowilla system sustains recruitment during periods of low-flow. Consequently, Chowilla provides a drought refuge, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance.

The plant community in the Chowilla system is a complex mosaic of vegetation types that are determined largely by the water regime (depth, duration and frequency of flooding), soil moisture and soil salinity. In permanently inundated areas the plant community was dominated by native submergent (e.g. *Vallisneria americana, Potamogeton crispus, P. tricarinatus, Hydrilla verticillata, Zanichellia palustris*) emergent (e.g. *Typha* spp., *Phragmites australis, Eleocharis acuta, Bolboschoenus caldwellii*) and amphibious (*Myriophyllum verrucosum*) species. Amphibious (e.g. *Ludwigia peploides, Cyperus gymnocaulos, Juncus usitatus, Limosella australis*), emergent (e.g. *Typha* spp., *Phragmites australis, Eleocharis acuta, Bolboschoenus caldwellii*) and floodplain (e.g. *Epaltes australis, Centipeda minima*) species were common around the edges of permanent waterbodies. Temporary wetlands and the remainder of the floodplain showed signs of degradation and were dominated by terrestrial (e.g. *Atriplex* spp., *Sclerolaena* spp., *Maireana* spp.) and salt tolerant (e.g. *Halosarcia pergranulata*) taxa. The plant community in permanently inundated areas, temporary wetlands which were not inundated or watered, and the floodplain did not change significantly over the study period.

The high river in spring 2005 resulted in the littoral zone of permanent wetlands and some low lying areas of temporary wetlands being inundated for the first time since 2000. The change in the littoral plant community due to the rise in water level was patchy across the system. Areas where ground water was discharging into a stream reach or wetland (gaining reaches) showed no significant change in floristic composition as a result of increased water levels. In contrast, areas where ground water is recharged by surface water (losing reaches) the plant community changed significantly and floodplain and amphibious species recruited in response to the higher water levels. It is unclear whether the elevated soil salinity in the littoral zone of gaining reaches prevented amphibious and floodplain species from recruiting or whether these reaches have a depauperate propagule bank.

Restoration of riverine fish communities needs to consider the spatio-temporal variability of fish life history strategies and movement patterns. Investigation of golden perch recruitment and movement in the Chowilla region indicates the need to account for the magnitude and frequency of flow events required for spawning, the origin and scale of downstream displacement of larvae, and the broad spatial scale and temporal variability in the movement of adult golden perch. The high spatio-temporal variability in golden perch behaviour and movement in the MDB, and the hydrological process that facilitate spawning and recruitment, highlight the need for a river basin scale approach to native fish management. Effective management needs to be relevant to the life histories of the constituent fish fauna and not constrained by human perspectives of artificially delineated sites or state boundaries.

The Chowilla system is characterised by a complex of physical and hydraulic habitats that support a range of life history phases of native and non-native fish species. The hydraulic heterogeneity and, for some species, the separation of spawning and potential rearing habitats at the micro and mesohabitat scale are facets of the Chowilla system that are now absent from the homogeneous weir pool habitats of the lower Murray River, particularly under non-flood flows. The conservation of the diverse aquatic mesohabitats in the Chowilla system, along with restoration of a more variable flow regime, and the promotion of physical and hydrological connectivity at the river-scale, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

1 Introduction

Chowilla Creek, a unique flowing water habitat in the lower Murray River.

1.1 The Chowilla Anabranch System

The Chowilla region is located in the *valley* section of the lower Murray River. The floodplain in this region is 5 – 10 km wide and is characterised by many off-channel habitats including anabranches, billabongs (oxbows) and deflation basins (Walker and Thoms 1993). The Chowilla region is the largest remaining area of undeveloped floodplain habitat in the lower Murray River and in 1987 the region was listed as a *Wetland of International Importance* under the Ramsar Convention (as part of the Riverland Ramsar site, which stretches from Renmark to the New South Wales border) recognising its unique birdlife and the extent of river red gum (*Eucalyptus camaldulensis* var. *camaldulensis*) and black box (*E. largiflorens*) woodlands.

The Chowilla system is a complex of perennial and ephemeral water bodies. The main perennial creeks in the system are Chowilla, Salt, Punkah, Hypurna, Monoman, Slaney and Pipeclay Creeks, minor creeks include Boat, Bank E and Swiftys (Bank I) Creeks. Large ephemeral lakes such as lakes Littra and Limbra, Werta Wert Wetland and Coombool Swamp are located in the north of the floodplain.

Data on the historical (pre-regulation) character of the system are scarce; nevertheless, some insight can be gained from the journal of the explorer Charles Sturt. In the summer of 1829 – 1830, Sturt travelled by boat from the mid reaches of the Murrumbidgee River down the Murray River to the Murray Mouth. He made numerous observations of the hydraulic character of the river. In late January 1830 he describes a significant 'rapid' in the vicinity of the Rufus River, then after passing the Lindsay River describes the river tending southwards (the approximate site of Lock 6) and passing down a series of several rapids. He does not describe the Chowilla Creek confluence but describes more 'rapids' and 'shoals' as he passes through the Murray gorge (Sturt 1833). The channel forms that Sturt describes have now been replaced by a series of contiguous weir pools.

Due to the head differential (~ 3 m) created by Lock and Weir No. 6 on the Murray River, 20 – 90% of Murray River flows are now diverted through the Chowilla system under low-flow conditions (i.e. < 10,000 ML/d) (Stace and Greenwood 2004). Consequently, the Chowilla system is composed of permanent lotic habitats in what previously would have been a combination of perennial and ephemeral streams. Given Sturt's 1830 description of the Murray River in this region it appears that regulation of the Murray River has shifted lotic waters from the main channel into the anabranch system. Lotic habitats are now uncommon in the South Australian section of the Murray River, as the construction of locks and weirs has generally created a series of lentic (still water) habitats (Walker *et al.* 1992; Walker 2006).

The uniqueness of these flowing waters in the Chowilla system has been recognised by numerous studies and the lotic environments are considered to maintain remnant populations of endangered flora and fauna that are uncommon or extinct elsewhere in the lower Murray (O'Malley and Sheldon 1990; Pierce 1990; Sharley and Huggan 1995). For instance, Sheldon and Lloyd (1990) suggest, "the rarity of anabranch habitats in the SA Murray River outside of the Chowilla region, and the characteristics they share with the original unregulated Murray River, makes them of great biological significance".

Whilst the permanent aquatic components of the Chowilla system are significant, the region has not escaped the major impacts of river regulation. An altered hydrological regime has increased the return intervals of small and medium sized floods (i.e. 20,000 – 60,000 ML/d) by approximately 50% leading to extended periods of floodplain isolation (Sharley and Huggan 1995). Along with soil salinisation this has been implicated in severe declines in the health of floodplain overstorey vegetation (Overton and Jolly 2004).

1.2 Previous Investigations

1.2.1 Fish

For what is considered to be a region of high conservation value in the lower Murray River, little research or survey work has been undertaken on the aquatic flora and fauna of the area. A few *ad hoc* fish surveys have been conducted but these have had a limited scope or have used selective techniques (Lloyd 1990; Nichols and Gilligan 2004; Dominelli unpublished data). Consequently data on fish assemblages of the creeks and off-stream habitats of the Chowilla system are patchy and incomplete. Nevertheless, numerous authors have suggested that the Chowilla system provides important and unique habitats (at least in South Australia) for fish such as golden perch (*Macquaria ambigua ambigua*), Murray cod (*Maccullochella peelii*) and silver perch (*Bidyanus bidyanus*), and that it may be an important spawning and nursery area for these species (Pierce 1990; Lloyd 1990). Furthermore both Pierce (1990) and Lloyd (1990) suggested the region may provide habitat for the threatened southern purple spotted gudgeon (*Mogurnda adspersa*), trout cod (*Maccullochella macquariensis*) and olive perchlet (*Ambassis agassizii*). Unfortunately there are no records of these species occurring in the Chowilla system but, Pierce (1990) did report capturing one southern pygmy perch (*Nannoperca australis*) in Chowilla.

1.2.2 Aquatic Macrophytes

The majority of previous studies of the vegetation of the Chowilla system have focussed largely on the *Eucalyptus camaldulensis* and *E. largiflorens* overstorey communities and the impact of groundwater and soil salinity on these communities (e.g. Jolly *et al.* 1993; Jolly *et al.* 1994; McEwan *et al.* 1995; Walker *et al.* 1996; Akeroyd *et al.* 1998; Doble *et al.* 2004; Overton and Jolly 2004). In the last 20 years there have been sporadic investigations of the understorey vegetation of the system. O'Malley (1990) and Roberts and Ludwig (1990; 1991) undertook extensive vegetation surveys of the floodplain and aquatic habitats respectively in 1988 and more extensive monitoring and scientific investigations were undertaken at specific sites such as Pilby Creek wetland (e.g. Stone 2001; Siebentritt 2003).

Whilst there is a good understanding of the overstorey dynamics of the system there is little information regarding the aquatic and understorey riparian plant communities. The last large-scale vegetation survey of the aquatic and riparian understorey occurred in 1988 (O'Malley 1990; Roberts and Ludwig 1990). Since then there have been four overbank flows (1989, 1991, 1993 and 1994) and two within-channel, high-flow events (1996 and 2000) followed by an extended period of low-flow and watering of temporary wetlands to improve overstorey condition. To better understand and manage the system, baseline information regarding the aquatic and riparian understorey communities and how they change seasonally is required.

1.3 Aims of the Study

The overarching objective of this project was to undertake a range of investigations to assist in determining the current status and ecological requirements of native fish and aquatic macrophytes in the Chowilla system. The outputs of the project were to be used primarily in the development of management strategies for achieving the ecological targets specified in the Chowilla Asset and Environmental Plan (AEMP) (DWLBC 2006).

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4. Assess the impacts to fish passage caused by barriers identified in the "structure assessment project".
5. Facilitate knowledge transfer to inform operation and modification of existing and new flow regulation structures.

This report describes the investigations undertaken between 2004 – 2007 to address aims 1 – 4 and discusses the results of these investigations with reference to freshwater fish ecology and river regulation in the MDB and more broadly. The transfer of this knowledge (Aim 5) has been an ongoing process throughout the life of the project and has involved close and extensive liaison with the Department for Water (DFW) formerly the Department of Water, Land Biodiversity and Conservation (DWLBC), the South Australian Murray Darling Basin Natural Resource Management Board (SAMDBNRMB), the Murray-Darling Basin Authority (MDBA) formerly the Murray-Darling Basin Commision (MDBC), the Department for Environment and Natural Resources (DENR) formerly the Department for Environment and Heritage (DEH), community groups and national and international researchers.

1.4 Hydrology and Water Physico-chemistry During the Study Period

The period of our investigations (September 2004 – June 2007) was characterised by an atypical period of low flows in the Murray River (Figure 1-1). Since the last significant within-channel flow event in late 2000, discharge in the lower Murray River has been highly regulated with the delivery of summer (7,500 ML/d) and winter (3,000 ML/d) entitlement flows for six consecutive years with only two minor within-channel increases in discharge (peaking at approximately 15,000 ML/d) in spring/summer 2003 and 2005 (Figure 1-1).

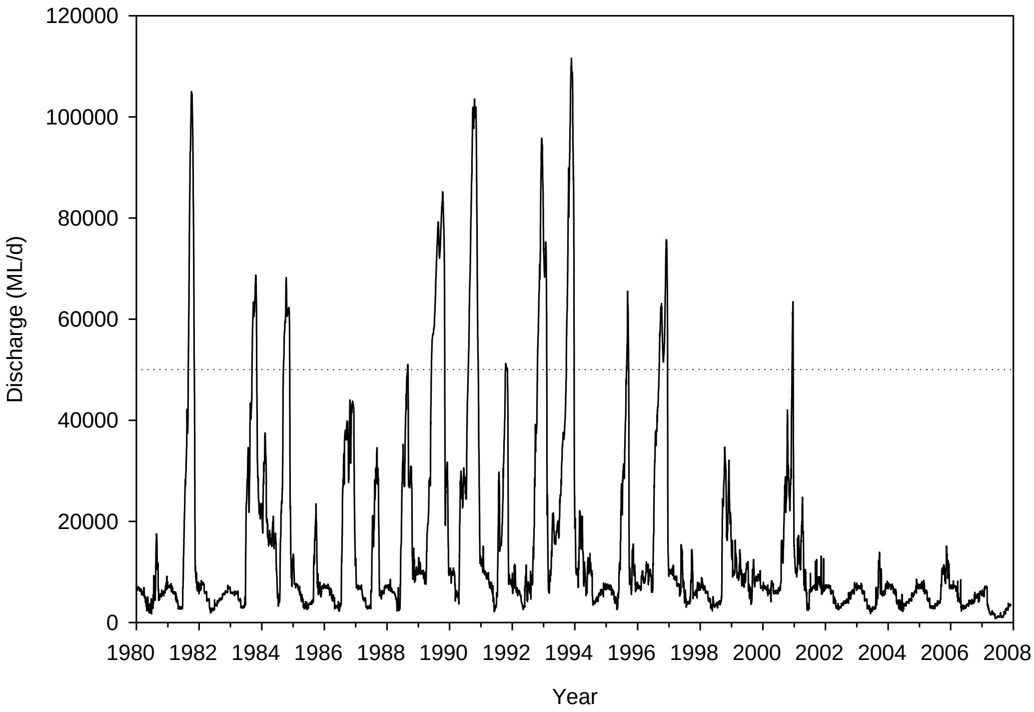


Figure 1-1 Murray River discharge into South Australia for the period 1980 – 2008. Dotted line indicates bankfull threshold (> 50,000 ML/d).

Due to the number of creeks entering the Chowilla system and the combined influence of Murray River discharge and Lock 6 weir pool height, the relationship between discharge in the Murray River and Chowilla Creek is not well quantified. At low Murray River flows (i.e. < 3,000 ML/d) up to 90% of the discharge into South Australia (SA) may pass through Chowilla Creek. This proportion decreases as discharge in the Murray increases until at Murray flows of 20,000 ML/d only 10% of discharge to SA flows through Chowilla Creek (Stace and Greenwood 2004).

Discharge into South Australia in the Murray River in the spring/summer of 2004/2005 increased from a winter entitlement flow of approximately 3,000 ML/d to a summer entitlement flow of approximately 7,500 ML/d. During the same period discharge in Chowilla Creek ranged from approximately 2,000 – 2,500 ML/d during winter and early spring before decreasing to 1,500 – 1,700 ML/d during summer (Figure 1-2).

Discharge into South Australia in the Murray River in the spring/summer of 2005/2006 increased from approximately 3,800 ML/d to a peak of 15,000 ML/d over approximately a 3 month period (Figure 1-2). The increase in discharge was the result of flow in the Murray River exceeding the capacity of the Lake Victoria inlet channel (Frenchmans Creek) and subsequently being bypassed down the Murray River. Discharge in the Chowilla Creek, however, does not clearly reflect the magnitude of this flow event and only a slight increase in discharge was observed (approximately 1,500 – 3,000 ML/d).

During the same period in 2006/2007 the discharge into South Australia increased from approximately 3,500 ML/d to a maximum of 6,500 ML/d (standard winter and decreased summer entitlement flow) and was the result of regulated releases from Lake Victoria. This increase in discharge in the Murray River was reflected by a slight increase in discharge in the Chowilla Anabranch system (1,500 – 2,500 ML/d) (Figure 1-2). Due to ongoing drought conditions in the Murray-Darling Basin (MDB) flows less than the 7,500 ML/d summer entitlement flow were delivered over the spring and summer of 2006/2007 with flows ranging from 4,500 to 6,500 ML/d. In late March 2007 discharge in the Murray River was decreased abruptly from approximately 6,500 – < 2,000 ML/d in response to ongoing drought condition (Figure 1-2). In response to this reduction in flow and in order to maintain the level of Lock 6 weir pool, discharge was restricted in Slaney, Pipeclay, Boat and Bank E creeks in the Chowilla system.

All flows recorded during the study period were well below a bankfull or overbank flow threshold of approximately 50,000 ML/d.

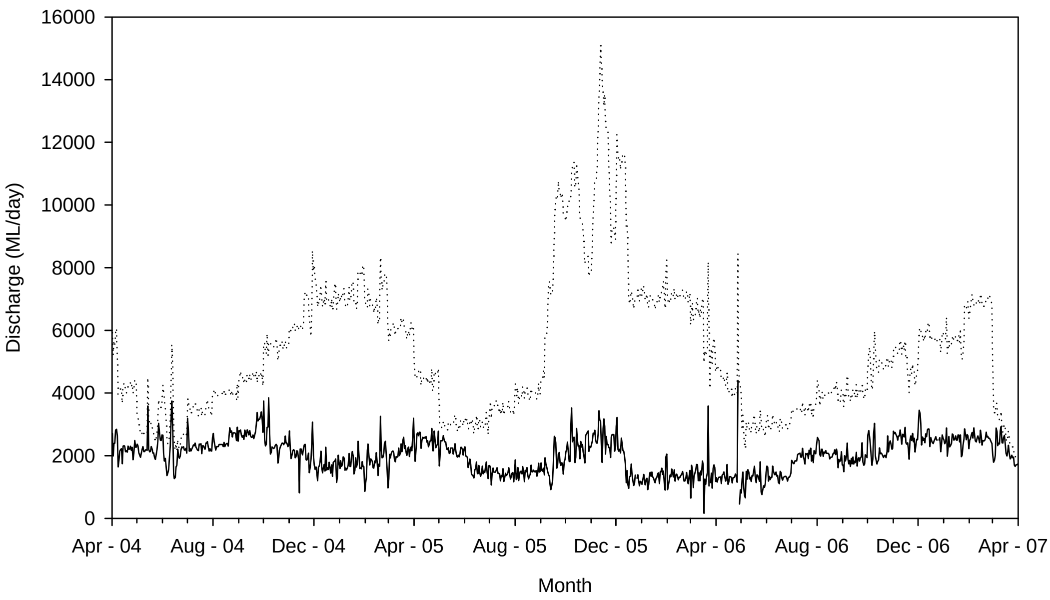


Figure 1-2 Murray River discharge into South Australia (dotted line) and Chowilla Creek discharge (solid line) from April 2004 – April 2007.

Stage heights recorded within the Chowilla system from September 2005 – March 2006 and September 2006 – April 2007 show a considerable difference in water level between years (Figure 1-3). Between mid September 2005 and January 2006 water surface levels in Chowilla Creek increased by approximately 0.5 – 0.7 m. During the same period, however, in 2006/2007 water levels were relatively stable. The increase in water surface level in 2005/2006 is likely the result of a combination of increased discharge and the raising of Lock 5 weir pool by 0.5 m.

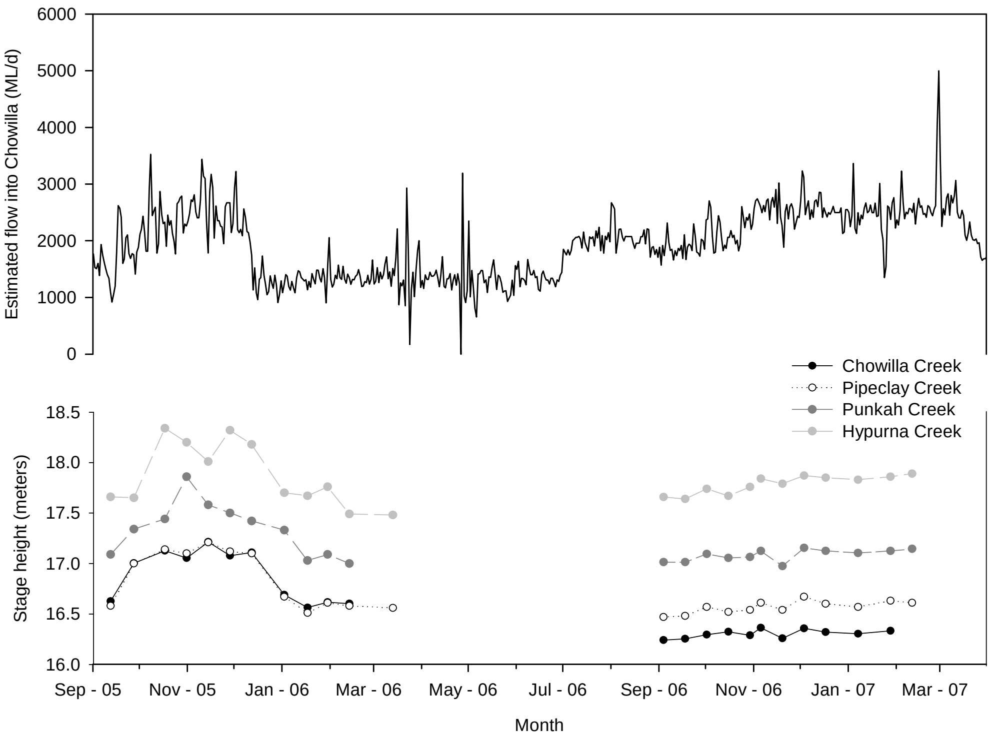


Figure 1-3 Stage height (m AHD) recorded at four sites within the Chowilla System for the period April 2005 – April 2007 plotted with the estimated discharge in Chowilla Creek (ML/d).

Water temperature regimes were similar between Chowilla Creek and the Murray River (Figure 1-4). Minimum water temperatures of 10 – 11ºC were recorded in July of each year and maximum temperatures of between 25 – 30ºC were recorded from January-February (Figure 1-4).

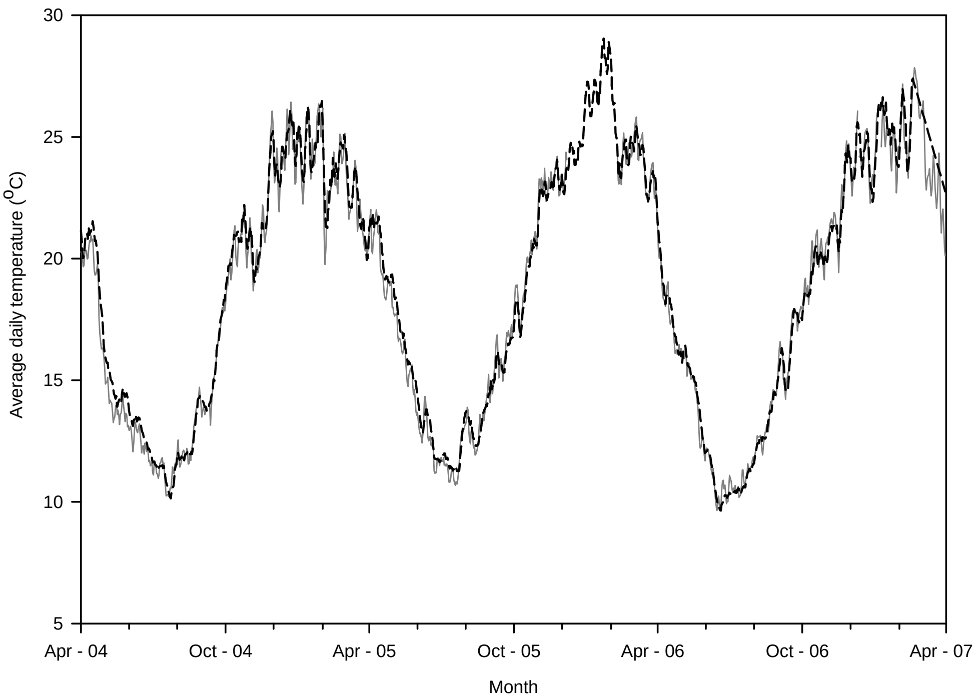


Figure 1-4 Water temperature in the Murray River (dashed black line) and Chowilla Creek (grey line) from April 2004 – April 2007.

Salinities (as measured by electrical conductivity) in the Murray River and Chowilla Creek were similar throughout the study period (September 2004 – June 2007) and generally show a decreasing trend over the three year period. Maximum conductivities of approximately 300 $\mu S/cm^{-1}$ were recorded in July 2005 and a minimum of < 150 $\mu S/cm^{-1}$ in November 2005 (Figure 1-5). The lowest conductivities were recorded during the small within-channel rise in discharge from October – December 2005 (Figure 1-5). This is likely to be a result of water delivered from the upper Murray River rather than Lake Victoria.

In general, salinities recorded in the Murray River and Chowilla system from 2004 – 2007, were not of a magnitude that is likely to directly impact on native fish or aquatic macrophytes (Leigh *et al.* 2008). Nevertheless, Leigh *et al.* (2008) cautioned that salinities following the next overbank flooding event may be of considerable concern.

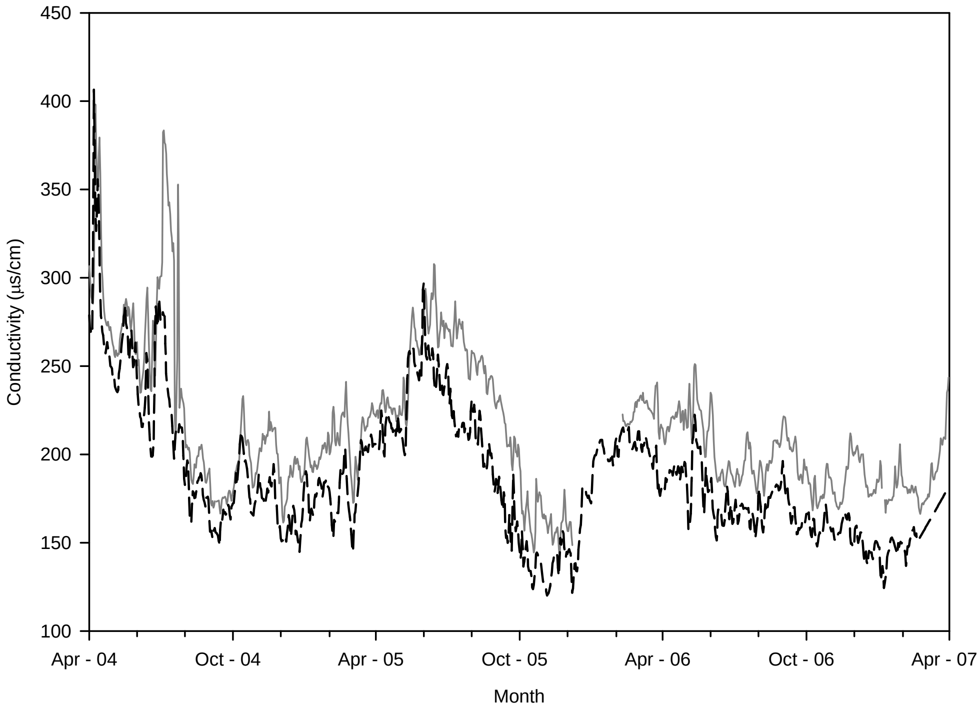
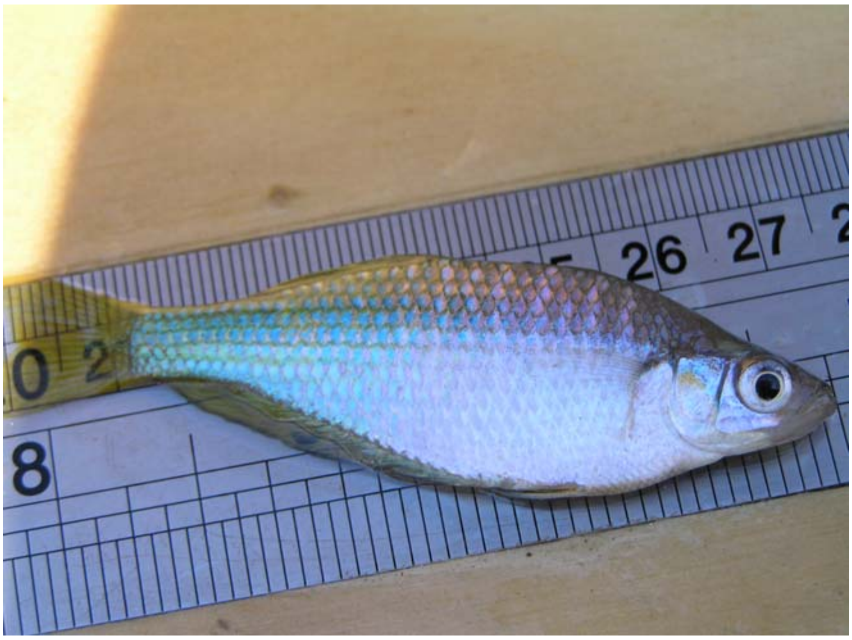


Figure 1-5 Electrical conductivity in the Murray River (dashed black line) and Chowilla Creek (grey line) from April 2004 – April 2007.

2 Fish Assemblages



Murray-Darling rainbowfish (*Melanotaenia fluviatilis*), a common small-bodied fish species in the Chowilla system.

2.1 Introduction

Fish communities are structured by biotic (e.g. predation, competition) and abiotic (e.g. geomorphological, hydrological and physico-chemical) factors that interact at varying spatio-temporal scales (Matthews 1998; Marsh-Matthews and Mathews 2000; Jackson *et al.* 2001). Semi-arid and arid lowland streams lack the pool-riffle sequence of upland streams, where much of our understanding of fish-habitat associations is derived (Pretty *et al.* 2003; Boys and Thoms 2006). Woody debris (snags) and different vegetation types provide most of the habitat heterogeneity present in lowland streams. Structural complexity interacts with other abiotic and biotic factors to influence assemblage diversity (Frissell *et al.* 1986; Jackson *et al.* 2001).

Structurally more complex areas, characterised by snags and/or aquatic macrophytes, enhance foraging opportunities and provide refuge from predation and thus contribute to increased diversity (Koehn 2006; Flebbe and Dollof 1995; Jackson *et al.* 2001). Hydraulic habitats are also important (Lamouroux 1998) and are determined by river channel morphology and the volume of flow. Spatio-temporal variability in both these factors creates a dynamic mosaic of hydraulic habitats (Matthews 1998; Maddock 1999). Ultimately, the interaction between fluvial dynamics and habitat structure influences the amount and suitability of habitat available to freshwater fish for spawning, feeding and refuge.

The Chowilla system is recognised for its diverse aquatic mesohabitats; most notably fast-flowing creeks, and fluvial heterogeneity that are now generally absent from the main channel of the Murray River downstream of Mildura (Walker 2006). In addition to fast-flowing creeks, Chowilla contains slow-flowing creeks, off-channel backwaters, terminal floodplain lakes and floodplain billabongs. This complex of aquatic habitats is considered to maintain remnant populations of endangered flora and fauna that are uncommon or extinct elsewhere in the lower Murray (O'Malley and Sheldon 1990; Pierce 1990; Sharley and Huggan 1995). Nevertheless, quantitative data on spatio-temporal variation in fish assemblages are scant.

We quantitatively sampled 16 sites in the Chowilla system and adjacent Murray River annually from 2005 – 2007 in order to describe the community composition and spatial variation in fish assemblages. Furthermore we investigated the recruitment of small and large-bodied fish using length and, in the case of golden perch, age frequency data. We also investigated the interactions between fish assemblages and aquatic mesohabitats, and individual fish species and microhabitats.

2.2 Methods

2.2.1 Spatio-temporal variation in fish assemblages

Sixteen sites were surveyed in the Chowilla system and adjacent Murray River in March 2005, 2006 and 2007 (Table 2-1 and Figure 2-1). Surveys were undertaken in March to enable young-of-year fish from the preceding spring/summer spawning season to be detected and thus allow us to investigate recruitment. Sites were located in all aquatic mesohabitats that were present in the Chowilla system during the study period; namely fast-flowing anabranches, slow-flowing anabranches, backwaters and the Murray River main channel, as described by Sheldon and Lloyd (1990).

Fish were sampled using a boat mounted 5kW Smith Root Model GPP electrofishing system. Electrofishing incorporated 12 (6 on each bank) x 90 second (power on time) electrofishing shots during daylight hours. All fish were dip netted and placed in a recirculating well. Any positively identified fish unable to be dip netted were recorded as "observed". Fish from each shot were identified, enumerated and measured for length

(±1 mm, caudal fork length, L_F or total length, L_T). Where large numbers of an individual species were collected a sub sample of 20 individuals was measured for length.

Differences in species composition and relative abundance between sites and mesohabitat types were analysed with NMS ordination, Analysis of Similarities (ANOSIM) and Indicator Species Analysis (Dufrene and Legendre 1997) using the packages PCOrd version 5.12 (McCune and Mefford 2006) and PRIMER version 6.1.12 (Clarke and Gorley 2006).

Bray-Curtis (1957) distances were used to calculate the similarity matrix for all multivariate analyses and two-dimensional ordination solutions with stress lower than 20% were deemed acceptable (*sensu* McCune *et al.* 2002). Replicates for each site were pooled for the ordinations for clarity, however ANOSIM and indicator species analysis were performed on unpooled data.

Table 2-1 Location of fish assemblage sampling sites, aquatic mesohabitat types are as defined by Sheldon and Lloyd (1990).

Site No.	Location	Mesohabitat Type
1	Chowilla Creek d/s Monoman Creek	Slow-flowing
2	Chowilla Creek u/s of Boat Creek	Fast-flowing
3	Chowilla Creek d/s Slaney Creek	Fast-flowing
4	Boat Creak u/s vehicle bridge	Fast-flowing
5	Swiftys Creek d/s Bank I	Fast-flowing
6	Pipeclay Creek d/s Pipeclay Weir	Slow-flowing*
7	Slaney Creek d/s Slaney Weir	Fast-flowing
8	Slaney Creek d/s Salt Creek junction	Fast-flowing
9	Slaney Billabong	Backwater
10	Hypurna Creek at Wilkadene	Slow-flowing
11	Punkah Creek d/s Punkah Island ford	Slow-flowing
12	Punkah Creek at Lake Littra	Slow-flowing
13	Murray River 10 km d/s Lock 6	Main River Channel
14	Murray River immediately d/s Lock 6	Main River Channel
15	Isle of Mann backwater	Backwater
16	Monoman Creek at campsite 29	Backwater

*was classified as a fast-flowing site in 2005 but reclassified as slow-flowing in 2006 following refurbishment of Pipeclay Weir and a subsequent decrease in discharge in this creek.

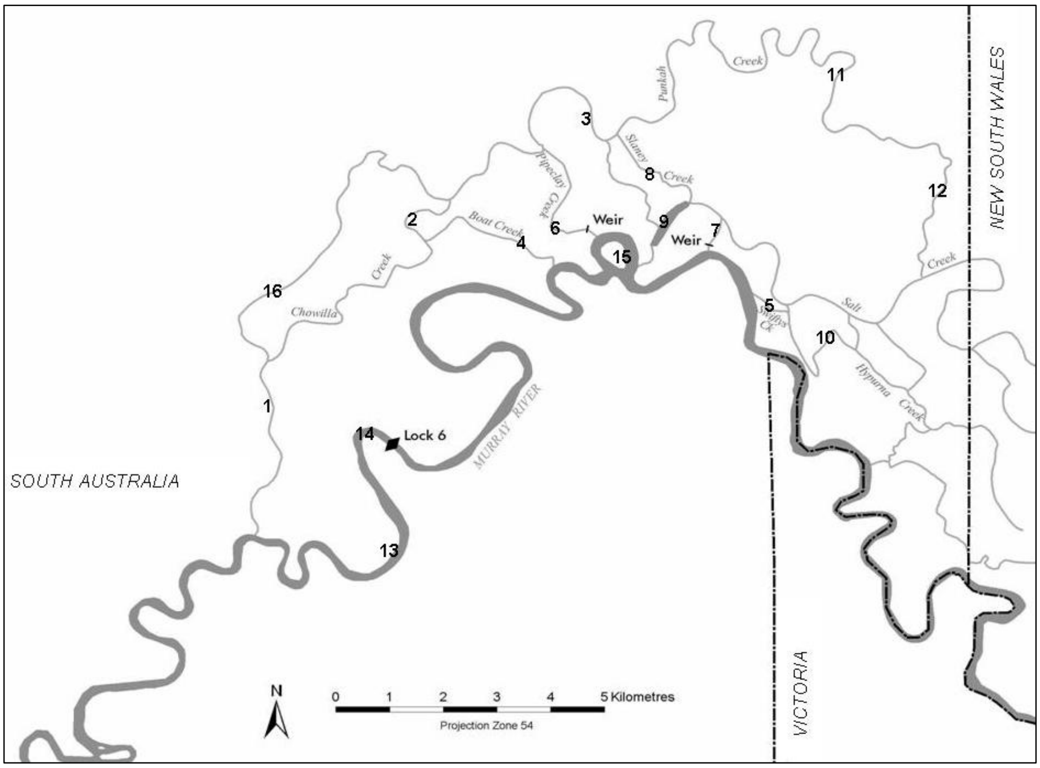


Figure 2-1 Map of the Chowilla system and adjacent Murray River showing the location of the 16 sites surveyed from 2005 – 2007.

2.2.2 Temporal variation in species diversity and recruitment

The Chowilla Floodplain Asset Environmental Management Plan (DWLBC 2006) includes three preliminary targets for fish populations in the Chowilla system, namely

Target 10. Maintain the diversity and extent of distribution of native fish species throughout Chowilla.
Target 12. Maintain successful recruitment of small-bodied native fish every year.
Target 13. Maintain successful recruitment of large-bodied fish at least once every five years.

In order to assist with *condition* reporting (MDBC 2006) against Target 10 we grouped sites into mesohabitats. Differences in species composition and relative abundance between mesohabitat groups were analysed with NMS ordination, Analysis of Similarities (ANOSIM) and indicator species analysis (Dufrene and Legendre 1997) using the packages PCOrd version 5.12 (McCune and Mefford 2006) and PRIMER version 6.1.12 (Clarke and Gorley 2006).

Bray-Curtis (1957) distances were used to calculate the similarity matrix for all multivariate analyses and two-dimensional ordination solutions with stress lower than 20% were deemed acceptable (*sensu* McCune *et al.* 2002). Replicates for each site were pooled for the ordinations for clarity, however ANOSIM and indicator species analysis were performed on unpooled data.

In order to assist in reporting against targets 12 and 13 we plotted the annual length distribution of the two most abundant large-bodied native species, namely, golden perch (*Macquaria ambigua ambigua*) and Murray cod (*Maccullochella peelii*), the four most abundant small to medium-bodied native species, namely, bony herring (*Nematalosa erebi*), unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Murray rainbowfish (*Melanotaenia fluviatilis*) and Australian smelt (*Retropinna semoni*) and the two most abundant non-native species common carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*). The length distributions are used as a non-destructive indicator of recruitment, with the exception of golden perch which were further investigated using otolith ageing techniques (see Chapter 6).

2.2.3 Fish assemblages and mesohabitats

In order to investigate the relationship between fish assemblages and mesohabitats we analysed the data from three years of electrofishing at 16 sites in the Chowilla system and adjacent Murray River (see section 2.2.1). Four additional sites were added to these data from the 2005 surveys (Table 2-2).

Table 2-2 Additional sites used to investigate the relationship between species composition and relative abundance and mesohabitat type.

Location	Mesohabitat type
Pilby Creek wetland	Backwater
Salt Creek d/s Hypurna Creek junction	Slow-flowing
Salt Creek tributary	Slow-flowing
Murray River at Border Cliffs	Main River channel

Each site was assigned to a mesohabitat category (*sensu* Sheldon and Lloyd 1990, namely slow-flowing, fast-flowing, backwater and main river channel). These aquatic mesohabitat categories were quantified and revised following the measurement of cross-sectional velocity profiles at all sites in March 2007. Fast-flowing habitats were subsequently characterised as having mean velocities (based on six cross sections) of > 0.18 ms^{-1}, slow-flowing habitats 0.05 – 0.18 ms^{-1}, backwaters < 0.05 ms^{-1} and Murray River main channel < 0.1 ms^{-1}.

Differences in species composition and relative abundance between mesohabitat types were analysed with NMS ordination, Analysis of Similarities (ANOSIM) and Indicator Species Analysis (Dufrene and Legendre 1997) using the packages PCOrd version 5.12 (McCune and Mefford 2006) and PRIMER version 6.1.12 (Clarke and Gorley 2006).

Bray-Curtis distances were used to calculate the similarity matrix for all multivariate analyses (Bray and Curtis 1957) and two-dimensional ordination solutions with stress lower than 20% were deemed acceptable. Replicates for each site were pooled for the ordinations for clarity, however ANOSIM and indicator species analysis were performed on unpooled data.

2.2.4 Fish species and microhabitats

In 2005, several of the aquatic macrophyte survey sites corresponded with electrofishing sites; however, the vegetation and fish data were collected at different scales and fish-habitat associations could not be determined (Zampatti *et al.* 2006). In 2006 habitat data was collected at the same time, location and scale as the fish community data, thus enabling fish-habitat associations to be investigated. Data on fish species presence and abundance was collected at the 16 sites, and using the methods described, in section 2.2.1.

Quantitative visual habitat assessments were carried out for every 90 second electrofishing shot. Two observers (immediately after each shot in the electrofishing area of influence) visually estimated the percentage cover of each plant species, large woody debris and open water in the area covered by the electrofishing shot. Large woody debris was divided into four categories:

- CWD 1: twigs and branches with diameters < 1 cm
- CWD 2: branches with diameters 1 – 5 cm
- CWD 3: branches and trunks with diameters > 5 cm
- Tree Roots: *Eucalyptus camaldulensis* and *Acacia stenophylla* roots

2.2.5 Data Analysis

Fish-habitat associations were determined by indicator species analysis (Dufrene and Legendre 1997) using the package PCOrd version 5.12 (McCune and Mefford 2006). This test was used to determine whether a plant species (or CWD category) had a significantly higher percentage cover when a fish species was either present or absent (for large-bodied species present in low numbers) or a particular abundance class (for fish present in large numbers).

Groups for indicator species analysis for large-bodied, less abundant species (i.e. Murray cod, golden perch and silver perch, (*Bidyanus bidyanus*), were assigned on a presence/absence basis. For abundant species (i.e. Australian smelt, Murray rainbowfish, flat-headed gudgeons (*Philypnodon grandiceps*), common carp, carp gudgeons (*Hypseleotris* spp.), bony herring, goldfish and gambusia (*Gambusia holbrooki*), groups were assigned on the basis of relative abundance: absent (0 fish.min^{-1}), low (0.01 – 1 fish.min^{-1}), medium (1.01 – 10 fish.min^{-1}), medium-high (10.01 – 100 fish.min^{-1}) and high (> 100 fish.min^{-1}).

2.3 Results

2.3.1 General

A total of 27,654 fish from 15 species (11 native and four non-native) were sampled from 16 sites over three sampling events in March/April of 2005, 2006 and 2007 (Table 2-3). Small to medium-bodied native fish such as bony herring (59.7% of total catch) and unspecked hardyhead (21.2%) were sampled in the greatest relative abundance (Table 2-4). Large-bodied native fish such as golden perch and Murray cod were sampled in lower relative abundances, 1.0% and 0.1% respectively (Table 2-4). In comparison the large-bodied non-native species common carp comprised 3.5% of the total catch (Table 2-4).

Three state and/or nationally protected or threatened species were collected. Namely Murray cod, silver perch and freshwater catfish (*Tandanus tandanus*). Murray cod is listed as threatened under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*, and freshwater catfish and silver perch are protected under the South Australia *Fisheries Management Act 2007*.

Most species were widespread with the exception of Murray cod, silver perch, dwarf flat-headed gudgeon (*Phylipnodon macrostomus*), freshwater catfish and non-native redfin perch (*Perca fluviatilis*). All five species were sampled in low abundances (1 – 7 fish/site/sampling event) (Table 2-4). Murray cod and silver perch were only sampled in fast-flowing mesohabitats and the Murray River, although one silver perch was collected in the Isle of Mann, a backwater of the Murray River (Table 2-4). Individual freshwater catfish were sampled in fast-flowing mesohabitats in Slaney and Boat Creeks (Table 2-4). Individual dwarf flat-headed gudgeon were sampled in Slaney Billabong and the Murray River, whilst redfin perch was sampled in the Murray River (main channel and Isle of Mann backwater) and Monoman Creek (slow-flowing mesohabitat) (Table 2-4).

Table 2-3 Total numbers of fish sampled from 16 sites in the Chowilla system and adjacent Murray River in March/April 2005 – 2007.

Common name	Scientific name	Total			Grand total
		2005	**2006**	**2007**	
Native species					
Golden perch	*Macquaria ambigua ambigua*	75	75	114	**264**
Murray cod	*Maccullochella peelii*	12	11	14	**37**
Silver perch	*Bidyanus bidyanus*	5	5	1	**11**
Bony herring	*Nematalosa erebi*	3970	6233	6320	**16523**
Australian smelt	*Retropinna semoni*	546	192	756	**1494**
Murray rainbowfish	*Melanotaenia fluviatilis*	436	396	125	**951**
Flat-headed gudgeon	*Phylipnodon grandiceps*	59	7	20	**86**
Dwarf flat-headed gudgeon	*Phylipnodon macrostoma*	2	0	0	**2**
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	2600	1673	1595	**5868**
Carp gudgeon spp.	*Hypseleotris* spp.	254	107	107	**468**
Freshwater catfish	*Tandanus tandanus*	0	0	2	**2**
Non-native species					
Common carp	*Cyprinus carpio*	223	469	279	**971**
Gambusia	*Gambusia holbrooki*	157	52	128	**337**
Goldfish	*Carassius auratus*	177	300	176	**653**
Redfin perch	*Perca fluviatilis*	0	0	9	**9**
	Total species	**13**	**13**	**14**	**15**
	Total fish	**8514**	**9493**	**9647**	**27654**

Table 2-4 Relative abundance of species captured at each site from 2005 – 2007.

Site	Year	Golden perch	Murray cod	Silver perch	Bony herring	Australian smelt	Murray rainbowfish	Flathead gudgeon	Dwarf flathead gudgeon	Unspecked hardyhead	Carp gudgeon spp	Freshwater catfish	Carp	Gambusia	Goldfish	Redfin perch	Total species	Total fish/site
	05	7	-	1	503	35	15	2	-	131	3	-	13	-	4	-	**10**	**714**
1	06	3	-	1	640	3	5	-	-	30	4	-	3	-	14	-	**9**	**703**
	07	5	-	1	201	5	6	-	-	12	6	-	19	-	3	-	**9**	**258**
	05	10	2	-	100	11	23	1	-	13	8	-	11	3	1	-	**11**	**183**
2	06	14	3	-	147	9	21	-	-	53	6	-	6	1	1	-	**10**	**261**
	07	10	3	-	191	49	13	-	-	37	4	-	13	2	2	-	**10**	**324**
	05	2	-	-	183	36	1	10	-	166	24	-	15	26	27	-	**10**	**490**
3	06	1	-	1	889	5	4	1	-	124	11	-	57	1	13	-	**11**	**1107**
	07	17	-	-	170	5	13	4	-	15	2	-	24	3	10	-	**10**	**263**
	05	5	1	-	27	5	17	-	-	20	5	-	17	53	1	-	**10**	**151**
4	06	10	2	-	98	1	12	1	-	38	2	-	9	23	3	-	**11**	**199**
	07	7	1	-	133	11	15	2	-	89	5	1	9	56	3	-	**12**	**332**
	05	1	2	1	390	166	46	2	-	57	4	-	19	10	-	-	**11**	**698**
5	06	4	2	1	183	74	73	-	-	113	3	-	24	-	-	-	**9**	**477**
	07	4	1	-	2104	142	14	-	-	100	-	-	23	2	1	-	**9**	**2391**
	05	9	1	-	296	25	16	4	-	381	27	-	10	11	10	-	**11**	**790**
6	06	7	-	-	129	15	29	1	-	524	22	-	26	5	21	-	**10**	**779**
	07	9	-	-	275	98	4	1	-	158	17	-	11	35	6	-	**10**	**614**
	05	10	4	-	100	34	22	3	-	18	6	-	11	2	1	-	**11**	**211**
7	06	6	1	-	889	27	84	1	-	119	15	-	20	-	3	-	**10**	**1165**
	07	18	1	-	935	319	26	-	-	353	50	-	12	7	1	-	**10**	**1722**
	05	10	2	-	462	56	30	4	-	76	14	-	8	1	1	-	**11**	**664**
8	06	6	3	-	85	12	21	-	-	28	1	-	11	4	-	-	**9**	**171**
	07	9	7	-	483	45	7	-	-	17	-	1	23	-	1	-	**9**	**593**
	05	-	-	-	61	29	-	1	1	34	3	-	3	3	40	-	**8**	**174**
9	06	-	-	-	104	1	-	-	-	93	1	-	13	-	14	-	**6**	**226**
	07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**	**-**
	05	6	-	-	184	19	13	3	-	79	7	-	14	8	17	-	**10**	**350**
10	06	1	-	-	209	6	3	1	-	76	9	-	47	5	27	-	**10**	**384**
	07	5	-	-	237	12	6	2	-	34	7	-	16	8	35	-	**10**	**362**
	05	1	-	-	164	26	6	-	-	23	-	-	12	-	19	-	**7**	**251**
11	06	-	-	-	184	3	23	-	-	16	5	-	52	-	40	-	**7**	**323**
	07	7	-	-	170	-	-	1	-	5	2	-	26	2	20	-	**8**	**233**
	05	3	-	-	148	20	7	4	-	34	8	-	13	11	28	-	**10**	**276**
12	06	-	-	-	216	1	5	-	-	26	1	-	48	7	24	-	**8**	**328**
	07	5	-	-	87	-	1	1	-	5	-	-	10	4	16	-	**8**	**129**
	05	2	-	2	124	48	124	10	1	413	24	-	6	3	7	-	**12**	**764**
13	06	6	-	2	695	27	40	1	-	227	3	-	25	5	27	-	**11**	**1058**
	07	8	1	-	183	55	8	3	-	298	5	-	21	-	-	1	**10**	**584**
	05	4	-	-	397	18	94	13	-	754	24	-	16	6	1	-	**10**	**1327**
14	06	14	-	-	661	7	42	-	-	132	9	-	30	-	68	-	**8**	**936**
	07	6	-	-	90	9	7	3	-	158	2	-	13	-	5	4	**10**	**297**
	05	2	-	1	104	1	17	-	-	300	-	-	36	4	4	-	**10**	**469**
15	06	2	-	-	138	-	5	-	-	10	2	-	47	1	8	-	**8**	**213**
	07	2	-	-	51	-	2	2	-	215	-	-	42	2	12	2	**9**	**330**
	05	3	-	-	727	17	4	2	-	101	97	-	19	16	16	-	**10**	**1002**
16	06	1	-	-	966	1	29	1	-	64	13	-	51	-	37	-	**9**	**1163**
	07	2	-	-	1010	6	3	1	-	99	7	-	17	7	61	2	**11**	**1215**
	05	**75**	**12**	**5**	**3970**	**546**	**436**	**59**	**2**	**2600**	**254**	**0**	**223**	**157**	**177**	**0**	**13**	**8514**
Total	**06**	**75**	**11**	**5**	**6233**	**192**	**396**	**7**	**0**	**1673**	**107**	**0**	**469**	**52**	**300**	**0**	**13**	**9493**
	07	**114**	**14**	**1**	**6320**	**756**	**125**	**20**	**0**	**1595**	**107**	**2**	**279**	**128**	**176**	**9**	**14**	**9647**
Grand total		**264**	**37**	**11**	**16523**	**1494**	**951**	**86**	**2**	**5868**	**468**	**2**	**971**	**337**	**653**	**9**	**40**	**27654**

2.3.2 Length Frequency

The length distribution of golden perch shows a unimodal distribution in 2005, with fish ranging from 250 – 450 mm, an additional small cohort of fish < 100 mm appears in 2006 and then a bi-modal distribution is present in 2007, this includes a strong size class of fish with a mode of approximately 200 mm (Figure 2-2). The length distribution, age and recruitment of golden perch are discussed in detail in Chapter 6.

The sample size for Murray cod is small (n = < 20 fish/year); nevertheless, in 2005 a bimodal length distribution of fish is present with the cohort of smaller fish ranging from 300 – 550 mm in length. In 2006 and 2007 this mode appears to progress and by 2007 few fish < 600 mm were collected. Further detail on Murray cod length distribution and recruitment are provided in Chapter 5.

For bony herring and the three small-bodied species (unspecked hardyhead, Murray rainbowfish and Australian smelt) length distributions were similar every year from 2005 – 2007. All species had broad length distributions and strong cohorts of small fish (Figure 2-3 and Figure 2-4). It is likely that these small fish are age 0+ (young-of-year) fish from the spring/summer spawning season.

The non-native species, common carp and goldfish, also had broad length distributions every year from 2005 – 2007. Both species, however, had strong cohorts of smaller fish (~ 90 – 110 mm) in 2006 (Figure 2-5). Length-at-age data indicate that fish of this size are likely to be young-of-year (Brown *et al.* 2005).

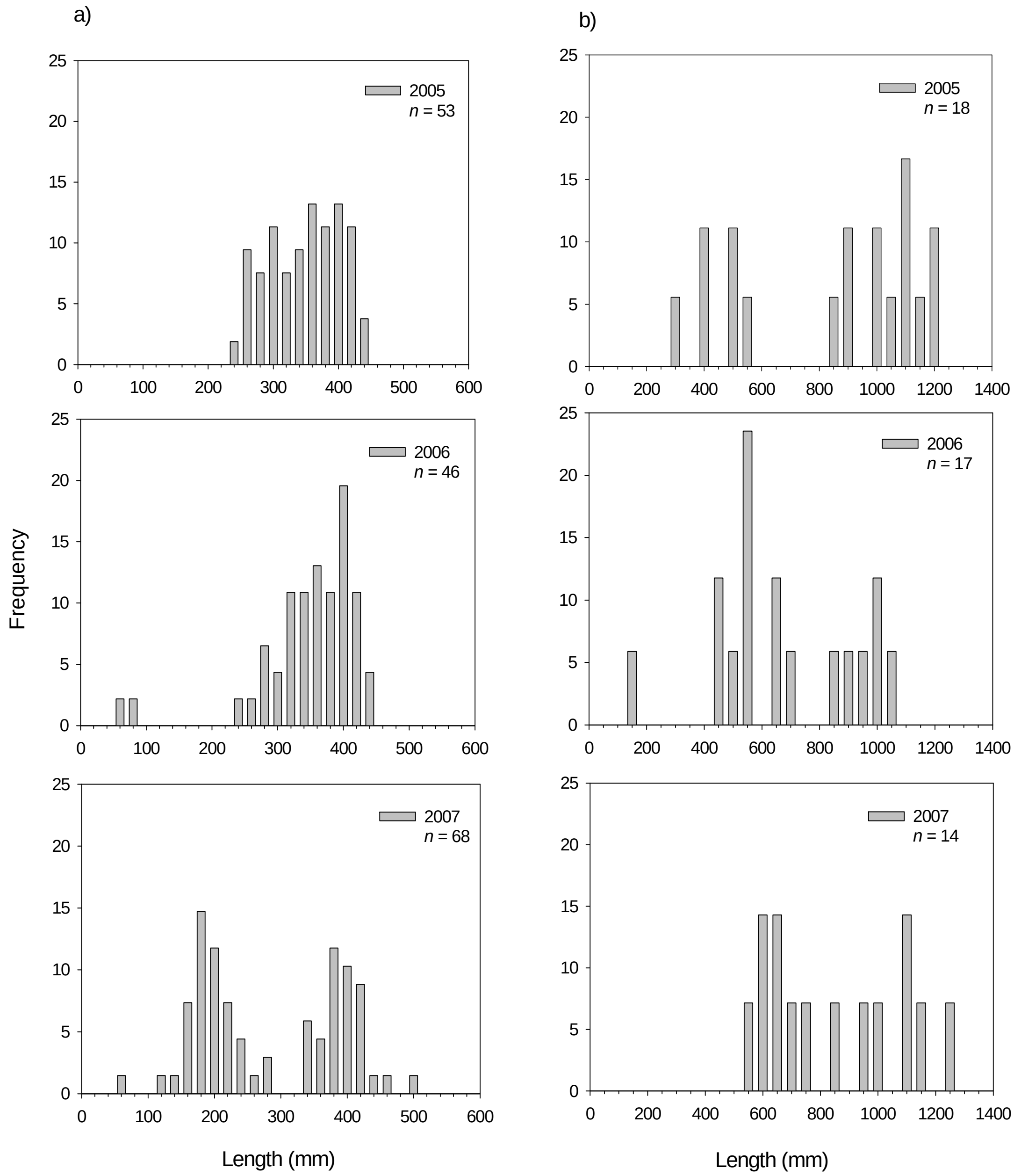


Figure 2-2 The length distribution of a) golden perch and b) Murray cod captured at sites within the Chowilla system in March 2005, 2006 and 2007.

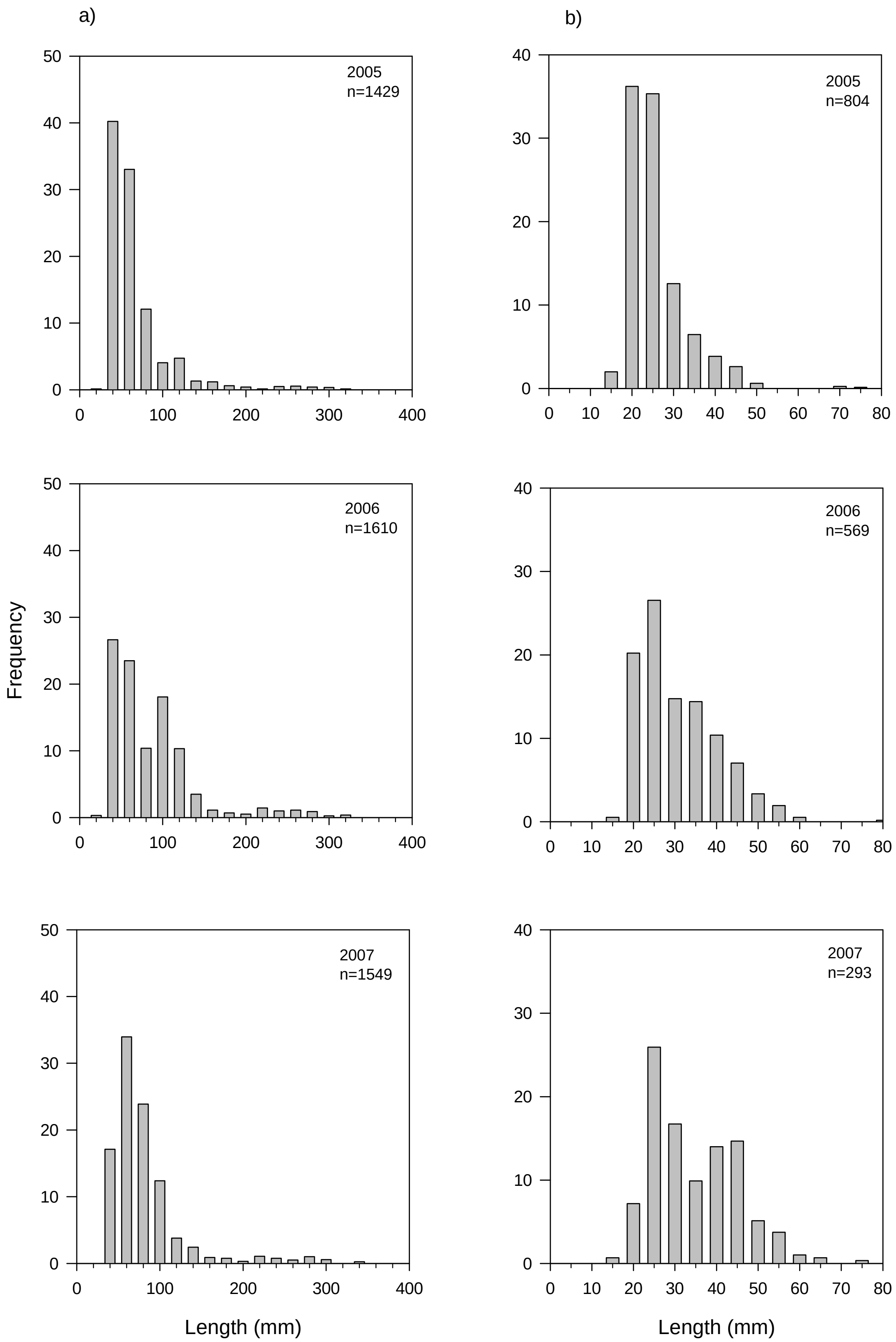


Figure 2-3 The length distribution of a) bony herring and b) unspecked hardyhead captured at sites within the Chowilla system in March 2005, 2006 and 2007.

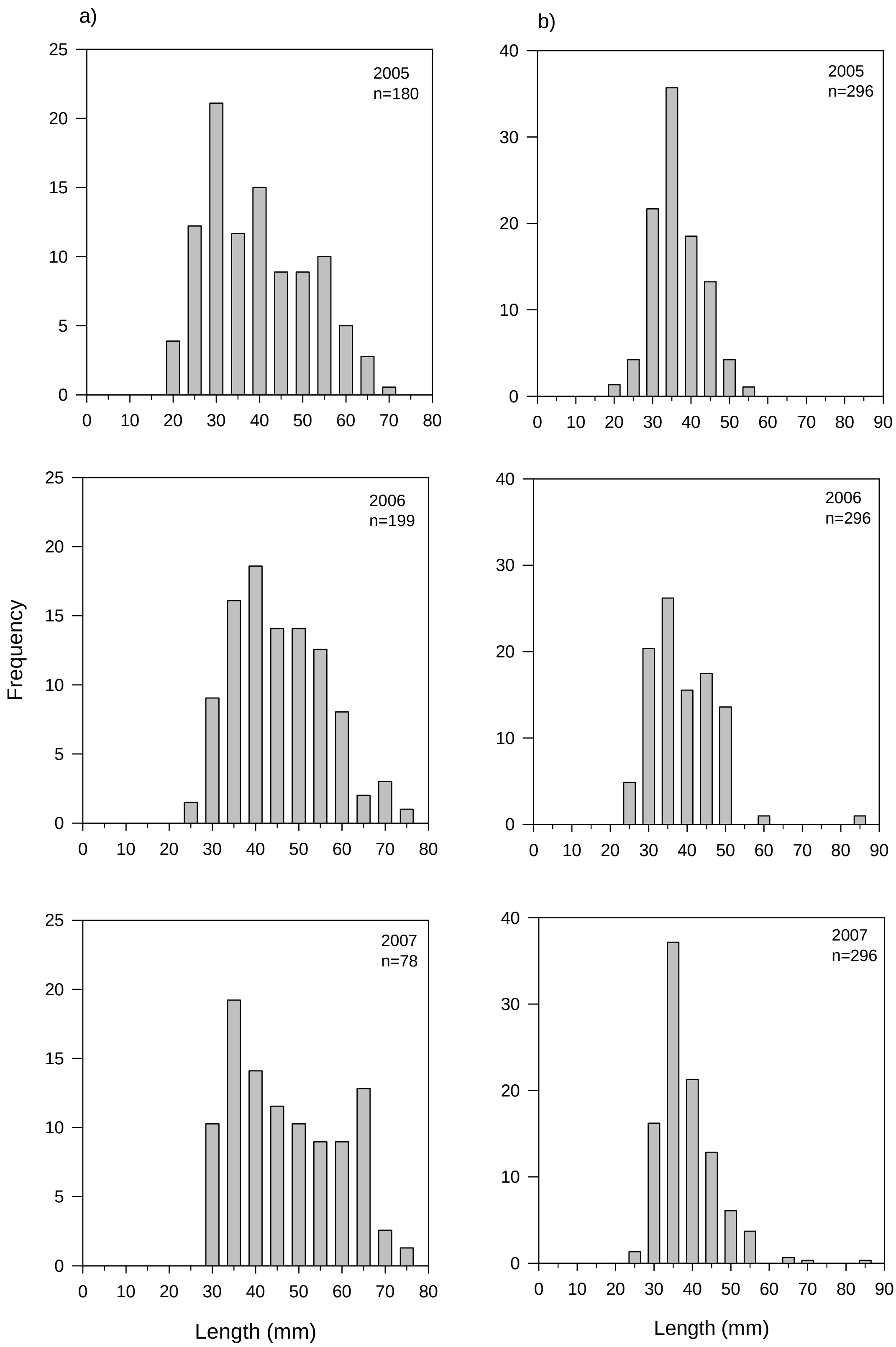


Figure 2-4 The length distribution of a) Murray rainbowfish and b) Australian smelt captured at sites within the Chowilla system in March 2005, 2006 and 2007.

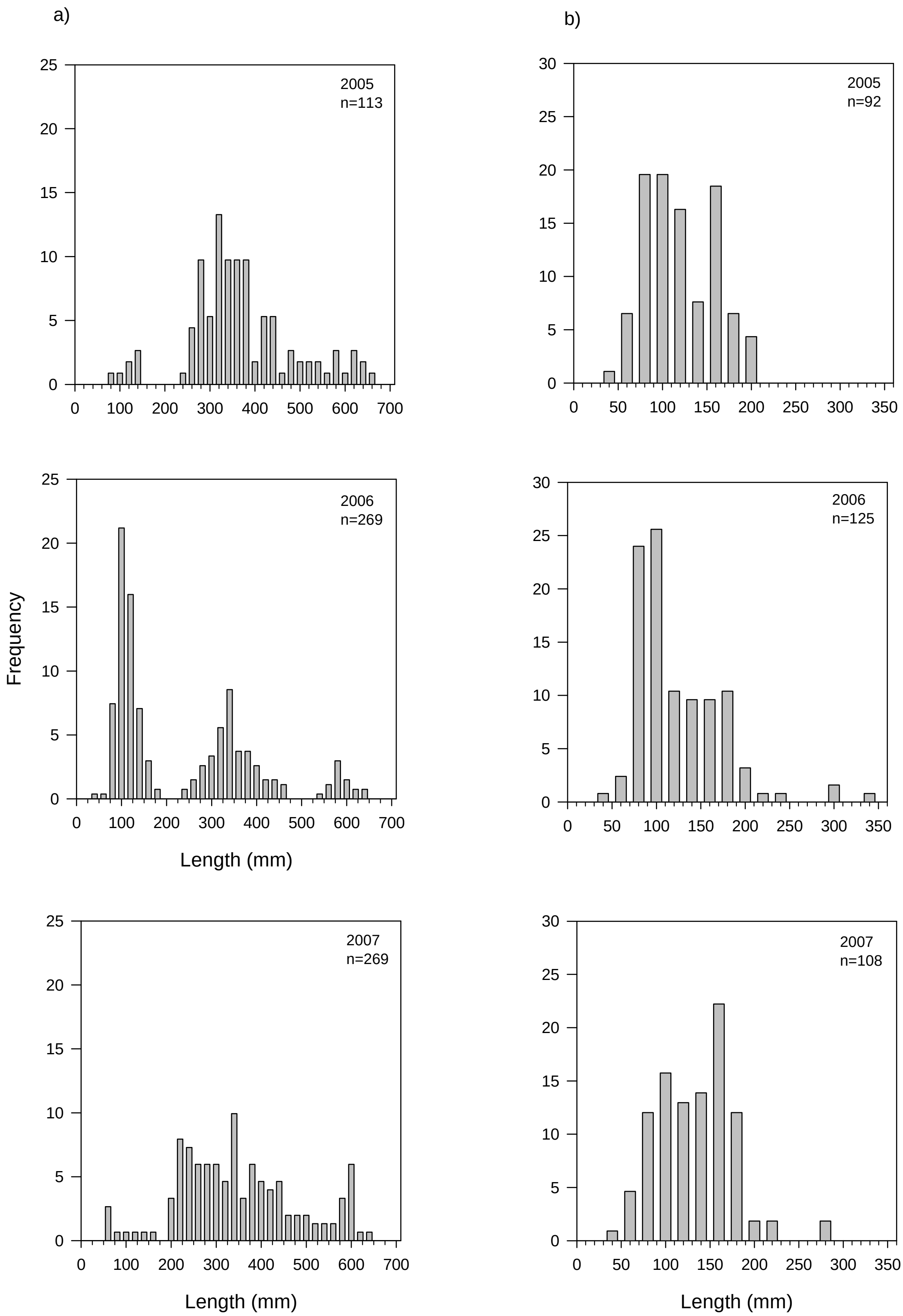


Figure 2-5 The length distribution of a) common carp and b) goldfish captured at sites within the Chowilla system in March 2005, 2006 and 2007.

2.3.3 Aquatic mesohabitats and fish communities

Significant differences in fish assemblages were detected among aquatic mesohabitat types with pair-wise tests identifying significant differences in fish assemblages between all mesohabitats (Table 2-5).

Table 2-5 One-way ANOSIM results testing for the effect of aquatic mesohabitat type on fish assemblages of the Chowilla system and adjacent Murray River. Significant differences ($p \leq 0.05$) are highlighted in bold.

Comparison	R-statistic	P-value
Global test		
Among mesohabitats	0.101	**0.001**
Pairwise tests		
Fast v Back Water	0.132	**0.001**
Fast v Slow	0.037	**0.001**
Fast v Main River Channel	0.044	**0.043**
Slow v Backwater	0.197	**0.001**
Slow v Main River Channel	0.097	**0.001**
Backwater v Main River Channel	0.188	**0.001**

Murray cod, golden perch, Australian smelt and gambusia were significant indicators of fast-flowing mesohabitats, goldfish, common carp and carp gudgeons were significant indicators of backwaters, and unspecked hardyhead and Murray rainbowfish were significant indicators of main river channel sites (Table 2-6).

Table 2-6 Indicator species analyses comparing the relative abundance of fish in four aquatic mesohabitats. A significant difference (P < 0.05) indicates that a species occurs in a higher relative abundance in a habitat and hence is contributing to differences between the fish assemblages of the habitats. Values that are not significant indicate that a species was either sampled in low numbers (uncommon) or was sampled consistently across habitats (widespread).

Species	Aquatic mesohabitat	P-value
Unspecked hardyhead	Main River Channel	**< 0.001**
Murray rainbowfish	Main River Channel	**< 0.001**
Gambusia	Fast-flowing	**0.050**
Bony herring	Fast-flowing	0.550
Goldfish	Backwater	**< 0.001**
Common Carp	Backwater	**< 0.001**
Carp gudgeons	Backwater	**< 0.001**
Flat-headed gudgeon	Backwater	0.110
Dwarf flat-headed gudgeon	Main River Channel	0.870
Murray cod	Fast-flowing	**< 0.001**
Golden perch	Fast-flowing	**< 0.001**
Silver perch	Main River Channel	0.140
Australian smelt	Fast-flowing	**< 0.001**
Freshwater catfish	Fast-flowing	0.280
Redfin perch	Main River Channel	0.080

2.3.4 Temporal variation in fish assemblages

Species richness and diversity in each mesohabitat remained reasonably consistent over time (Table 2-7). Fast-flowing mesohabitats were characterised by the same fish community in 2005 and 2006; however in 2007 silver perch were not sampled and freshwater catfish were (Table 2-7). Slow-flowing mesohabitats retained the same fish community from 2005 to 2007 and in backwater mesohabitats dwarf flat-headed gudgeon and silver perch were only sampled in 2005, and redfin perch only in 2007 (Table 2-7). In the main river channel dwarf flat-headed gudgeon were only sampled in 2005 and Murray cod and redfin perch were only sampled in 2007 (Table 2-7).

There were significant inter-annual differences in the relative abundance of fish in each mesohabitat (Table 2-8). Relative abundances of small to medium-bodied generalist species such as unspecked hardyhead, bony herring, carp gudgeons and flat-headed gudgeon varied significantly between years across a range of habitats but particularly in the main river channel (Table 2-9). Of the large-bodied species the non-native common carp was significantly more abundant in slow-flowing and backwater mesohabitats in 2006. In the same year goldfish were significantly more abundant in slow-flowing and main river channel mesohabitats (Table 2-9).

Table 2-7 Presence/absence of native and non-native (+) fish species in each mesohabitat type from 2005 – 2007. Species names abbreviated from the scientific name by the first three letters of the genus and species names.

	Fast-flowing			Slow-flowing			Backwater			Main river channel		
Species	**05**	**06**	**07**	**05**	**06**	**07**	**05**	**06**	**07**	**05**	**06**	**07**
Craste	*	*	*	*	*	*	*	*	*	*	*	*
Melflu	*	*	*	*	*	*	*	*	*	*	*	*
Nemere	*	*	*	*	*	*	*	*	*	*	*	*
Hypspp	*	*	*	*	*	*	*	*	*	*	*	*
Phigra	*	*	*	*	*	*	*	*	*	*	*	*
Phisp							*			*		
Macpee	*	*	*									*
Macamb	*	*	*	*	*	*	*	*	*	*	*	*
Bidbid	*	*		*	*	*	*			*	*	
Retsem	*	*	*	*	*	*	*	*	*	*	*	*
Tantan			*									
Caraur+	*	*	*	*	*	*	*	*	*	*	*	*
Cypcar+	*	*	*	*	*	*	*	*	*	*	*	*
Gamhol+	*	*	*	*	*	*	*	*	*	*	*	*
Perflu+									*			*

Table 2-8 One-way ANOSIM results testing for the effect of year on fish assemblages in four aquatic mesohabitats of the Chowilla system and adjacent Murray River. Significant differences ($p \leq 0.05$) are highlighted in bold.

Comparison		Mesohabitat: Fast-flowing	Slow-flowing	Backwater	Main river channel
Global test					
Among years	R-statistic	0.042	0.077	0.081	0.369
	P-value	**0.001**	**0.001**	**0.005**	**0.001**
Pairwise tests					
2005 v 2006	R-statistic	0.047	0.075	0.074	0.476
	P-value	**0.003**	**0.001**	**0.012**	**0.001**
2005 v 2007	R-statistic	0.062	0.089	0.079	0.212
	P-value	**0.002**	**0.001**	**0.022**	**0.001**
2006 v 2007	R-statistic	0.02	0.067	0.091	0.415
	P-value	**0.046**	**0.002**	**0.012**	**0.001**

Table 2-9 Indicator species analyses comparing the relative abundance of fish over three years (2005, 2006 and 2007) in four aquatic mesohabitats. A significant difference (P < 0.05) indicates that a species occurs in a higher relative abundance in a habitat and hence is contributing to differences between the fish assemblages of the habitats. Values that are not significant indicate that a species was either sampled in low numbers (uncommon) or was sampled consistently across habitats (widespread).

	Mesohabitat							
	Fast-flowing		**Slow-flowing**		**Backwater**		**Main river channel**	
Species	**Year**	**P-value**	**Year**	**P-value**	**Year**	**P-value**	**Year**	**P-value**
Unspecked hardyhead	2006	0.099	**2006**	**0.003**	2005	0.066	**2005**	**<0.001**
Murray rainbowfish	2006	0.422	2006	0.058	2006	0.316	**2005**	**<0.001**
Bony herring	**2007**	**<0.001**	2006	0.118	2006	0.688	**2006**	**<0.001**
Carp gudgeons	**2005**	**0.005**	**2006**	**0.034**	**2005**	**0.008**	**2005**	**<0.001**
Flat-headed gudgeon	**2005**	**0.007**	**2005**	**0.010**	2007	0.450	**2005**	**0.003**
Dwarf fh gudgeon	-	-	-	-	2005	1.000	2005	0.652
Murray cod	2007	0.837	-	-	-	-	2007	0.662
Golden perch	2007	0.227	2007	0.065	2007	0.907	2006	0.062
Silver perch	2006	0.410	2005	0.93	2005	1.000	2006	0.778
Australian smelt	2005	0.231	**2005**	**<0.001**	**2005**	**<0.001**	2005	0.186
Freshwater catfish	2007	0.330	-	-	-	-	-	-
Goldfish	2005	0.923	**2006**	**0.020**	2007	0.479	**2006**	**0.002**
Common Carp	2006	0.463	**2006**	**<0.001**	**2006**	**0.011**	2006	0.262
Gambusia	**2005**	**0.024**	2007	0.423	**2005**	**0.028**	2005	0.113
Redfin perch	-	-	-	-	**2007**	**0.005**	2007	0.063

2.3.5 Aquatic microhabitats and fish species

Each fish species showed a distinct association with one or more plant species or coarse woody debris class (Table 2-10 and Table 2-11). Murray cod showed a strong association with CWD 3 and tree roots and silver perch were also strongly associated with tree roots (Table 2-10). Golden perch were captured in areas with a high percentage cover of *Phragmites australis* and to a lesser extent *Typha domingensis* but not in areas with *Vallisneria americana, Ludwigia peploides* or *Cyperus gymnocaulos* (Table 2-10).

Common carp were captured in high numbers in areas with large amounts of *Vallisneria americana* and *Potamogeton crispus* (submergent species) and in small numbers in areas with no structural habitat (open water) and tree roots (Table 2-11). Areas with high percent cover of submergent (*Chara* sp. and *Myriophyllum verucossum*) or emergent species (*Typha domingensis, Schoenoplectus validus* and to a lesser extent *Phragmites australis*) or *Paspalum distichum* (a fringing species) had a positive association with large numbers of goldfish (Table 2-11). In contrast only small numbers of goldfish were present in areas where there was a high percent cover of CWD 3 (Table 2-11).

Table 2-10 Significant habitat associations for Murray cod, silver perch and golden perch (Sh = shrub, E = emergent, F = fringing species, Fl = floating leaved, S = submergent).

Species	Significant positive association	Significant negative association
Murray cod	CWD3 *P* = 0.0078	
	Muehlenbeckia florulenta (Sh) *P* = 0.0306	
	Tree roots *P* = 0.0050	
	Phragmites australis (E) *P* = 0.0378	
	Juncus usitatus (E) *P* = 0.0332	
Silver perch	CWD2 *P* = 0.034	
	Paspalum distichum (F) *P* = 0.048	
	Tree roots *P* = 0.0038	
Golden perch	Open water *P* = 0.0424	*Cyperus gymnocaulos* (E) *P* = 0.0152
	Phragmites australis (E) *P* = 0.0002	*Ludwigia peploides* (Fl) *P* = 0.0214
	Typha domingensis (E) *P* = 0.0262	*Vallisneria americana* (S) *P* = 0.0004

Table 2-11 Significant habitat associations for flat-headed gudgeon, common carp, carp gudgeon, bony herring, Australian smelt, Gambusia, goldfish and Murray rainbowfish (Sh = shrub, E = emergent, F = fringing species, Fl = floating leaved, S = submergent).

Species	Significantly associated with high numbers of fish	Significantly associated with medium numbers of fish	Significantly associated with low numbers of fish	Significant negative association
Flat-headed Gudgeons		*Myriophyllum verrucosum* (S) *P* = 0.0370 *Zannichellia palustris* (S) *P* = 0.0296		Open Water *P* = 0.0220
Common Carp	*Potamogeton crispus* (S) *P* = 0.0064 *Valisneria americana* (S) *P* = 0.0088		Open water *P* = 0.0082 Tree roots *P* = 0.0174 *Senecio* sp. (F) *P* = 0.0404	
Carp Gudgeons	*Bolboschoenus caldwellii* (E) *P* = 0.0002 *Potamogeton tricarinatus* (S/Fl) *P* = 0.0076			
Bony Herring	Open water *P* = 0.0302 CWD3 *P* = 0.0370 *Ludwigia peploides* (Fl) *P* = 0.0206			
Australian smelt	*Cyperus exaltatus* (E) *P* = 0.0322 *Muehlenbeckia florulenta* (Sh) *P* = 0.0018 *Senecio* sp. (F) *P* = 0.0128			
Gambusia	*Typha domingensis* (E) *P* = 0.0460		*Cyperus exaltatus* (E) *P* = 0.0056	
Goldfish	*Chara* sp. (S) *P* = 0.0100 *Myriophyllum verrucosum* (S) *P* = 0.0308 *Paspalum distichum* (F) *P* = 0.0056 *Phragmites australis* (E) *P* = 0.0494 *Schoenoplectus validus* (E) *P* = 0.0004 *Typha domingensis* (E) *P* = 0.0114		CWD3 *P* = 0.0276	
Murray Rainbowfish	Open water *P* = 0.0194 *Cyperus exaltatus* (E) *P* = 0.0402 *Muehlenbeckia florulenta* (Sh) *P* = 0.0022			

2.4 Discussion

Total fish species richness (*n* = 14) in the Chowilla system and adjacent Murray River was similar to that reported in recent investigations of fish assemblages in the lower Murray River main channel and other anabranch systems (e.g. the Lindsay-Mullaroo system) (Villizzi *et al.* 2006; Baumgartner *et al.* 2008; Davies *et al.* 2008) with no species being found exclusively in the Chowilla system. The fish assemblage was dominated by native bony herring, unspecked hardyhead and Australian smelt whilst large-bodied native fish, such as golden perch and Murray cod formed a relatively small proportion of the catch (1.0% and 0.1% respectively). Nevertheless, the non-native common carp also only formed a relatively small proportion of the catch (3.5%). Despite extensive surveys, four species considered potentially present in the Chowilla system by Pierce (1990), namely trout cod, river blackfish, southern purple-spotted gudgeon and southern pygmy perch, were not collected.

Species richness was highest in fast-flowing mesohabitats and the Murray River and lowest in slow-flowing and backwater mesohabitats. Fast-flowing habitats tended to be characterised by greater habitat complexity (e.g. large woody debris, variable channel form, diverse aquatic vegetation and heterogeneous hydraulic environments) whilst slow-flowing and backwater mesohabitats were less complex. Habitat complexity is an important determinant of species richness and diversity (Pusey *et al.* 1995; Jackson *et al.* 2001). Structural complexity, in this case woody debris, interacts with stream flow to increase hydraulic diversity and create scour holes. In turn, complex habitats provide greater opportunities for foraging and refuge and consequently support increased species diversity (Flebbe and Doloff 1995).

Golden perch, bony herring, most small-bodied native species and non-native carp, goldfish and gambusia were widespread and collected in all mesohabitats in the Chowilla system. Conversely, Murray cod, silver perch and freshwater catfish were only sampled in fast-flowing mesohabitats and the Murray River. Most native and non-native species collected in the Chowilla system have broad physicochemical and habitat tolerances; hence are likely to be present in most mesohabitats (Lloyd and Walker 1986; Pusey *et al.* 2004; Lintermans 2007). Murray cod and silver perch, however, may have more specific requirements (e.g. Murray cod may be constrained by depth and silver perch may prefer lotic environments) and may be restricted to mesohabitats that provide these attributes. Freshwater catfish would be expected to occupy a broad range of mesohabitats in the Chowilla system, including backwaters and slow-flowing mesohabitats (Pusey *et al.* 2004; Lintermans 2007). Freshwater catfish, however, are not efficiently sampled by electrofishing (authors' personal observations) and we may have underestimated the relative abundance of this species in the Chowilla system. More specific surveys for freshwater catfish are recommended.

Length frequency and recruitment

Length frequency data indicate a broad size distribution of most fish species sampled, with the exception of species captured in low abundances (e.g. freshwater catfish). Based on length data most small-bodied fish species and bony herring recruited annually from 2005 – 2007. These species are annual spawners and whilst flow may influence recruitment, relatively low stable flows appear to result in consistent recruitment (Humphries *et al.* 1999; Humphries *et al.* 2002). Length and/or age frequency data indicate that there was also recruitment of golden perch, Murray cod and common carp but this was not temporally consistent.

A strong cohort of young-of-year common carp in 2006 and 1+ golden perch in 2007 corresponds with recruitment of these species following the small but prolonged within-channel increase in discharge in spring/early summer of 2005 (see section 1.4). Only low numbers of young-of-year common carp were collected in years where no flow event occurred (apart from a gradual increase in entitlement flows). Similarly, golden perch recruitment in these low-flow years appeared absent. The recruitment ecology of golden perch in the Chowilla system and lower Murray River is discussed in more detail in Chapter 6.

The mechanisms involved in the observe increase in recruitment are likely different for golden perch and common carp. Golden perch are considered a flow cued spawner (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003) thus the small within-channel increase in discharge is likely to have facilitated some spawning and recruitment. Common carp, however, spawn annually independently of flow (Humphries *et al.* 2002) and increased within-channel flow may have increased the number of suitable spawning sites and/or enhanced the survival of eggs and/or larvae (Brown *et. al.* 2005).

Length frequency data indicate some recruitment of Murray cod during the period of our investigations. Fish less than 300 mm total length were rare. Fish of this size are generally cryptic, inhabiting complex habitats such hollow logs (Jarod Lyon, Department of Sustainability and Environment, Victoria, pers. comm.) and may be difficult to effectively electrofish in turbid lowland rivers. Once fish reach ~ 400 mm, however, their catchability appears to increase (authors' personal observations). Despite generally low annual sample sizes (n < 20), there appears to be a cohort of fish that progresses from approx 400 – 500 mm in 2005 to 600 – 700 mm in 2007. A similar progression was observed in the Lindsay-Mullaroo Anabranch system during the same period (Villizzi *et al.* 2006). Importantly, fish of this size range were noticeably absent in the lower reaches of the Murray River, particularly in the ~ 500 km of main channel downstream of Lock 5 (Ye and Zampatti 2007). The spawning and recruitment of Murray cod in the Chowilla system is discussed in more detail in Chapter 5.

Fish and mesohabitats

Significant differences in fish assemblages were detected between mesohabitats. Fast-flowing mesohabitats were characterised by greater abundances of Murray cod, golden perch, Australian smelt and gambusia. Murray cod are found across a broad range of habitats from upland streams to low land rivers (McDowall 1996); nevertheless, recent research indicates that flowing water may be an important habitat attribute for Murray cod (Koehn 2009). Golden perch, Australia smelt and gambusia are generally described as occurring in slow-flowing habitats (McDowall 1996; Lintermans 2007), however, Australian smelt have also been shown to preferentially use fast-flowing meso and microhabitats (Pusey *et al.* 2004). Fast-flowing mesohabitats in the Chowilla system were hydraulically complex and contained a mosaic of fast-flowing, slow-flowing and backwater microhabitats. Furthermore these mesohabitats contained diverse instream structure such as LWD and aquatic macrophytes; consequently they have the potential to facilitate the habitats requirements of a large range of species. Habitat heterogeneity and hydraulic complexity may promote a more productive aquatic ecosystem with a greater ability to support a range of life stages and life history processes of native fish (Thorp *et al.* 2006). Importantly, such lotic habitats may represent fragmented relicts of the hydrodynamically complex unregulated Murray River.

Backwater mesohabitats were characterised by higher abundances of native carp gudgeon and non-native common carp and goldfish, and Murray River mesohabitats by unspecked hardyhead and Murray rainbowfish. Carp gudgeon, common carp and goldfish are characteristic of lentic habitats and backwaters may form important spawning and recruitment sites for all three species (Brown *et al.* 2005; Allen *et al.* 2002). Murray rainbowfish and unspecked hardyhead are generally considered wetland specialists being associated with lentic habitats and abundant aquatic vegetation (Allen *et al.* 2002). The high abundances of these species collected in Murray River sites reflects the highly regulated nature of weir pools in the lower Murray River and an extended period of low flows. Such conditions have transformed a lotic riverine environment to a lentic wetland type environment with little hydraulic complexity and abundant submerged aquatic macrophytes thus favouring generalist and wetland fish species.

Fish and microhabitats

Determining the use of physical habitats by stream fish is important for the development of conservation measures to aid in species recovery, particularly habitat restoration (Rice 2005). Habitat use by native and non-native fish in the MDB has been primarily explored for large-bodied fish in the mid-reaches and tributaries of the Murray River (e.g. Crook 2004a and b; Koehn 2009) but data on fish habitat associations in the highly regulated lower reaches of the Murray River are scarce (although see Wedderburn *et al.* 2008).

In the Chowilla system and adjacent Murray River small-bodied native fish and non-native fish such as common carp and goldfish were often significantly associated with vegetated edge habitats where the vegetation was comprised of emergent, floating and submerged macrophytes. These vegetation complexes were wide spread across mesohabitats and provide structurally complex regions important for reproduction; food resources and refuge from predators (Pusey *et al.* 1993; Weaver *et al.* 1997).

CWD and associated river red gum root masses were identified as a significant instream habitat for Murray cod and silver perch. Large wood has also been identified as an important structural habitat for trout cod *Maccullochella macquariensis* and Murray cod in the mid reaches of the Murray River (Nicol *et al.* 2007; Koehn 2009). Large wood provides important structural habitat and creates a diversity of physical habitats in rivers (Crook and Robertson 1999). Large wood creates scour pools that exhibit greater variance in depth than free form pools (Andrus *et al.* 1988). Importantly, when compared to the largely desnagged and hydraulically homogenous Murray River, the combination of large wood and flow within fast-flowing mesohabitats of the Chowilla system provides habitat at a range of depths catering for various sizes of Murray cod, including very large individuals (i.e. fish > 1 m TL) and juveniles (< 600 mm TL).

Golden perch were significantly associated with emergent macrophyte (i.e. *Phragmites australis* and *Typha domingensis*) and open water microhabitats. Where fish were collected in open water they had usually been attracted out from a macrophyte stand by the electrofishing field. These results contrast to investigations in the mid reaches of the Murray River (main channel and tributaries) and the Darling River where golden perch have been strongly correlated with large wood habitats (Koehn and Nicol 1998; Crook *et al.* 2001; Boys and Thoms 2006). Emergent macrophyte stands are common in the highly regulated lower Murray River (e.g. Blanch *et al.* 2000) and may provide a significant proportion of instream structural complexity. In turn, providing shelter for golden perch and habitat for aquatic macrocrustaceans such as shrimps, prawns and crayfish that form an important food source for golden perch (Baumgartner 2007).

Temporal variation in fish assemblages

Species assemblages in each mesohabitat remained relatively consistent between 2005 and 2007 with any difference being driven by the presence or absence of low numbers (n = 1 – 3) of rarer species such as silver perch or freshwater catfish. Abundance of individual species, however, did vary between years. Most notably, in 2006, non-native common carp were sampled in significantly higher abundances in backwater and slow-flowing habitats and goldfish were sampled in significantly higher abundances in slow-flowing and Murray River mesohabitats.

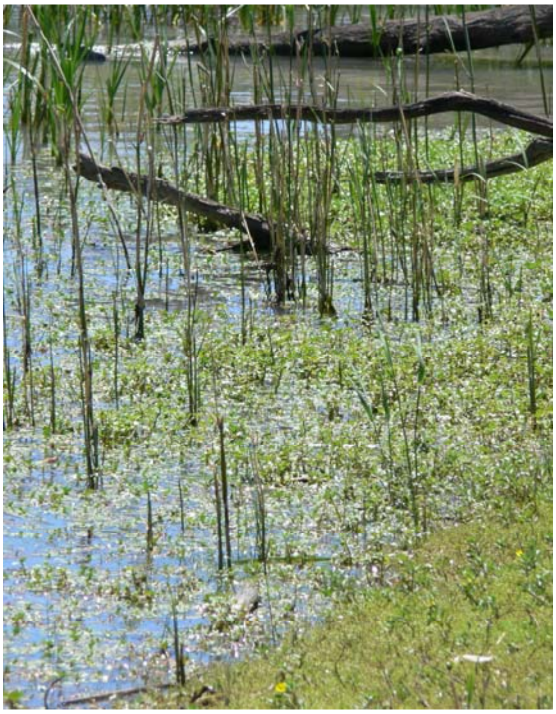
This increase in abundance of common carp and goldfish is likely to be a result of strong recruitment of young-of-year fish following the within-channel flow event in spring/summer 2005. During this event water levels rose approximately 0.5 m and negligible floodplain habitat was inundated; nevertheless carp abundances increased significantly. Floodplain inundation has been proposed as a key mechanism for carp recruitment in the MDB (Brown *et al.* 2005; Balcombe *et al.* 2006). Our results, however, suggest that within-channel rises in flow may also promote significant recruitment, particularly in the permanently inundated lentic habitats of the lower Murray River.

Conclusions

The Chowilla system provides a complex of physical and hydraulic habitats that support a range of life history phases of native and non-native fish species. The hydraulic heterogeneity and separation of spawning (fast-flowing reaches) and potential rearing habitats (slow-flowing reaches) particularly for large-bodied native fish species are facets of the Chowilla system that are now absent from the homogeneous weir pool habitats of the lower Murray River. The conservation of the diverse range of aquatic mesohabitats in the Chowilla system, along with restoration of a more variable flow regime, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

Our investigations were undertaken during a period of generally low, stable, within-channel flows in the Murray River with one minor within-channel rise in water level and discharge in the spring/summer of 2005. Patterns in fish distribution, relative abundance and recruitment, however, may be significantly different during times of flooding and overbank flows when floodplain habitats (e.g. Lake Littra) are inundated. To develop a more complete understanding of fish ecology in the lower Murray River and Chowilla region additional investigations of fish ecology should be undertaken during a period of overbank flows.

3 Aquatic Macrophyte Assemblages



The native aquatic species *Bolboschoenus caldwellii* and *Ludwigia peploides* ssp. *montevidensis* growing on the edge of a permanently flooded creek.

3.1 Introduction

Water regime is the primary determinant of plant community composition in freshwater systems (e.g. Rea and Ganf 1994; Blanch *et al.* 1999; Nicol *et al.* 2003) and in riverine ecosystems the water regime experienced by plants is determined by flow and elevation. Water regime determines flooding depth, duration and frequency, which acts as an environmental sieve (*sensu* van der Valk 1981) and allows the establishment of some species whilst preventing the establishment of others. Furthermore, floods play a major role in structuring vegetation communities (both floodplain and aquatic) in river systems (e.g. Junk *et al.* 1989; Blanch *et al.* 1999; Blanch *et al.* 2000; Petit and Froend 2001; Petit *et al.* 2001; Capon 2003; Lytle and Poff 2004). Floods remove standing vegetation and allow recruitment from the propagule bank (e.g. Scott *et al.* 1997; Petit and Froend 2001; Nicol and Bald 2006), provide fresh water for seed germination (e.g. Capon 2003; Nicol 2004) and supply water to the extant vegetation (e.g. Jolly *et al.* 1993; Jolly *et al.* 1994). Changes to the flow regime of the lower Murray River brought about by river regulation has resulted in a reduction of frequency, duration and magnitude of overbank flows and the impact on *E. camaldulensis* condition has become visible in recent years throughout the lower Murray River floodplain (MDBC 2003; Overton and Jolly 2004; Smith and Kenny 2005). Nevertheless, the impact on the understorey vegetation has not been widely investigated and is a knowledge gap that needs to be addressed to better understand the system.

The first aim of the vegetation component arose because of the aforementioned knowledge gap and was developed to gain baseline vegetation data and better understand the short-term changes in floristic composition of the vegetation in permanently inundated areas and areas that flood during small to medium-sized (< 60,000 ML/d) floods. In spring 2005, a small in channel flow pulse coupled with a weir pool raising, caused water levels to rise approximately 70 cm throughout the Chowilla system (DWLBC 2006). Five of the sites where baseline vegetation data was collected in 2004 were selected and surveys were undertaken at those sites in February 2006 after water levels had fallen to pool level. The second aim arose because there was baseline vegetation data, which could be used to assess the change in floristic composition due to the small in channel water level rise in spring 2005.

3.2 Methods

3.2.1 Site Selection

Wetlands were selected to reflect the different habitats and hydraulic regimes present in the Chowilla system where management intervention is possible (Table 3-1). The areas where management intervention is possible are:

- Permanent wetlands (lentic and lotic wetlands that are flooded at pool level).
- Temporary wetlands that flood when river flows are less than 60,000 ML/d.

Areas that flood when river flows are greater than 60,000 ML/d were not included in the surveys because they cannot be managed by hydrological manipulation under regulated conditions.

Table 3-1 Wetlands selected for vegetation survey sites (* denotes wetland was artificially flooded as part of the river red gum watering project).

Lotic Creeks/Wetlands	Lentic Creeks/Wetlands	Temporary Wetlands
Chowilla Creek	Monoman Creek	Woolshed Creek*
Pipeclay Creek	Slaney Backwater	Hancock Creek
Slaney Creek	Isle of Mann Backwater	Punkah Island Horseshoes*
Salt Creek		Lake Limbra
Hypurna Creek		
Boat Creek		
Punkah Creek		
Murray River		

One or more sites were selected in each permanent wetland to correspond with larvae sampling sites and electrofishing sites (Figure 3-1). Sites were selected in the temporary wetlands at regular intervals (1 km except in Lake Limbra) (Figure 3-1). A list of all sites and GPS coordinates of all sites where vegetation surveys were undertaken is given in (Appendix 1).

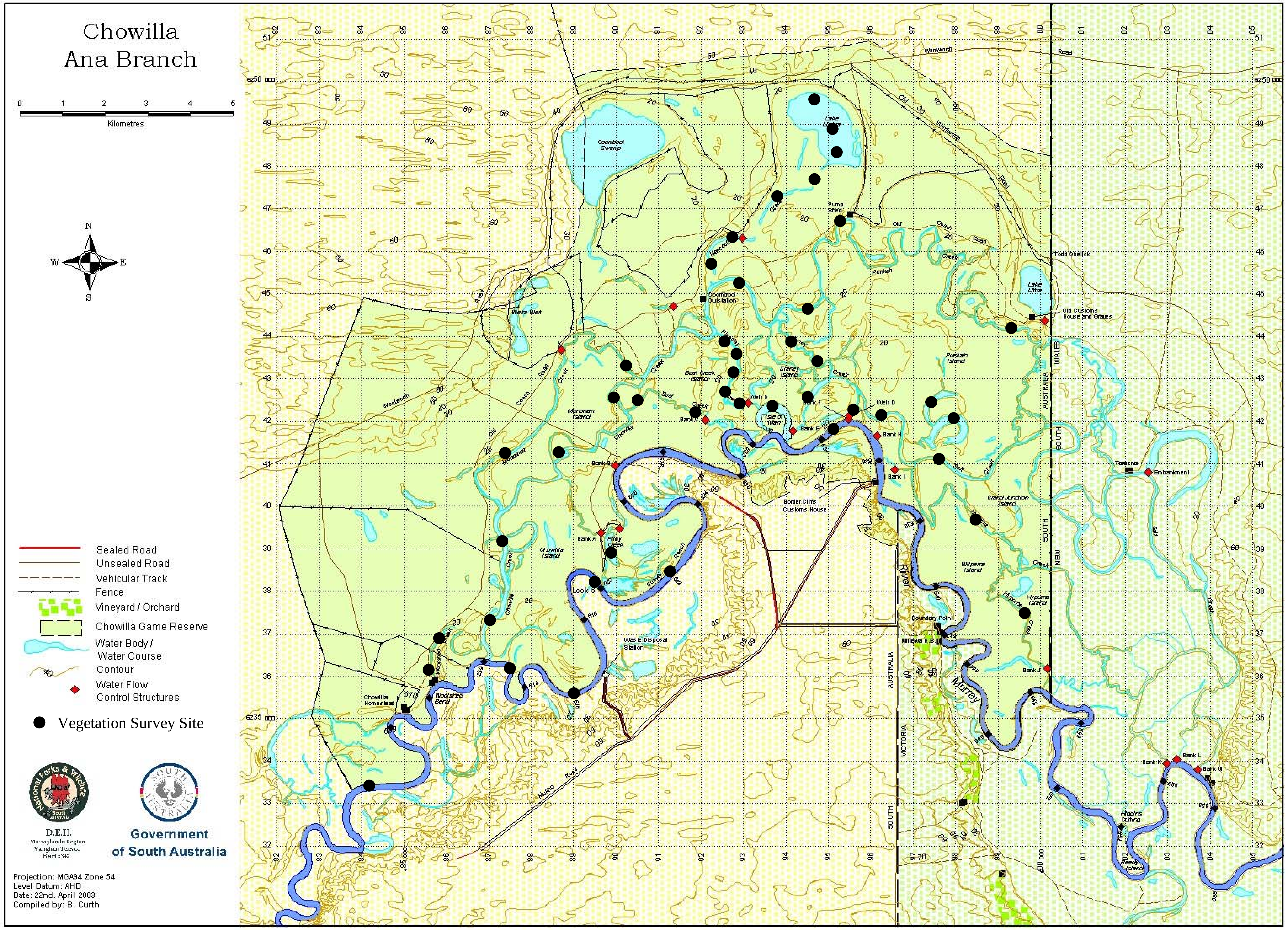


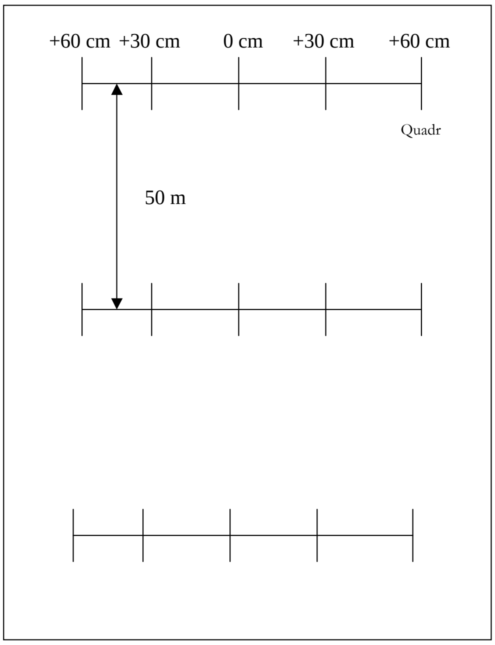
Figure 3-1 Location of survey sites for the quantitative vegetation surveys.

3.2.2 Survey Protocol

3.2.2.1 Temporary Wetlands

Replicate transects (*n* = 3) 50 m apart (Figure 3-2a) were established at 1 km intervals along Hancock and Woolshed Creeks and Punkah Island Horseshoes (Figure 3-1) perpendicular to the bank. Five quadrats (15 x 1 m) were established perpendicular to the transect (Figure 3-2a), one quadrat was located at the lowest point of the transect and quadrats at 30 and 60 cm higher than the lowest point were established on each bank (Figure 3-2b).

a.



b.

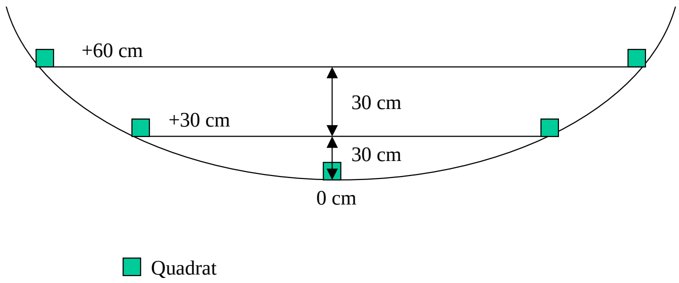


Figure 3-2 Vegetation surveying protocol for Hancock and Woolshed Creeks and Punkah Island Horseshoes a. plan view and b. cross section.

The survey protocol for Lake Limbra was different to the temporary creeks due to its wide, flat morphology and floristic composition. Three quadrats at three locations 500 m apart were established along the north-south axis of the lake (Figure 3-3).

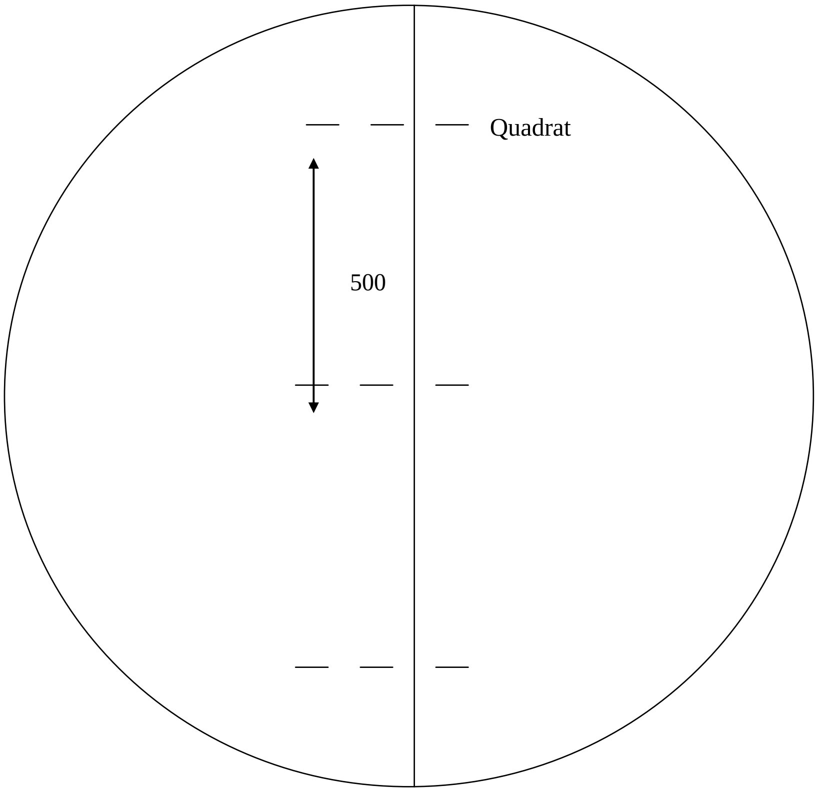


Figure 3-3 Vegetation surveying protocol for Lake Limbra.

3.2.2.2 Permanent Wetlands

Three replicate transects were established at each site perpendicular to the bank (Figure 3-4a). Quadrats were established at 0 cm (the water level at pool), +30 and +60 cm and 30 cm below the water on each bank (Figure 3-4b).

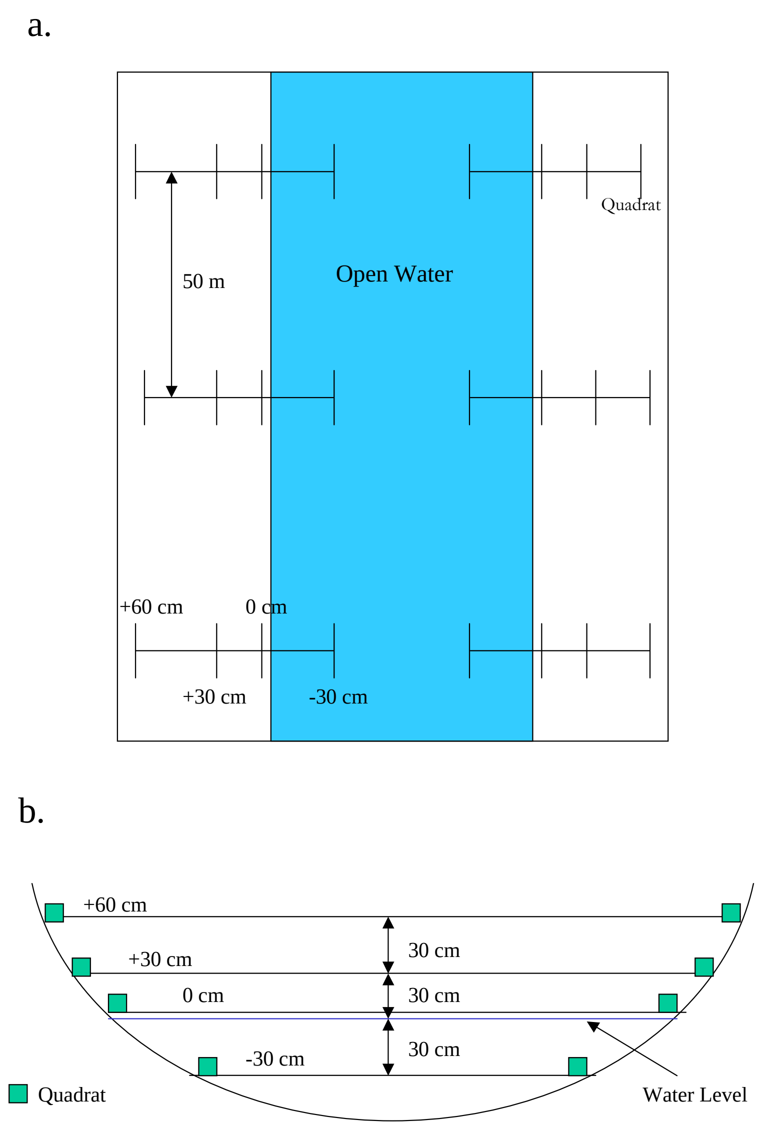


Figure 3-4 Vegetation surveying protocol for permanently inundated wetlands a. plan view and b. cross section.

In many creeks, the banks were too steep to fit the 0, +30 and +60 cm elevations (the quadrats overlapped). In these instances one or two quadrats were used and labelled 0 to +60 cm or +30 to +60 cm, depending on which quadrats overlapped. Elevations were determined using a dumpy level and the location of all sites was recorded by GPS (Appendix 1).

In all sites except Lake Limbra, each bank (or side) was labelled A or B. The left hand bank, looking upstream or moving to a higher elevation, was always labelled A to ensure that the same quadrat was given the same label.

Quadrat size was determined by species area curves (Figure 3-5). Species abundances in each quadrat were determined by dividing the quadrat into 15, 1 x 1 m cells and the presence or absence of each species recorded for each cell. This gave a frequency score for each species in each quadrat of between 0 and 15. In addition to vegetation, bare soil (a cell that had no live plants present was given a score of one for bare soil in that cell) was recorded for all sites.

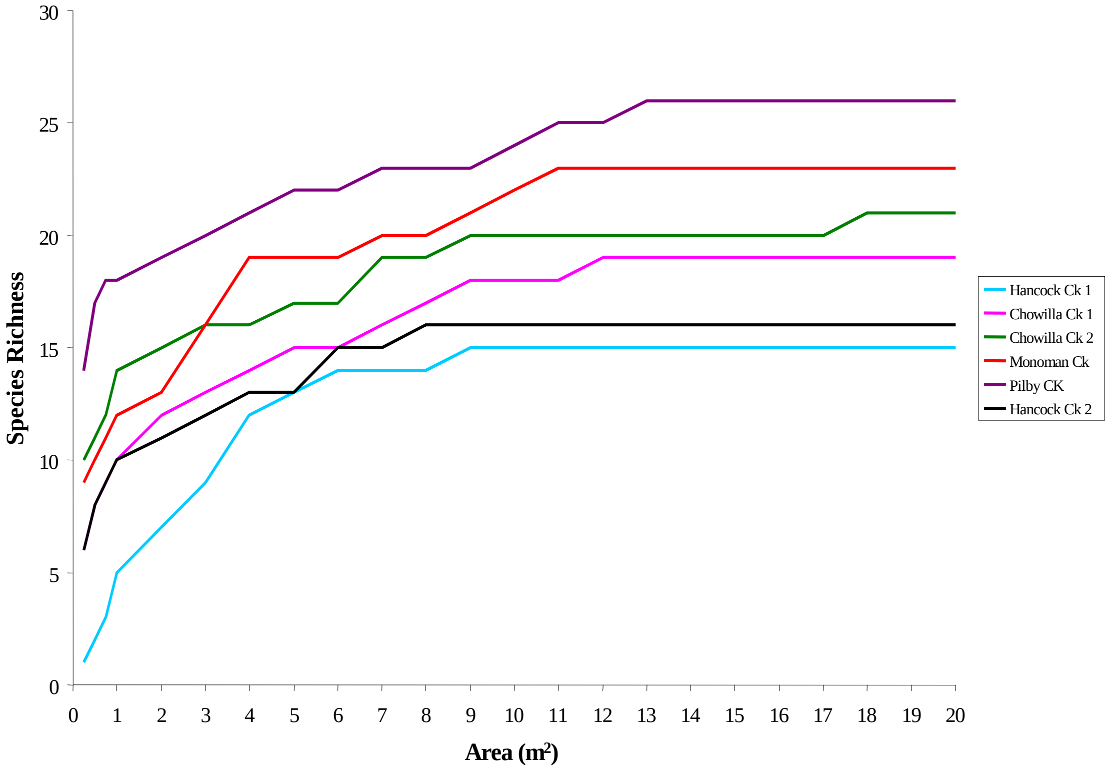


Figure 3-5 Species-area curves for selected locations in Hancock Creek and the riparian zones of Chowilla, Monoman and Pilby Creeks.

3.2.3 Data Analysis

3.2.3.1 Temporal changes from spring 2004 to winter 2005

Surveys were undertaken on three occasions, November 2004, January 2005 and May/June 2005. Change through time was compared with NMS ordination (Bray-Curtis (1957) similarities) and Indicator Species Analysis (Dufrene and Legendre 1997) using the package PCOrd v5.12 (McCune and Mefford 2006).

3.2.3.2 Response to the in channel high water event in spring 2005

A sub-set of five sites (Murray River downstream of Chowilla Creek, Slaney Backwater, Punkah Larvae, Monoman Creek adjacent to the upstream junction with Chowilla Creek and Salt Creek upstream of Swiftys) where surveyed in February 2006 following the high water event in spring 2005. Sites were selected in areas where a shallow sloping bank was opposite a steep bank. Data from the quadrats on the shallow sloping banks at and above pool level will only be presented because the plant communities on the steep banks and permanently inundated quadrats did not change significantly.

Comparisons between the survey dates at 0, +30 and +60 cm were made using NMS ordination (Bray-Curtis (1957) similarities, Indicator Species Analysis (Dufrene and Legendre 1997) and PERMANOVA (Anderson 2001) using the Package PCOrd v5.12 (McCune and Mefford 2006). Data were pooled for the ordinations for clarity but PERMANOVA and Indicator Species Analysis were performed on unpooled data.

3.2.3.3 Indicator Species Analysis

Dufrene and Legendre's (1997) Indicator Species Analysis combines information on the concentration of species abundance in a particular group (survey date) and the faithfulness of occurrence of a species in a particular group (McCune *et al.* 2002). A perfect indicator of a particular group should be faithful to that group (always present) and exclusive to that group (never occurring in other groups) (McCune *et al.* 2002). This test produces indicator values for each species in each group based on the standards of the perfect indicator. Statistical significance of each indicator value is tested by using a Monte Carlo (randomisation) technique, where the real data is compared against 5000 runs of randomised data (Dufrene and Legendre 1997). For this study, the groups were assigned according to survey date; therefore, this procedure was used for hypothesis testing (planned comparisons) and gives an indication of whether a species has increased or decreased significantly in abundance. A species that is deemed not to be a significant indicator of a particular group is either uncommon or widespread. An uncommon species is only found in one group but in low numbers and a widespread species is found in more than one group in similar numbers (Dufrene and Legendre 1997). Whether a species was classed as a widespread or uncommon non-significant species was determined by examination of the raw data.

3.3 Results

A total of 91 taxa were recorded across all sites and surveys, including 24 non-natives (Appendix 2). The most commonly encountered taxon in the exposed quadrats was bare soil and *Azolla filiculoides* was the most common species in the inundated quadrats.

3.3.1 Temporal patterns from spring 2004 to winter 2005

Results from examples of a fast-flowing habitat (Boat Creek), a slow-flowing habitat (Chowilla Creek), a lentic habitat (Monoman Creek), a backwater (Isle of Mann Backwater), a temporary creek (Hancock Creek), a temporary lake (Lake Limbra) and the Murray River will be presented. The patterns of change over the study period were consistent for each of the mesohabitats.

3.3.1.1 Boat Creek

The high elevation quadrats at both sites in Boat Creek showed no patterns of change between the three surveys. The quadrats near the bridge that were dominated by *Sporobolus mitchelli* and *Phyla canescens* in November 2004 were dominated by the aforementioned species for all of the surveys (Figure 3-6). Similarly the quadrats dominated by bare soil at the larvae and Bridge sites showed little changes between surveys (Figure 3-6).

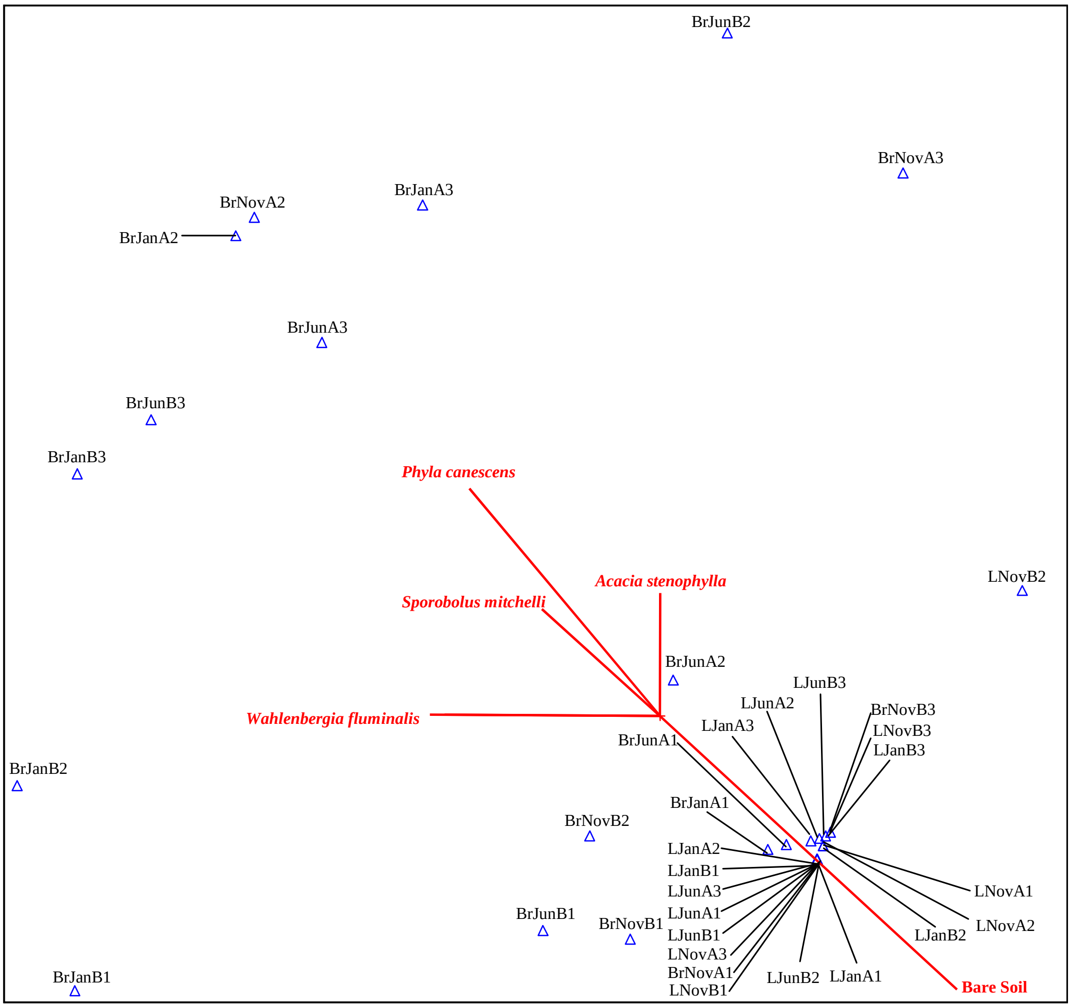


Figure 3-6 NMS ordination of the +30 to +60 cm quadrats in Boat Creek (Br = Bridge Site, L = Larvae Site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.146).

The 0 cm quadrats at the larvae site showed very little change from November 2004 to June 2005, with bare soil the dominant taxon (Figure 3-7). The quadrats dominated by *Typha domingensis* at the bridge site in November 2004 were dominated by this species for the other surveys (Figure 3-7). Several quadrats showed an increased abundance of *Centipeda minima*, *Senecio* sp., *Wahlenbergia fluminalis*, *Xanthium occidentale* and *Sporobolus mitchelli* in the June 2005, when compared with the earlier surveys (Figure 3-7).

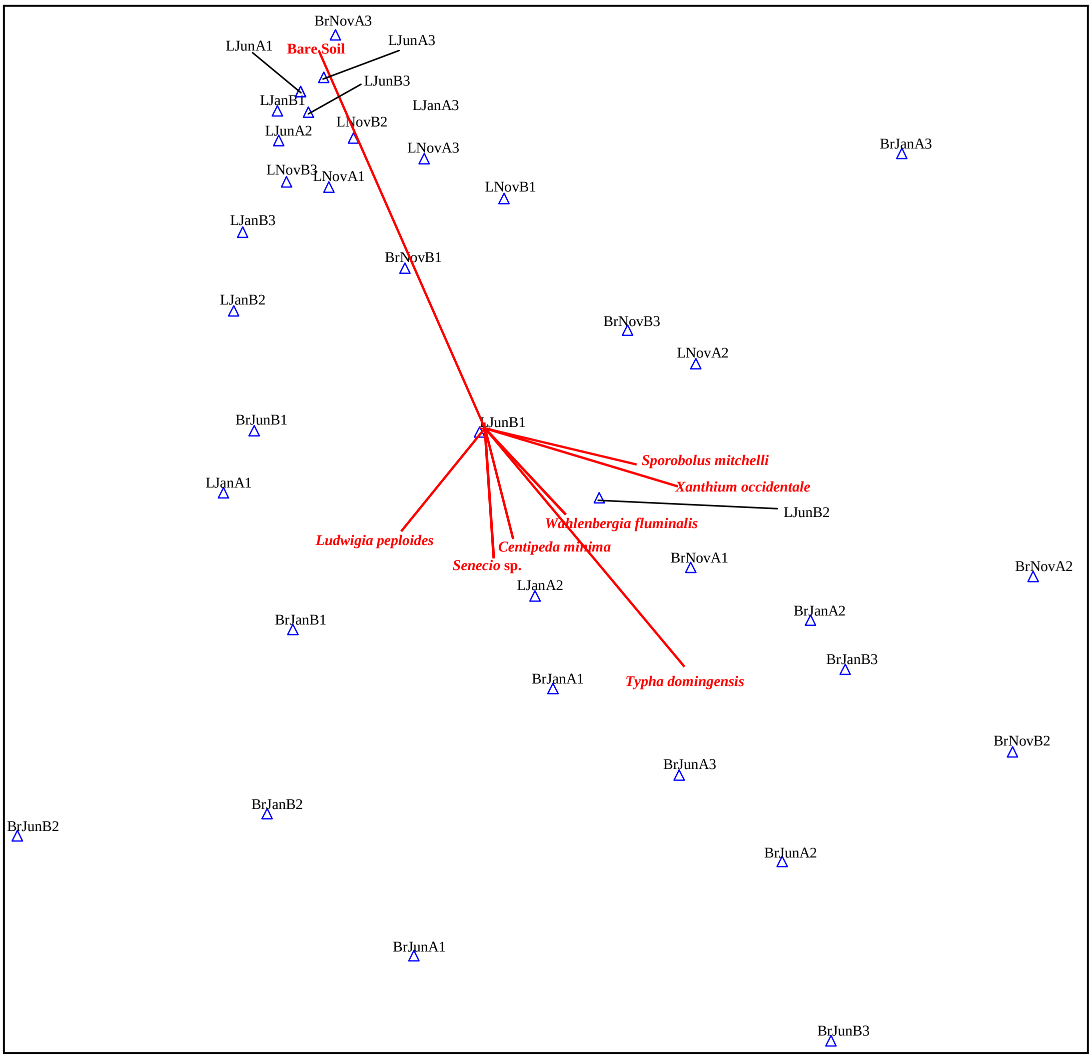


Figure 3-7 NMS ordination of the 0 cm quadrats in Boat Creek (Br = Bridge Site, L = Larvae Site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.167).

The -30 cm quadrats at the larvae site and the bridge site had very different floristic compositions (Figure 3-8). The quadrats at the larvae site were dominated by *Valisneria americana* when surveyed on each occasion; however, the abundance of *Azolla filiculoides* was higher for the January and June 2005 surveys (Figure 3-8). The majority of the quadrats at the bridge were dominated by *Typha domingensis* for each survey; however, *Juncus usitatus* and *Ludwigia peploides* were also common (Figure 3-8). *Azolla filiculoides* increased in abundance when these quadrats were surveyed in January and June 2005 (Figure 3-8). The quadrats that were dominated by bare soil in November 2004 and January 2005 were dominated by *Azolla filiculoides* in the June 2005 survey (Figure 3-8).

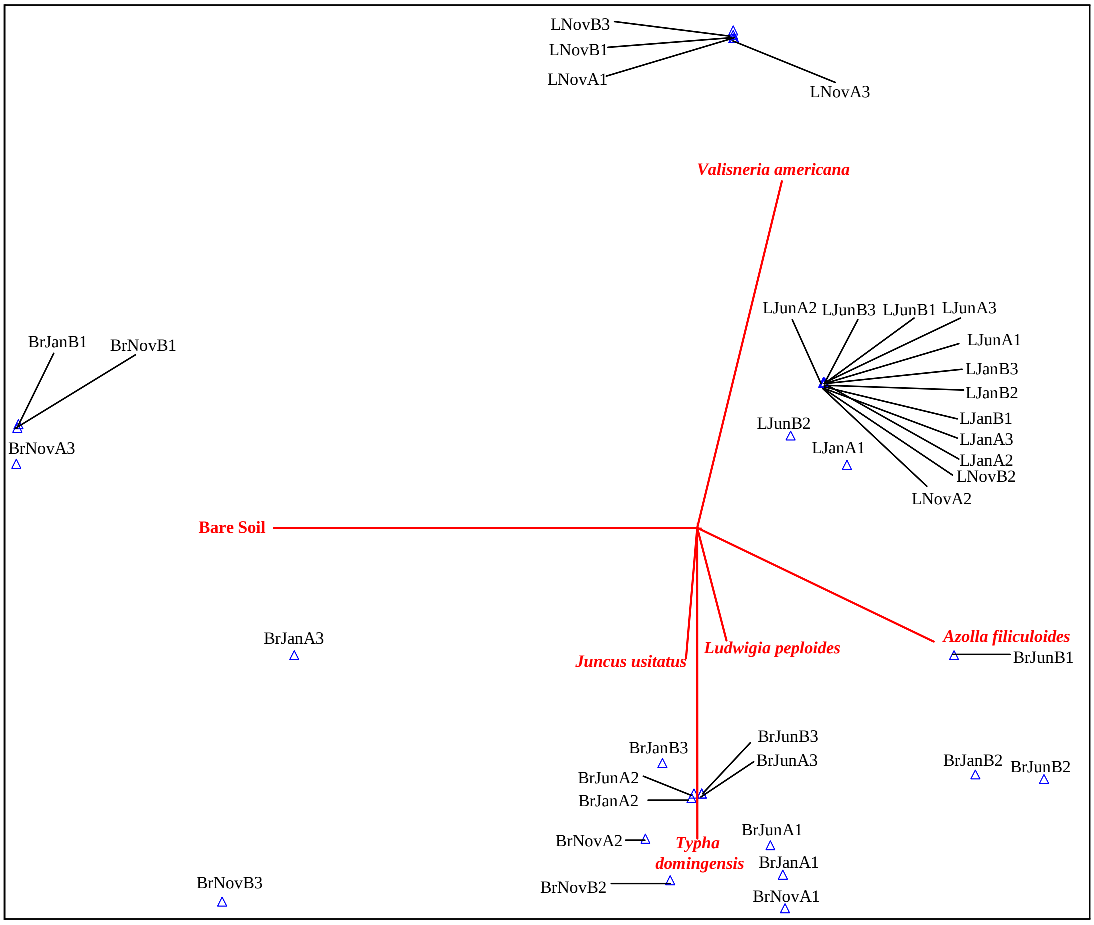


Figure 3-8 NMS ordination of the -30 cm quadrats in Boat Creek (Br = Bridge Site, L = Larvae Site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.171).

3.3.1.1 Chowilla Creek

There were no clear patterns of change for the high elevations quadrats in Chowilla Creek (Figure 3-9). The majority of the quadrats that were dominated by bare soil, *Cyperus gymnocaulos* and *Phragmites australis* and did not change between surveys (Figure 3-9).

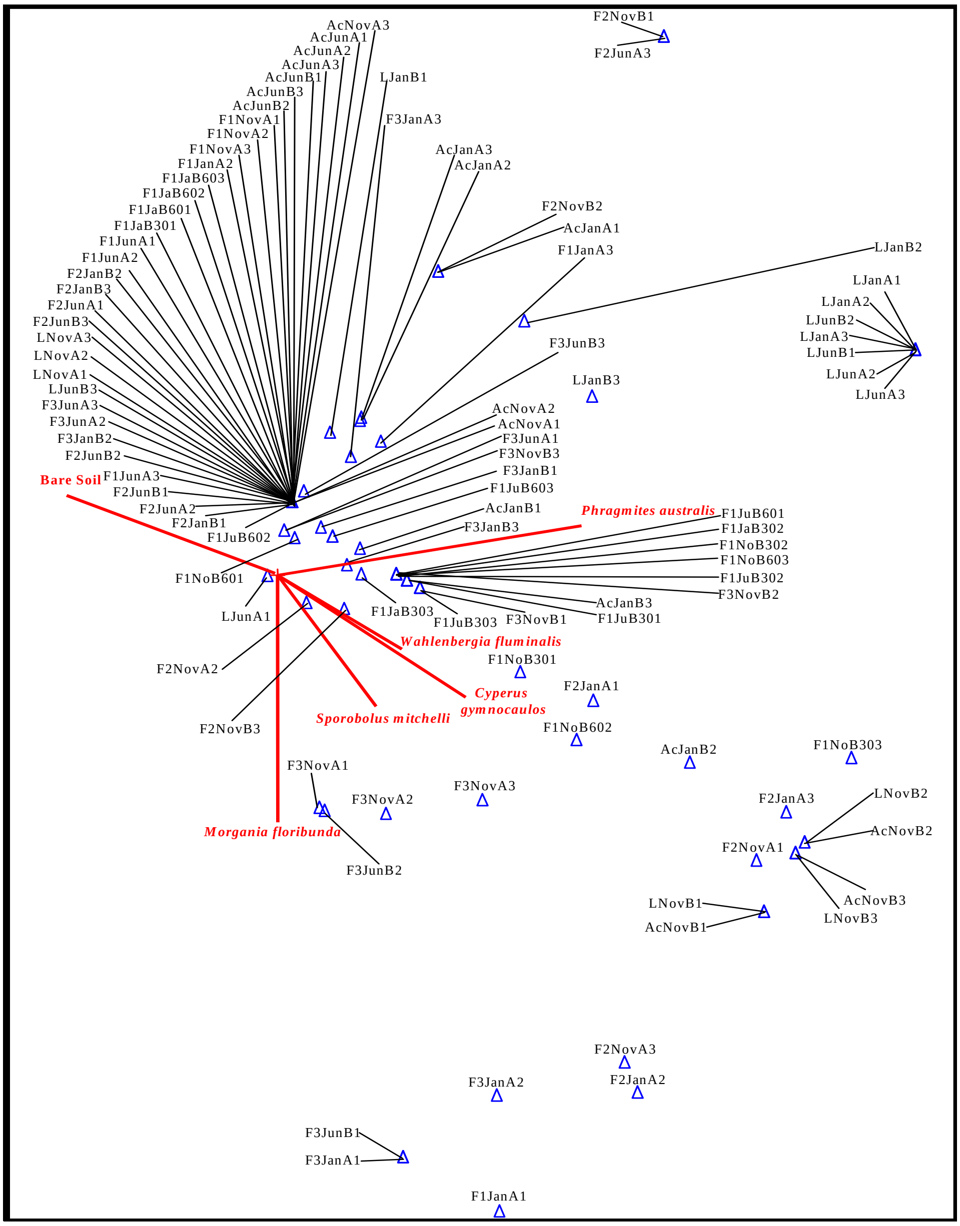


Figure 3-9 NMS ordination of the +30 and +60 cm quadrats in Chowilla Creek (Ac = Fish Accumulation Site, L = Larvae Site, F = Fish Assemblage Site, 30 or 60 = elevation, if 30 or 60 is present the banks were steep and the +30 and +60 cm quadrats were pooled, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.176).

Similar to the high elevation quadrats, the quadrats at 0 cm dominated by *Phragmites australis* and bare soil did not change significantly between surveys and there were no clear patterns of change for the other quadrats (Figure 3-10). The -30 cm quadrats in Chowilla also showed no clear patterns of change except that *Azolla filiculoides* was present in greater in abundance in the January and June 2005 surveys.

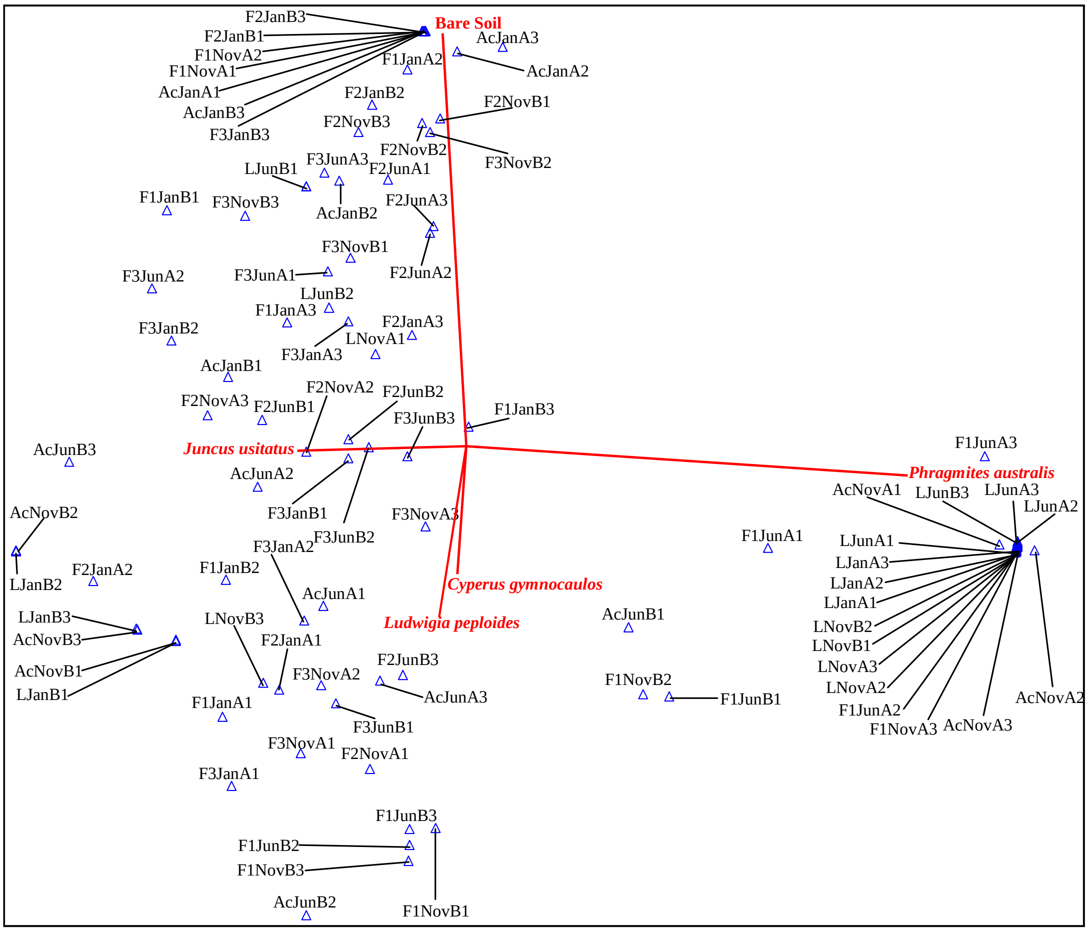


Figure 3-10 NMS ordination of the 0 cm quadrats in Chowilla Creek (Ac = Fish Accumulation Site, L = Larvae Site, F = Fish Assemblage Site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.104).

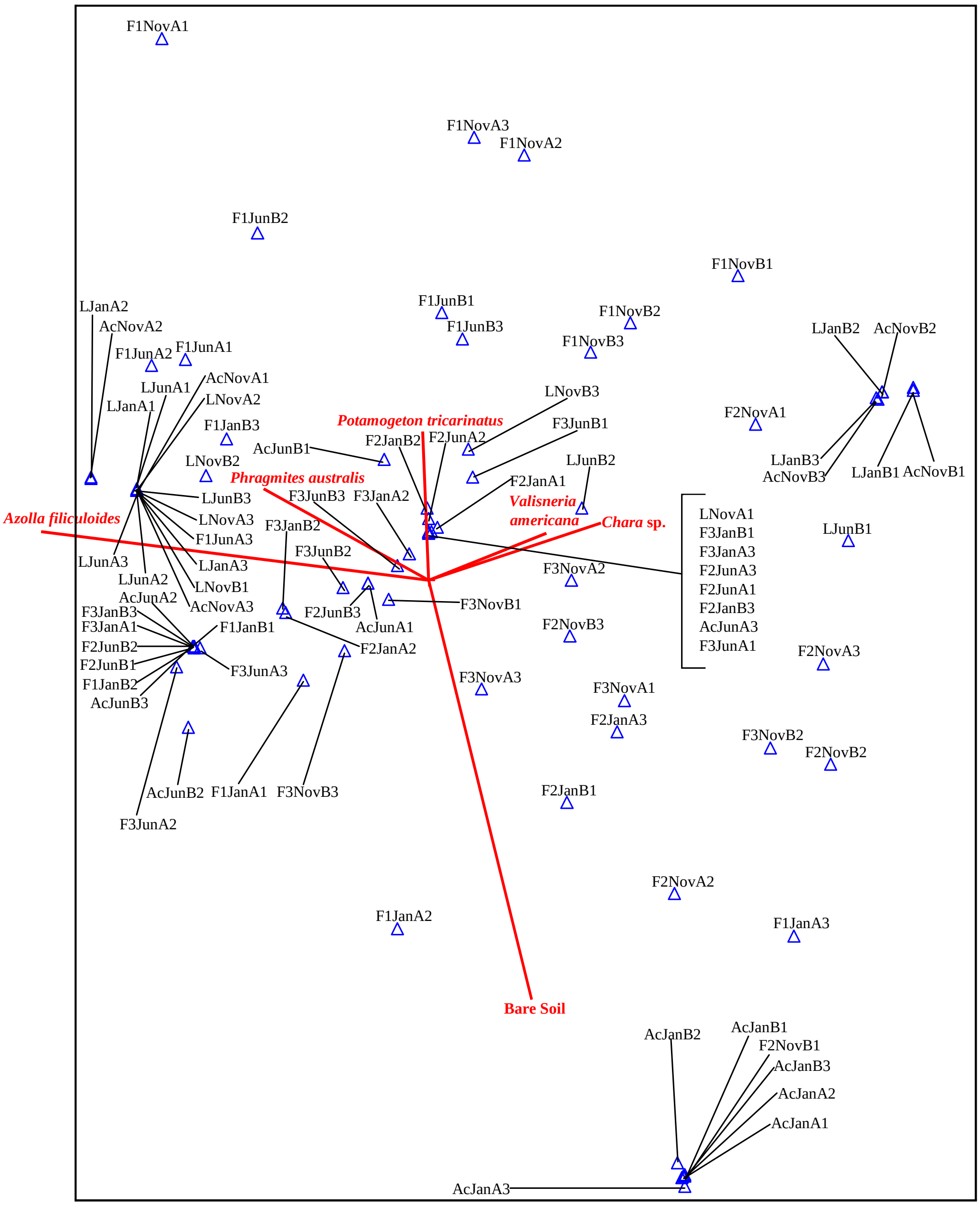


Figure 3-11 NMS ordination of the -30 cm quadrats in Chowilla Creek (Ac = Fish Accumulation Site, L = Larvae Site, F = Fish Assemblage Site A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.161).

3.3.1.2 Monoman Creek

Little change was observed from November 2004 to June 2005 in the +30 to +60 cm quadrats at both sites in Monoman Creek (Figure 3-12). The quadrats that were dominated by bare soil remained dominated by bare soil throughout the study period, similarly those dominated by *Cyperus gymnocaulos* and *Morgania floribunda* also remained similar (Figure 3-12).

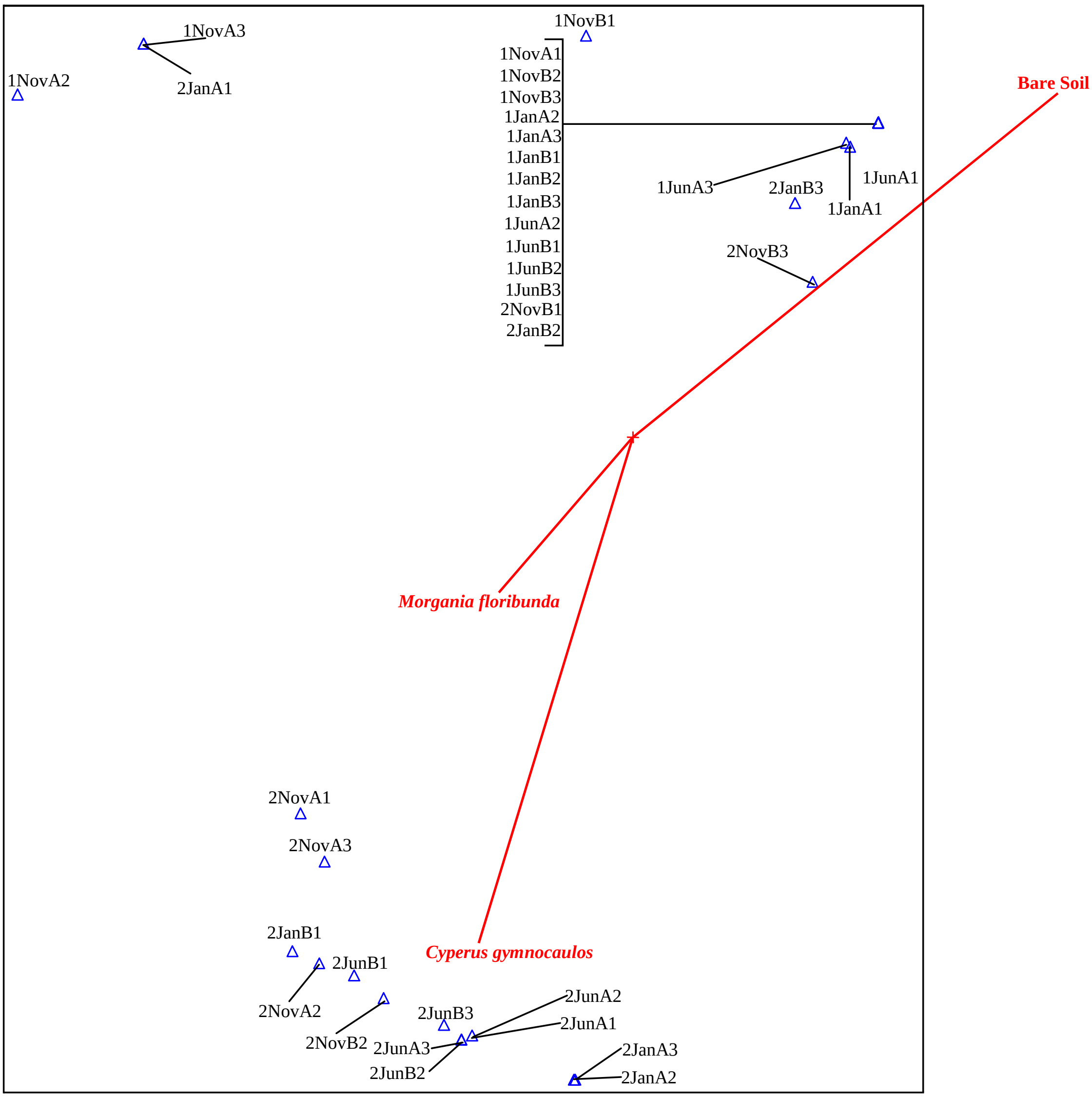


Figure 3-12 NMS ordination of the +30 to +60 cm quadrats in Monoman Creek (1 or 2 = site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.096).

The 0 cm quadrats in Monoman Creek were dominated by three taxa, *Cyperus gymnocaulos, Ludwigia peploides* and bare soil (Figure 3-13). The quadrats dominated by the aforementioned taxa showed little change over the study period (Figure 3-13).

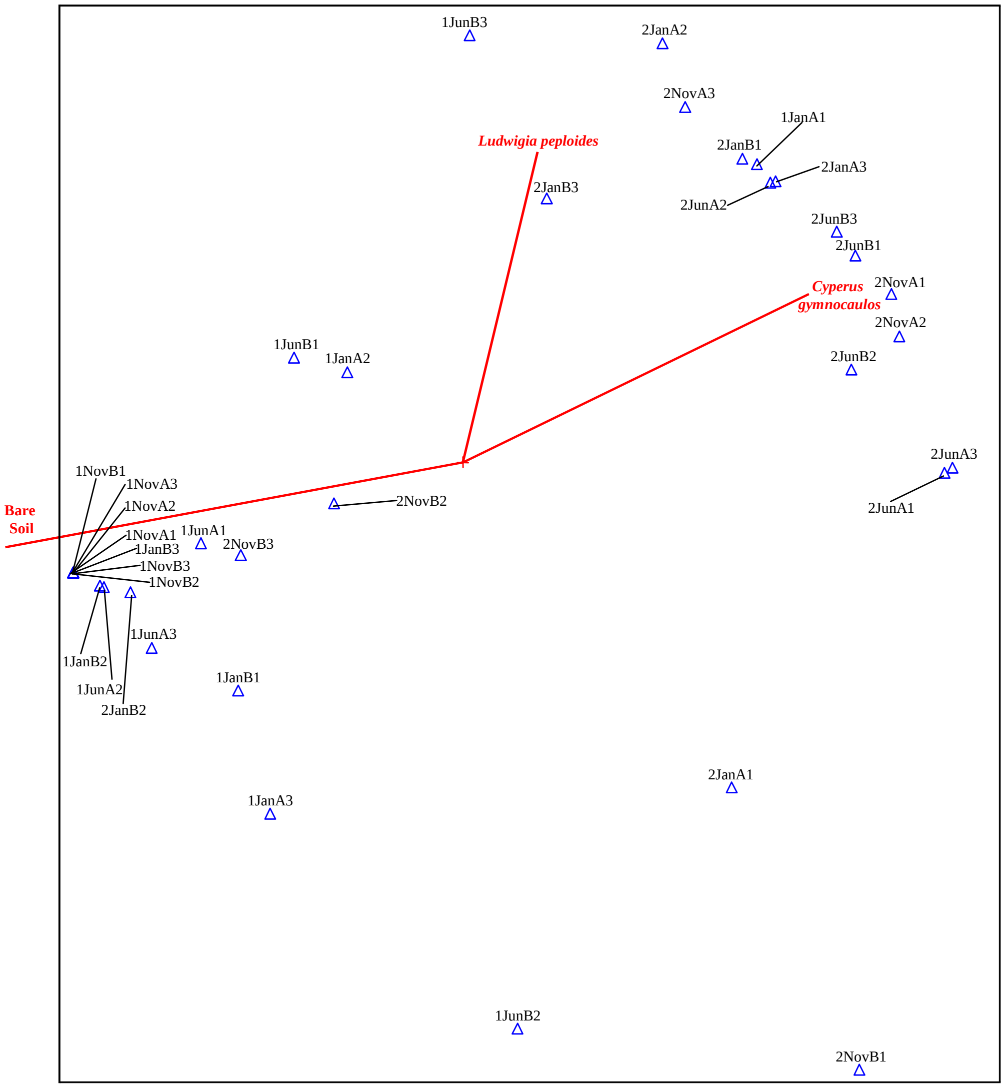


Figure 3-13 NMS ordination of the 0 cm quadrats in Monoman Creek (1 or 2 = site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.161).

Azolla filiculoides, Ludwigia peploides, Vallisneria americana and *Potamogeton tricarinatus* increased in abundance and bare soil decreased in abundance from November 2004 to June 2005 in the inundated (-30 cm) quadrats for both sites in Monoman Creek (Figure 3-14).

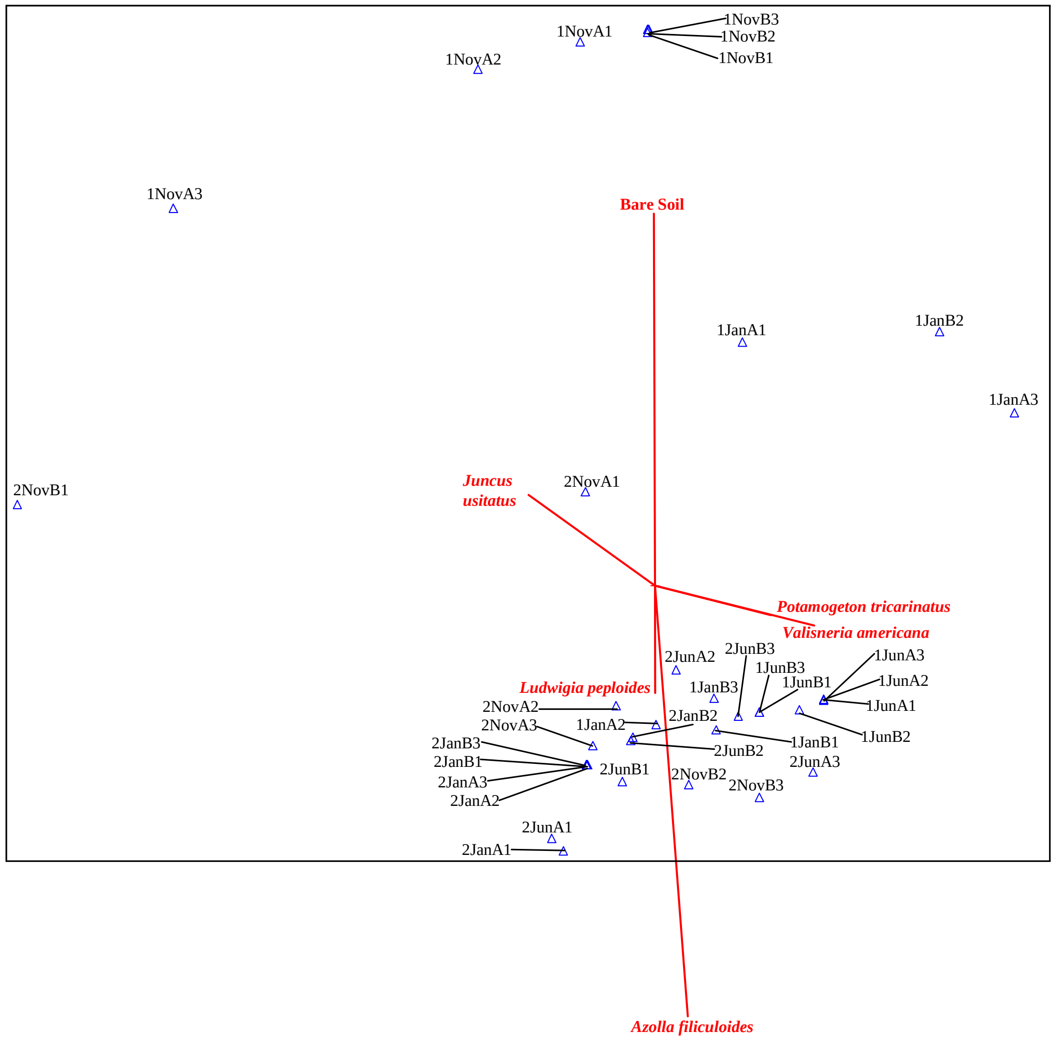


Figure 3-14 NMS ordination of the -30 cm quadrats in Monoman Creek (1 or 2 = site, A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.104).

3.3.1.3 Isle of Mann Backwater

All of the high elevation quadrats on the right hand bank and the majority of the quadrats on the left hand bank in the Isle of Mann Backwater were dominated by *Phragmites australis* and did not change significantly over the study period (Figure 3-15). The quadrats on the left hand bank when surveyed in June 2005 were different from each other because *Phragmites australis* was not present in quadrat two (*Senecio* sp. and *Enchylaena tomentosa* were the dominant taxa in quadrat two). *Phragmites australis*; however, was present in low numbers in quadrat one and dominated quadrat three (Figure 3-15).

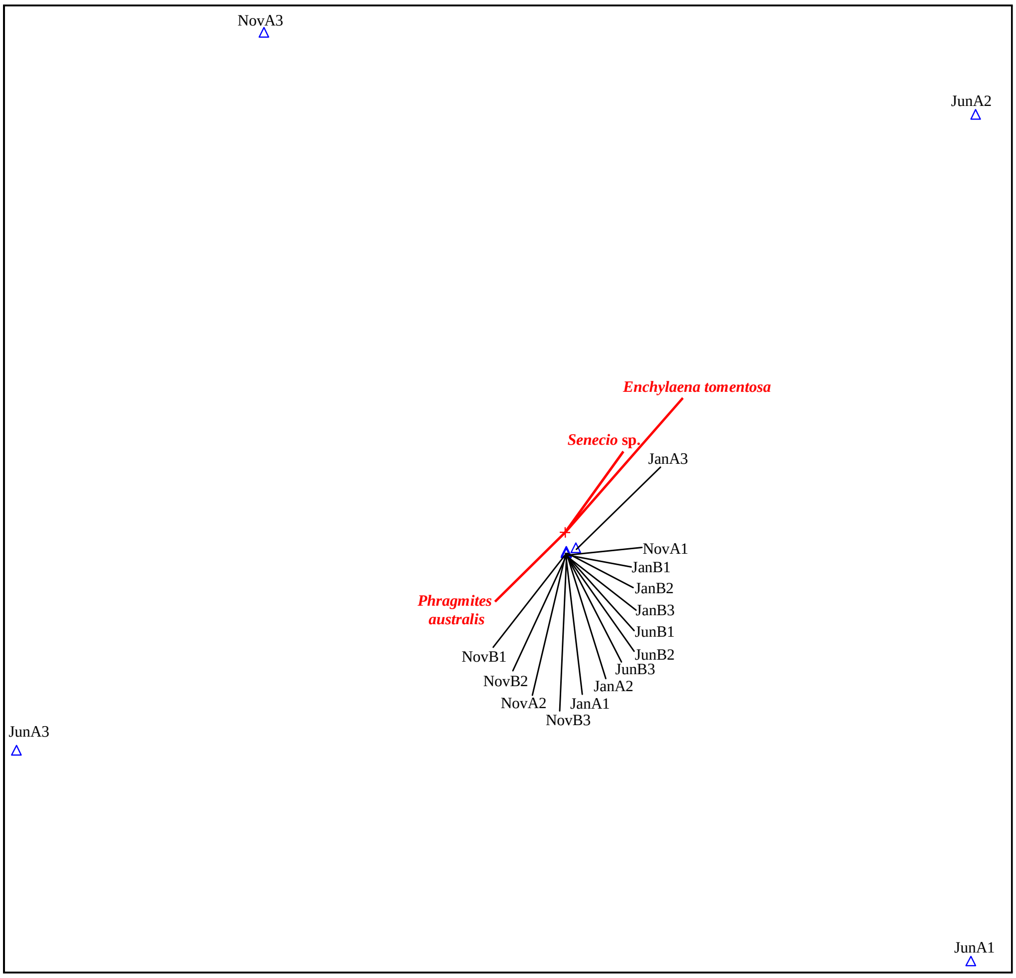


Figure 3-15 NMS ordination of the +30 to +60 cm quadrats in Isle of Mann Backwater (A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.035).

The 0 cm quadrats in the Isle of Mann Backwater on the right hand bank were dominated by *Phragmites australis* in November 2004 and June 2005, but were dominated by *Typha domingensis* in January 2005 (Figure 3-16). The quadrats on the left hand bank were dominated by *Phragmites australis* in January 2005; however, this species was in lower abundances in November 2004 and June 2005 when *Persicaria lapathifolium, Aster subulatus* and *Ludwigia peploides* were present (Figure 3-16).

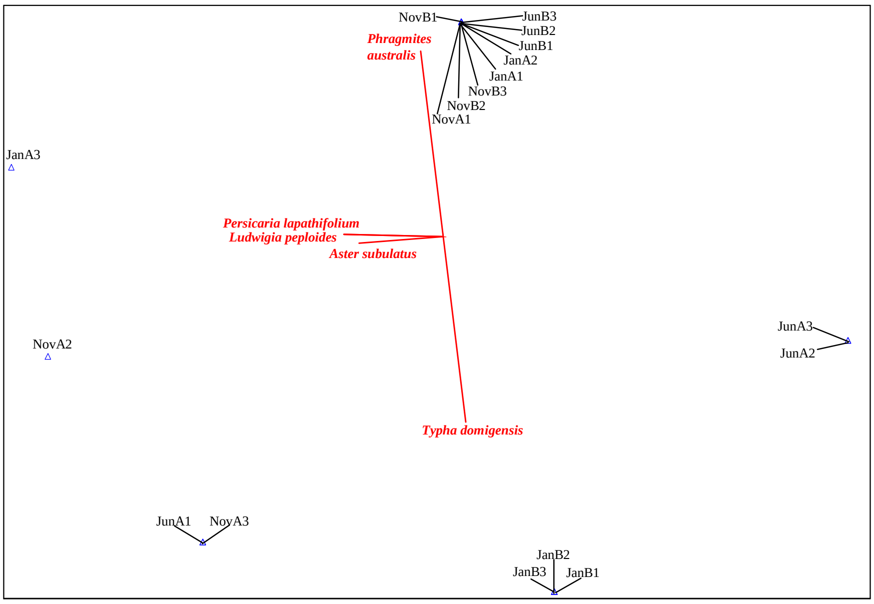


Figure 3-16: NMS ordination of the +0 cm quadrats in Isle of Mann Backwater (A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.050).

The -30 cm quadrats on the left and right hand banks in the Isle of Mann Backwater showed very different floristic compositions, which did not change (with the exception of an increase in abundance of *Azolla filiculoides* in January and June 2005) over the study period (Figure 3-17). The quadrats on the right hand bank were dominated by *Typha domingensis* and the quadrats on the left hand bank by *Phragmites australis* (Figure 3-17).

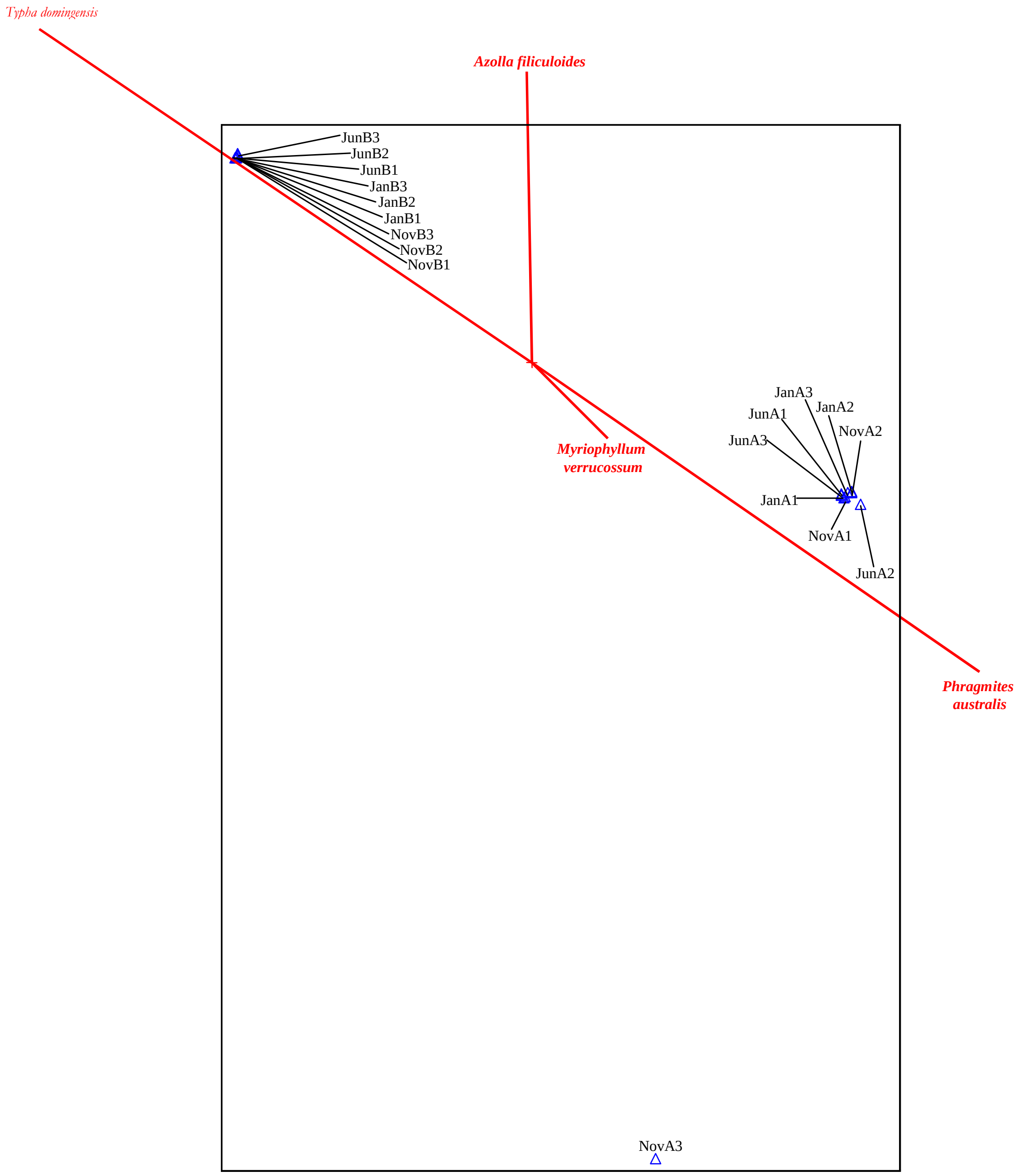


Figure 3-17 NMS ordination of the -30 cm quadrats in Isle of Mann Backwater (A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.035).

3.3.1.4 Hancock Creek

The quadrats at site one in Hancock Creek showed a similar pattern at all elevations; *Mesembryanthemum crystallinum* and *Sclerolaena brachyptera* were abundant in November 2005 and then declined over the study period and the abundances of *Sporobolus mitchelli* and *Atriplex* spp. remained relatively constant (Figure 3-18). This pattern of change was similar at each site in Hancock Creek throughout the study period.

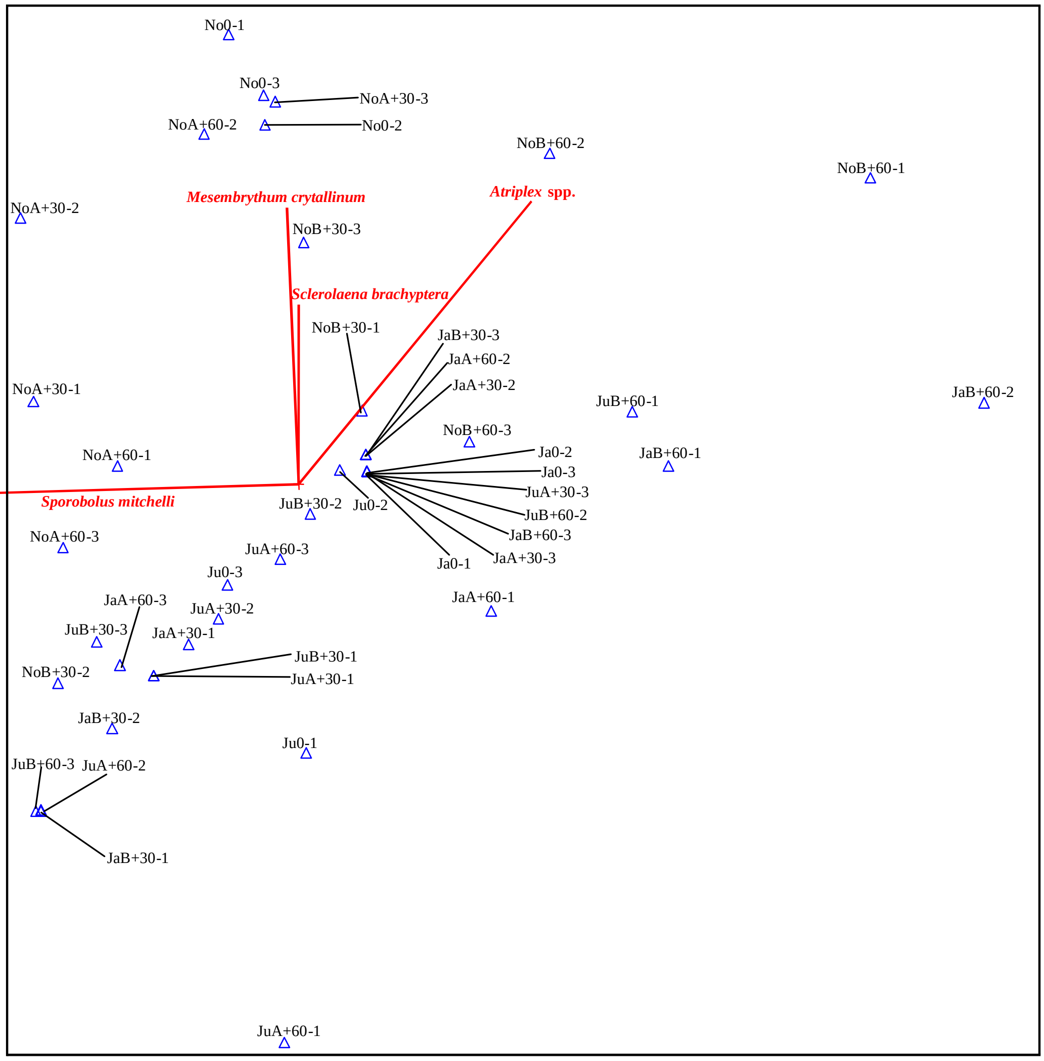


Figure 3-18 NMS ordination of the Site 1 quadrats for all elevations in Hancock Creek (A or B = Bank, No = November 04, Ja = January 05, Ju = June 05, Stress = 0.136).

3.3.1.5 Lake Limbra

All quadrats at all sites and all surveys were identical for Lake Limbra, with *Halosarcia pergranulata* present in each cell of each quadrat (a frequency of 15 for each quadrat).

3.3.1.6 Murray River

Four distinct groups of quadrats are displayed in the NMS ordination of the high elevation quadrats in the Murray River (Figure 3-19). The quadrats dominated by *Salix babylonica* (all quadrats on the right hand bank at fish assemblage site 2) and *Phragmites australis* did not change over the study period (Figure 3-19). The quadrats dominated by *Senecio* sp. and bare soil showed no clear change in plant communities over the study period (Figure 3-19).

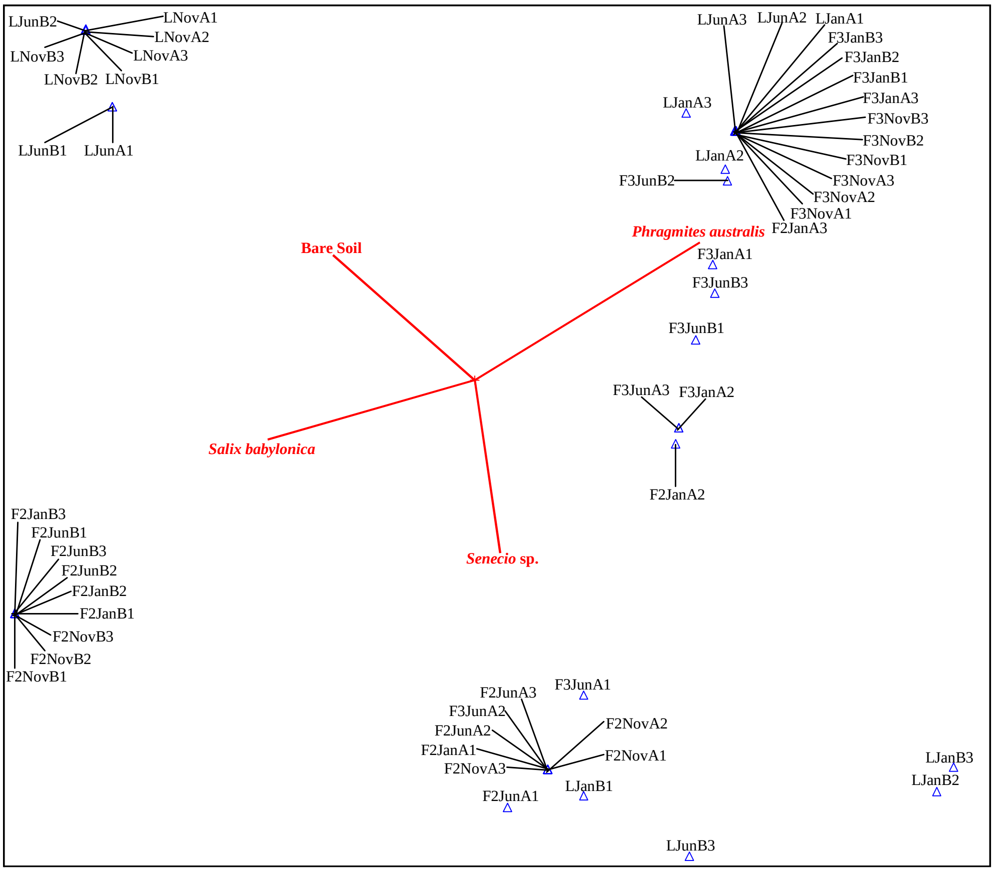


Figure 3-19 NMS ordination of the +30 to +60 cm quadrats in the Murray River (L = Larvae Site, F = Fish Assemblage Site A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.190).

Three distinct groups are evident in the NMS ordination of the 0 cm quadrats from the Murray River sites (Figure 3-20). The quadrats dominated by *Salix babylonica* all quadrats on the right hand bank at fish assemblage site 2 showed no change over the study period (Figure 3-20). The quadrats dominated by *Typha domingensis* and *Phragmites australis* and *Senecio* sp. showed no clear patterns of change over the study period (Figure 3-20).

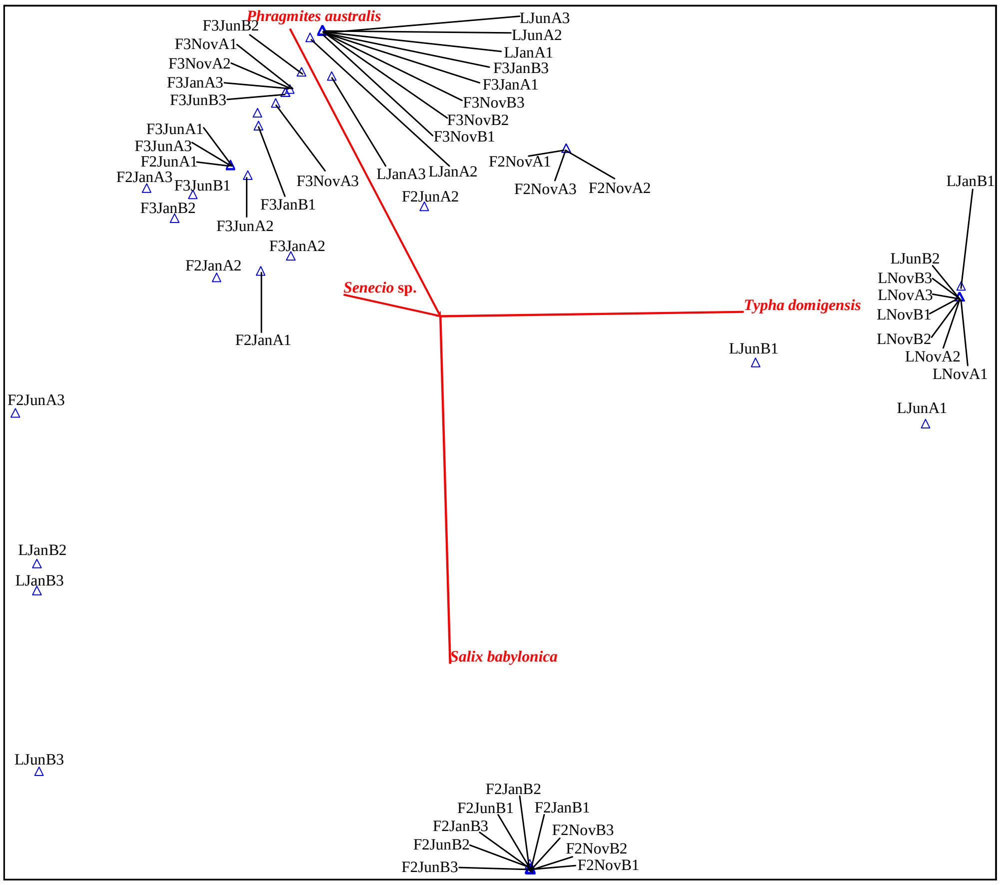


Figure 3-20 NMS ordination of the 0 cm quadrats in the Murray River (L = Larvae Site, F = Fish Assemblage Site A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.162).

The inundated quadrats in the Murray River that were initially dominated by *Salix babylonica, Typha domingensis* and *Phragmites australis* remained dominated by this species for the duration of the study. Other quadrats showed no clear pattern of change.

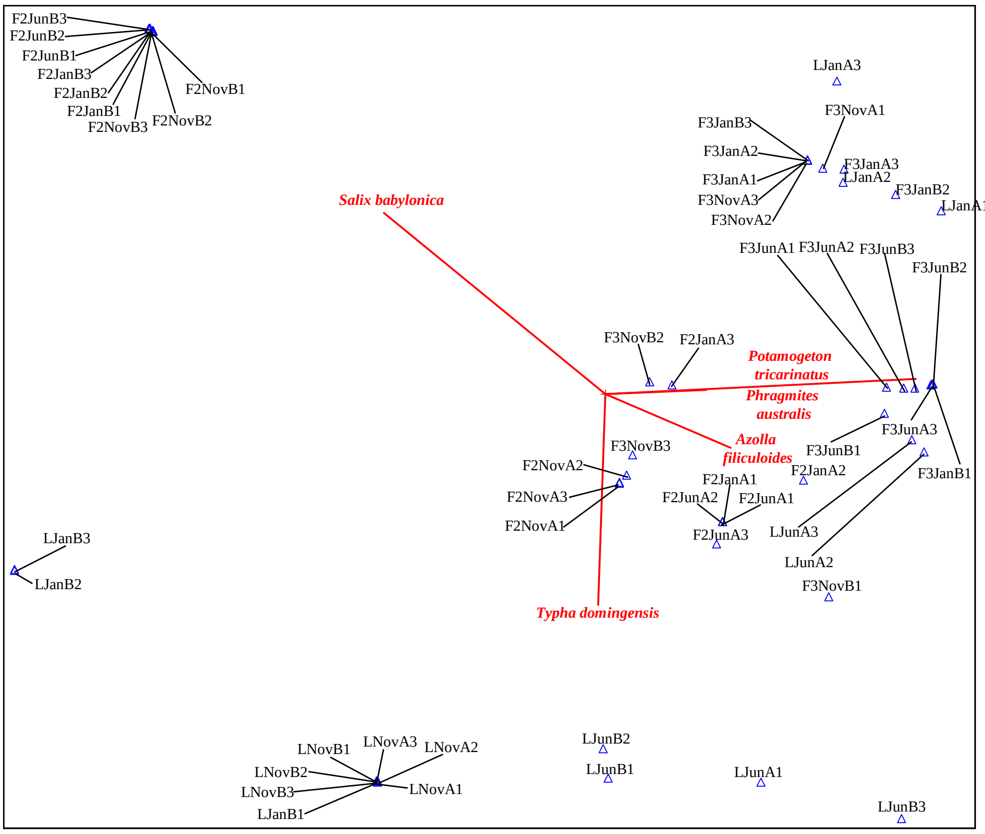


Figure 3-21 NMS ordination of the -30 cm quadrats in the Murray River (L = Larvae Site, F = Fish Assemblage Site A or B = Bank, Nov = November 04, Jan = January 05, Jun = June 05, Stress = 0.184).

3.3.2 Response to the spring 2005 in channel high flow event

The response of the vegetation on the banks of the Murray River downstream of Chowilla Creek at +30 and +60 cm showed a similar response (Figure 3-22). The floristic composition changed significantly from November 2004 to February 2006 (+60 cm PERMANOVA $F_{3,11}$ = 2.46; P = 0.007 and +30 cm PERMANOVA $F_{3,11}$ = 2.92; P = 0.004) with corrected multiple comparisons showing that there was no significant change until after the flood (November 2004 = January 2005 = June 2005 ≠ February 2006). The February 2006 survey was also the only survey where there were significant indicator species; at +60 cm *Centipeda minima* (P = 0.017) and *Xanthium occidentale* (P = 0.017) were present in higher numbers and at +30 cm *Centipeda minima* (P = 0.017) was more abundant. The vegetation at 0 cm; however showed a different response with each survey having a significantly different floristic composition (PERMANOVA $F_{3,11}$ = 1.64; P = 0.026; November 2004 ≠ January 2005 ≠ June 2005 ≠ February 2006). Despite the different floristic composition there were no significant indicator species.

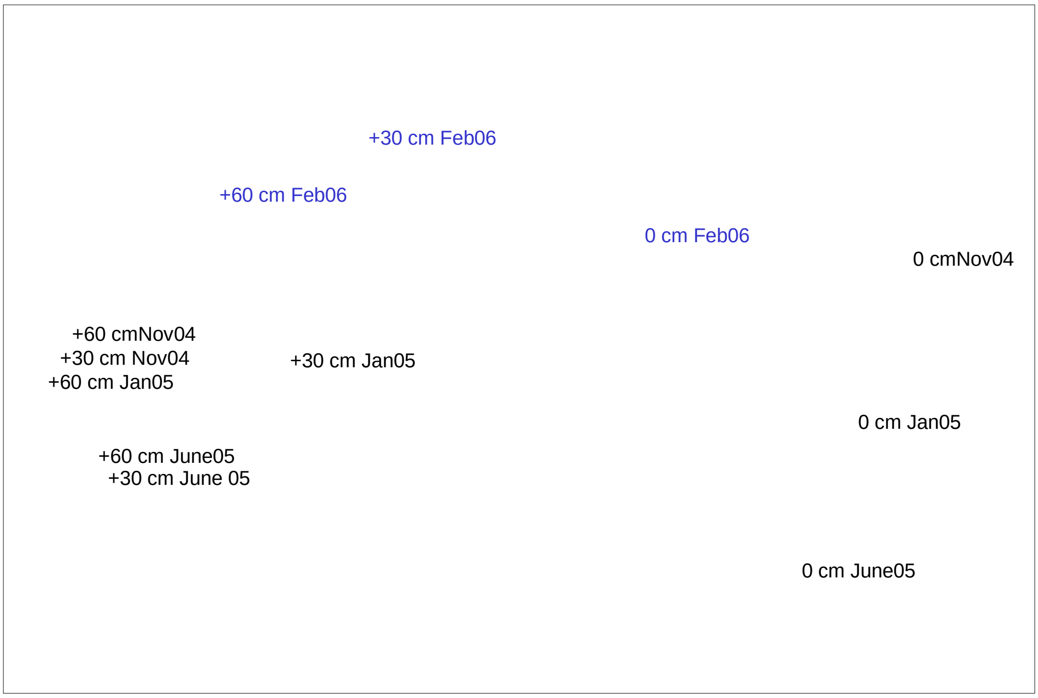


Figure 3-22 NMS ordination of pooled data from the 0 and +30 to +60 cm from the Murray River downstream of Chowilla Creek between November 2004 and February 2005 (blue labels represent the post flood survey, Stress = 0.05).

The NMS ordination of the floristic composition from the banks of Salt Creek upstream of Swiftys Creek showed two distinct groups; the 0 cm elevation was located on the right hand side of the ordination and the +30 and +60 cm elevations of the left hand side (Figure 3-23). In contrast to the Murray River downstream of Chowilla Creek, the floristic composition did not change significantly through time at any elevation (PERMANOVA +60 cm: $F_{3,11}$ = 0.65; P = 0.65, +30 cm: $F_{3,11}$ = 1.52; P = 0.22, 0 cm: $F_{3,11}$ = 1.09; P = 0.36). The only significant indicator was *Mesembryanthemum crystallinum* (P = 0.019), which was in present in higher numbers at the +60 cm elevation in November 2004.

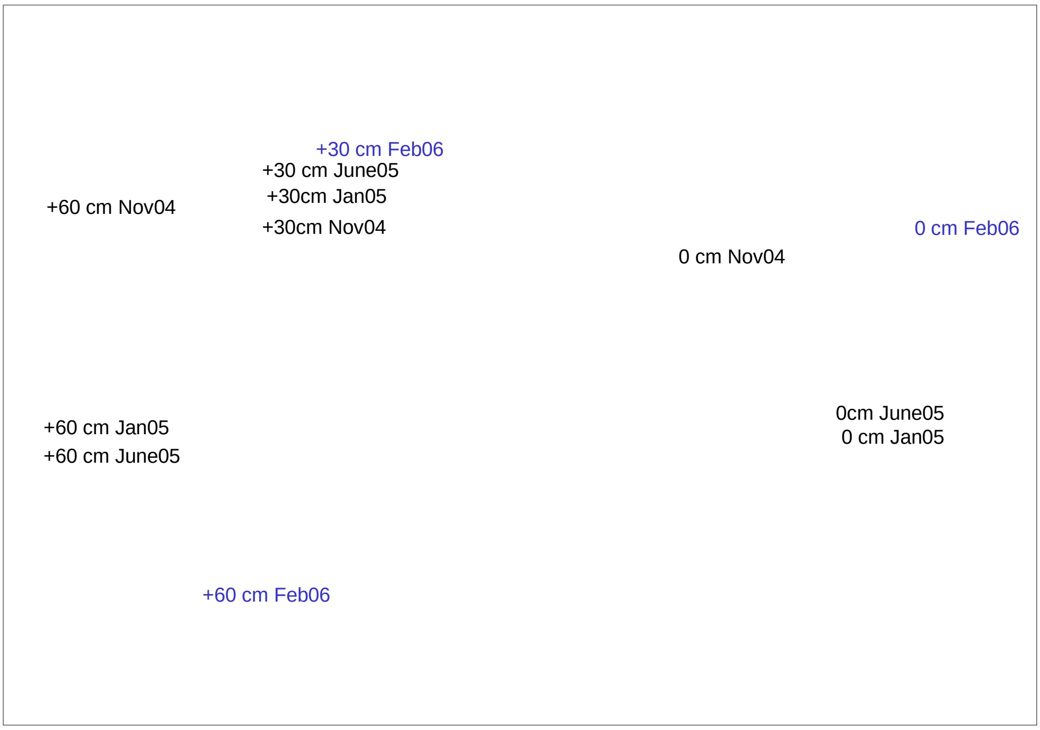


Figure 3-23 NMS ordination of pooled data from the 0 and +30 to +60 cm from Salt Creek upstream of Swiftys Creek between November 2004 and February 2005 (blue labels represent the post flood survey, Stress = 0.02).

The response of the vegetation across sites and can be split into two groups. Sites where there was no significant change in floristic composition before and after the high river (Salt Creek upstream of Swiftys Creek, Punkah Creek and Slaney Backwater) and sites where there was a significant change (Murray River downstream of Chowilla Creek and Monoman Creek adjacent to the upstream junction with Chowilla Creek).

3.4 Discussion

Generally quadrats that were vegetated with long-lived perennial vegetation (e.g. *Phragmites australis, Typha domingensis, Salix babylonica, Vallisneria americana, Cyperus gymnocaulos*) did not change significantly over the study period, especially those in or close to permanent water. Similarly, the quadrats that had high frequencies of bare soil in the riparian zone also did not change over the study period. However, there were some exceptions; the change in floristic composition at Hancock Creek was driven by the seasonal change in abundance of the winter annual *Mesembryanthemum crystallinum* (Cunningham *et al.* 1981). There also was an increase in the abundance of submergent vegetation in Monoman Creek over the study period and an increase in the abundance of *Azolla filiculoides* in all of the inundated sites between November

2004 and January 2005. It is unclear why there was an increase in *Azolla filiculoides* and submergents in Monoman Creek.

Whilst there was no significant change in floristic composition over the study period at most sites (permanently or temporarily inundated), condition monitoring has shown that the vegetation community on the majority of the floodplain has changed from a drought tolerant terrestrial community to a salt tolerant community between 2006 and 2007 (Weedon *et al.* 2007).

The conditions for recruitment of many riparian species did not occur over the study period; nevertheless, there is evidence to suggest that there is still the potential for native floodplain species to recruit given favourable conditions (natural or engineered flooding). Recruitment of native riparian species was observed in the majority of the environmental watering sites (Weedon *et al.* 2007; Nicol *et al.* 2010b) and at some sites after the high river in spring 2005. The +30 and +60 cm elevations on the banks of the Murray River downstream of Chowilla Creek and Monoman Creek adjacent to the upstream Chowilla Creek junction showed a response to the increase in river levels. At these sites flood dependent herbs (*Centipeda minima* and *Epaltes australis*) were present in significantly higher abundances in the post flood survey. However, the riparian weed, *Xanthium occidentale* was also present in significantly higher numbers at these sites in the February 2006 survey.

The remaining sites surveyed after the spring 2005 flood showed no significant change in floristic composition at the +30 and +60 cm elevations. At these sites there was evidence of salinisation (presence of salt tolerant species, powdery soils with very little structure and salt scald). The high soil salinity may have prevented many species from germinating or recruiting or the seed bank may have been depauperate at these sites; however, the impacts of salinity on seed longevity are not well understood.

Generally the 0 cm elevations had a significantly different floristic composition for each survey (except for Salt Creek upstream of Swifty's Creek). This was probably the result of small water level fluctuations that inundate part (or all) of the quadrat periodically, which provides water for seeds to germinate from the seed bank. In addition much of the surface soil in the quadrat has high moisture content because creek or river water is being brought to the surface by capillary action. This also provides water for seeds to germinate from the seed bank and survive to maturity to replenish the seed bank both locally and as a source of seeds that may be dispersed to other areas of the floodplain.

The seed bank is important to maintain persistent populations of floodplain species, especially in a system such as Chowilla (*sensu* Nicol 2004). Hassam (2007) showed that within two years of a wetland that was artificially flooded drying, the majority of flood dependent species had died and only drought tolerant terrestrial species were present. These results suggest that regular flooding or a persistent seed bank (*sensu* Thompson and Grime 1979) is required to maintain persistent populations of flood dependent understorey species.

Whilst there is evidence the floodplain has been severely degraded by the lack of flooding (MDBC 2003; Doble *et al.* 2004; Overton and Jolly 2004; Smith and Kenny 2005; Weedon *et al.* 2007) permanently inundated areas in the Chowilla system did not show the same signs of degradation (from a botanical perspective). The permanent wetlands and creeks had high abundances of native submergent (e.g. *Potamogeton crispus, Potamogeton tricarinatus, Myriophyllum verucossum*, *Vallisneria americana*) and floating species (e.g. *Azolla filiculoides, Lemna* sp.). In addition the majority of the highly abundant emergent species, which fringed the permanently inundated areas, were also natives (e.g. *Typha* spp., *Eleocharis acuta, Bolboschoenus caldwellii, Phragmites australis, Juncus usitatus, Ludwigia peploides* spp. *montevidensis*, *Cyperus gymnocaulos*).

4 Spatial and Temporal Patterns of Fish Spawning

A larval freshwater catfish (*Tandanus tandanus*) captured in Slaney Creek.

4.1 Introduction

Changes to the natural flow regime are considered to have had a significant impact on the health of floodplain and wetland systems of the lower Murray River (Cadwallader 1978; Walker and Thoms 1993; Arthington and Pusey 2003; MDBC 2006) and have been attributed to the decline in abundance and distribution in native fish populations (Cadwallader 1978; Walker and Thoms 1993; Gehrke *et al.* 1995). These observed declines in abundance and distribution are likely due to a number of factors associated with flow regulation including changes to the natural flow regime, reduced connectivity with off-channel habitats and physical barriers to fish passage (Cadwaller 1978; Mallen-Cooper 1993).

Native fish populations are recognised as key indicators of the broader physical condition of riverine ecosystems (Ryan and Davies 1996; Humphries and Lake 2000; Boys and Thoms 2006). The study of larval fish in particular can provide important information on the effects of river regulation on fish population ecology (Humphries and Lake 2000). High mortality is generally experienced at the egg, larval and juvenile stages hence the environmental conditions present at these early life history stages can have a profound influence on the level of recruitment to the adult population and may ultimately influence the structure of fish communities (Houde 1987; Trippel and Chambers 1997).

In order to manage off-channel habitats effectively a greater understanding of the effects of flow on fish recruitment ecology is required. However, the importance of off-channel habitats and flooding in the life cycle of native fish for specific regions of the Murray-Darling Basin (MDB) remains unresolved (Humphries *et al.* 1999; King *et al.* 2003; Graham and Harris 2005). The Chowilla system provides a unique opportunity to study the interactions between the larval fish community and stream hydrology within the lower Murray River.

In this chapter we investigate various aspects of the larval fish assemblage in the Chowilla system surveyed during the spring/summer of 2004/2005, 2005/2006 and 2006/2007. Specifically we describe spatial and temporal variation in the presence of larval fish, the approximate spawning period of individual species, and investigate the potential interactions between the larval fish community and stream hydrology. Furthermore we discuss the importance of the Chowilla system as a recruitment source for native and non-native fish populations in the lower Murray River.

4.2 Methods

4.2.1 Pilot study

A pilot study was undertaken in 2004/2005 to provide preliminary information on the larval fish community within the Chowilla region. Six sites, namely Slaney, Pipeclay, Boat, Punkah and Chowilla Creek and the main channel of the Murray River were selected to represent the mesohabitat types present within the Chowilla system. Larval drift nets (500 µm mesh, 0.5 m diameter opening, 1.5 m length, n = 2 – 5 nets) were set overnight (range 13 – 18 hours) at each site, fortnightly from 4/10/2004 to 17/1/2005. A flow meter (general Oceanics Inc. Florida, USA) was fixed into the mouth of each drift net to determine the volume of water filtered. Upon retrieval the contents of the net were rinsed into a sample jar and preserved in 95% ethanol. Additional samples were collected from Slaney and Chowilla Creeks and the Murray River using the sweep net electrofishing (SNEF) method described by King and Crook (2002). Available habitat at each site was sampled for larval fish. Three replicates were collected at each site and samples were preserved with 95% ethanol.

Larval fish were separated from vegetation in drift net samples under a magnification lamp (x 2). Samples from SNEF did not require sorting prior to identification. Fish were then identified under a dissecting microscope using descriptions from Puckridge and Walker (1990) and Serfafini and Humphries (2004) and from comparison with specimens provided by NSW DPI, Narrandera Fisheries Centre. Gudgeon species (i.e. *Hypseleotris* spp. and *Philypnodon* spp.) were grouped together given the difficulty of distinguishing these species at early larval stages in drift net samples.

4.2.2 Spatial and temporal variation in larval fish assemblage

For further investigation of the larval community within the Chowilla region, larval samples were collected fortnightly from September to February in 2005/2006 and 2006/2007 (Figure 4-1). Eight sites were chosen to represent a broader range of permanent aquatic mesohabitat types (Sheldon and Lloyd 1990) than in the 2004/2005 sampling season (Table 4-1). Based on average cross-sectional velocities collected as part of a concurrent project, fast-flowing mesohabitats were characterised by velocities > 0.18 ms^{-1}, slow-flowing mesohabitats by velocities 0.05 – 0.18 ms^{-1} and Murray River main channel mesohabitats by < 0.10 ms^{-1}.

Sampling methods were refined following the pilot study. At each site three drift nets and three modified quatrefoil light traps (Floyd *et al.* 1984) were set concurrently. Drift nets were set to actively fish the flow path and collect drifting larvae. Light traps replaced SNEF and were set adjacent to available littoral habitats (e.g. submerged and emergent macrophytes and large woody debris). A cyalume light stick (yellow) was placed inside the trap to attract larvae with a positive phototactic response to a light source (Gehrke 1994). Mesh (5 mm stretched) was used to prevent predation of larvae by larger fish (Meredith *et al.* 2002). Drift net samples were sorted as per the pilot study. Samples from light traps did not require sorting prior to identification. Fish were identified as described for the pilot study.

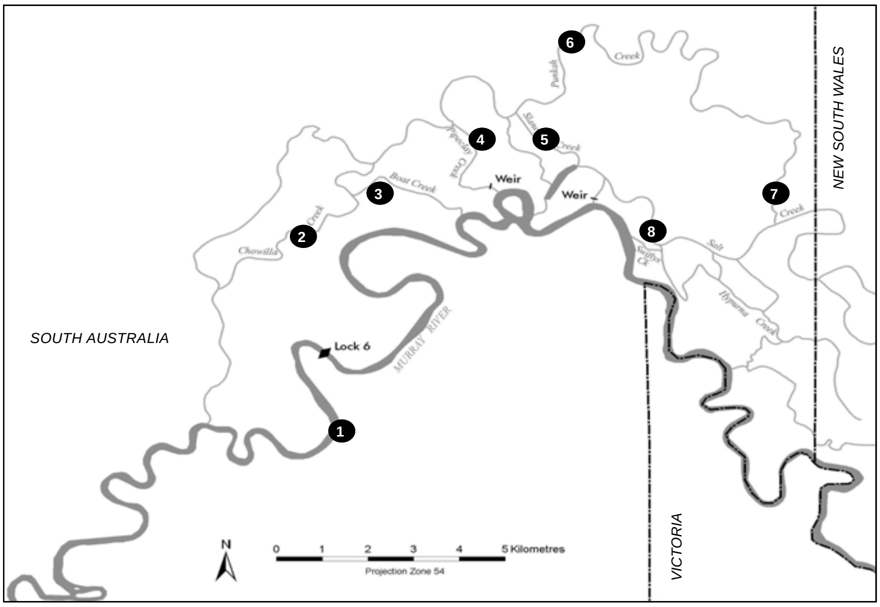


Figure 4-1 Sites sampled in the Chowilla region during the 2005/2006 and 2006/2007 sampling season.

Table 4-1 Site locations and aquatic mesohabitat type.

Site no.	Location	Mesohabitat type
1	Murray River at groynes downstream of Lock 6	Main river channel
2	Chowilla Creek d/s of Chowilla Bridge	Slow-flowing
3	Boat Creek	Fast-flowing
4	Pipeclay Creek	Slow-flowing
5	Slaney Creek u/s Chowilla junction	Fast-flowing
6	Punkah Creek d/s Punkah Island ford	Slow-flowing
7	Salt Creek	Slow-flowing
8	Hypurna Creek	Slow-flowing

Drift net data was standardized as the number of larvae per 1000 m^3 of water and light trap data as the number of larvae per 12 hours. At each site both sampling techniques were combined to represent the relative abundance of each species (number of larvae/1000 m^3 + number of larvae/12 hr).

Differences in larval fish communities between sites, mesohabitats and years were compared using NMS ordination, UPGMA clustering, Multi Response Permutation Procedures (MRPP) (McCune *et al.* 2002) and Indicator Species Analysis (Dufrene and Legendre 1997) using the package PCOrd version 5.12 (McCune and Mefford 2006). Bray-Curtis (1956) similarities were used to calculate the similarity matrix for all multivariate analyses. NMS ordinations and UPGMA cluster analyses were performed using pooled data from each site for comparisons between years but all other analyses were performed using unpooled data. A probability significance (α) value of 0.05 was used for all statistical analyses.

Percent cover data collected in March 2006 from representative sites within the Chowilla region, were used to define seven microhabitat categories (emergent, submergent and floating aquatic macrophytes, coarse woody debris (CWD) 1 (twigs < 1 cm diameter), CWD 2 (branches 1 – 5 cm diameter), CWD 3 (wood > 5 cm diameter) and river red gum roots (RG roots)). Sites from 2005/2006 and 2006/2007 were then grouped into one of the three mesohabitat types outlined in Table 4-1. The percent cover each microhabitat contributed to the three mesohabitat types was then compared and described.

4.3 Results

4.3.1 Pilot study

Eight fish species (six native and two non-native) were captured as larvae within the Chowilla system and adjacent Murray River (Table 4-2). The most abundant species were gudgeons (*Hypseleotris* spp. and *Philypnodon* spp.), Australian smelt (*Retropinna semoni*) and bony herring (*Nematalosa erebi*). Lesser numbers of common carp (*Cyprinus carpio*), unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), freshwater catfish (*Tandanus tandanus*), gambusia (*Gambusia holbrooki*) and Murray rainbowfish (*Melanotaenia fluviatilis*) were also collected (Table 4-2). Drift nets were more effective at capturing Australian smelt, bony herring, carp and gudgeons whilst hardyhead, gambusia and Murray rainbowfish were more abundant in SNEF samples (Table 4-2).

Table 4-2 Total raw numbers (drift net and SNEF methods combined) of fish captured during the pilot study undertaken in 2004/2005 and a comparison of fishing methods (drift nets and SNEF) using abundance categories for species captured as larvae within the Chowilla system and adjacent Murray River.

Common name	Total number captured	Drift nets	SNEF
Gudgeons	2533	High	High
Australian smelt	594	High	High
Bony herring	278	High	Low
Gambusia	53	Low	High
Common carp	41	High	Low
Unspecked hardyhead	28	Low	High
Murray rainbowfish	25	Low	High
Freshwater catfish	17	Low	Low
Total	**3569**		

4.3.2 Spatial and temporal variation in the larval fish assemblage

Eight native and two non-native species were captured as larvae in the Chowilla system and adjacent Murray River during the 2005/2006 and 2006/2007 sampling periods (Table 4-3). All species with the exception of golden perch and non-native redfin perch (*Perca fluviatilis*) were collected in both years. Golden perch were only collected in 2005/2006 and redfin perch were only collected in 2006/2007. Australian smelt and gudgeons dominated the catch for both years. The relative abundance of larvae was greater in 2006/2007 than in 2005/2006 (23,227 and 15,177 respectively), primarily due to greater abundances of Australian smelt, gudgeons, and unspecked hardyhead in 2006/2007 (Table 4-3).

Two highly regarded recreational fish species were captured as larvae within the Chowilla system, namely golden perch (*Macquaria ambigua ambigua*) and Murray cod (*Maccullochella peelii*). Murray cod are considered threatened under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*.

Table 4-3 Relative abundance of larvae (drift net and light trap relative abundance data combined) for each site sampled within the Chowilla system during the 2005/2006 and 2006/2007 sampling periods.

Common name	Boat Creek		Chowilla Creek		Hypurna Creek		Murray River		Pipeclay Creek		Punkah Creek		Salt Creek		Slaney Creek		Total	
	05/06	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**06/07**	**05/06**	**05/06**
Unspecked hardyhead	11.9	3.1	6.9	71.6	1.4	21.0	26.5	165.0	34.1	9.0	2.2	3.3	0.7	3.8	8.9	8.5	92.7	285.3
Gudgeons	23.6	61.6	538.6	809.1	6063.4	2337.4	1221.3	1265.9	2245.7	981.8	67.2	675.9	943.3	2934.9	157.9	190.3	11261.0	9256.8
Golden perch	1.3	-	1.3	-	0.8	-	-	-	-	-	-	-	3.5	-	0.7	-	7.7	-
Murray cod	-	0.3	6.0	17.0	-	-	-	2.4	17.1	13.4	2.2	0.7	-	-	0.9	3.2	26.2	37.0
Murray rainbowfish	1.9	-	1.5	0.7	5.7	0.7	0.8	1.8	1.9	-	-	-	1.9	-	-	-	13.8	3.3
Bony herring	-	3.4	155.9	35.8	22.8	97.9	148.7	132.6	285.8	49.0	8.8	29.4	144.7	122.6	44.8	16.5	811.4	487.1
Australian smelt	10.8	54.3	115.1	1473.3	306.6	1242.0	108.9	1799.3	1370.5	2139.2	107.2	1616.1	262.4	3634.6	46.0	324.5	2327.5	12283.3
Common carp	34.2	2.8	24.6	12.6	321.7	212.7	-	2.0	36.8	182.2	8.3	139.0	205.8	275.3	3.7	3.1	635.2	829.7
Redfin perch	-	0.7	-	6.1	-	1.4	-	3.8	-	30.6	-	-	-	-	-	1.7	-	44.3
Total	**83.8**	**126.1**	**849.8**	**2426.2**	**6722.3**	**3913.1**	**1506.1**	**3372.9**	**3991.9**	**3405.1**	**196.1**	**2464.4**	**1562.3**	**6971.2**	**263.0**	**547.9**	**15176.8**	**23226.9**

Samples from the 2005/2006 and 2006/2007 season show that although the timing, duration and presence of larvae differed between species, similar intraspecific patterns were apparent between years (Figure 4-2). Murray cod, golden perch and non-native redfin perch larvae were present for discrete periods. Murray cod larvae were collected in both years from mid October to late November, golden perch were collected from late November to early January in 2005/2006 and redfin perch were collected from late September to early November in 2006/2007. Larvae of most small-bodied species and bony herring were collected over a protracted period in both years. Gudgeons and Australian smelt were present from September till February, whilst bony herring, unspecked hardyhead and Murray rainbowfish were generally not sampled until later in the season (mid October till February). Common carp larvae were present early in the season in both years from early September to December.

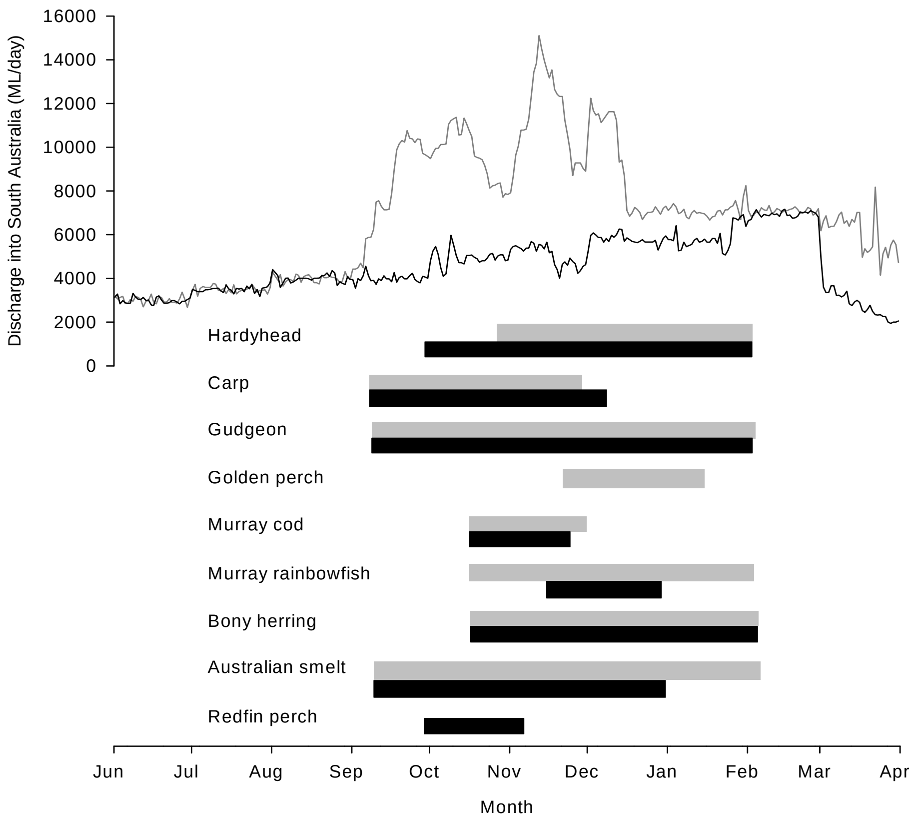


Figure 4-2 Fish species captured as larvae within the Chowilla system and adjacent Murray River during the 2005/2006 and 2006/2007 sampling events plotted with discharge into South Australia for both years. Grey bars and line graph represent 2005/2006 and black indicates 2006/2007.

The NMS ordination of the larval fish communities using CPUE data (Table 4-3) showed that the samples from 2005/2006 and 2006/2007 formed relatively distinct groups (Figure 4-3). MRPP (A = 0.0098, P = 0.0029) confirmed that the larval fish communities were significantly different between 2005/2006 and 2006/2007. Indicator Species Analysis showed that golden perch were significantly more abundant in 2005/2006 and redfin perch and Australian smelt were significantly more abundant in 2006/2007 (Table 4-4). All other species were present in similar abundances in each year (temporally widespread) (Table 4-4).

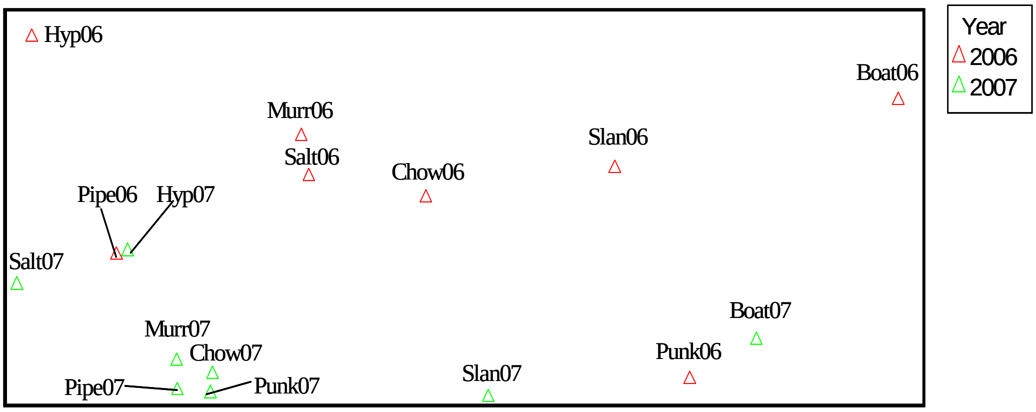


Figure 4-3 MDS plot showing differences between the two sampling years (2005/2006 (red marker) and 2006/2007 (green marker)) (stress = 3.08%).

Table 4-4 Indicator species analyses comparing the relative abundance of fish species between years. A significant difference (P < 0.05) indicates that a species occurs in higher abundances in a particular year. Values that are not significant indicate that a species was sampled in similar abundances over both years (W = widespread (temporally)).

Species	Year	*P*-value
Unspecked hardyhead	06/07	0.118 (W)
Common carp	06/07	0.412 (W)
Gudgeons	05/06	0.635 (W)
Golden perch	05/06	**0.025**
Murray cod	06/07	0.579 (W)
Murray rainbowfish	06/07	0.392 (W)
Bony herring	06/07	0.658 (W)
Australian smelt	06/07	**< 0.001**
Redfin perch	06/07	**0.003**

Cluster analysis on the relative abundances of larval fish from both years showed two distinct groups at a similarity of 25% (Figure 4-4). The two fast-flowing creeks (Boat and Slaney Creek) formed group 1. Punkah Creek, a slow-flowing creek, was also present in this group but only in 2005/2006 (Figure 4-4). Group 2 contained the slow-flowing creeks (Chowilla, Salt, Hypurna, Pipeclay Creeks and Punkah Creek 2006/2007) and the Murray River main channel site. Indicator species analysis showed that gudgeons, bony herring, Australian smelt and common carp were significant indicators of the group that contained the majority of slow-flowing and Murray River main channel sites (Table 4-5).

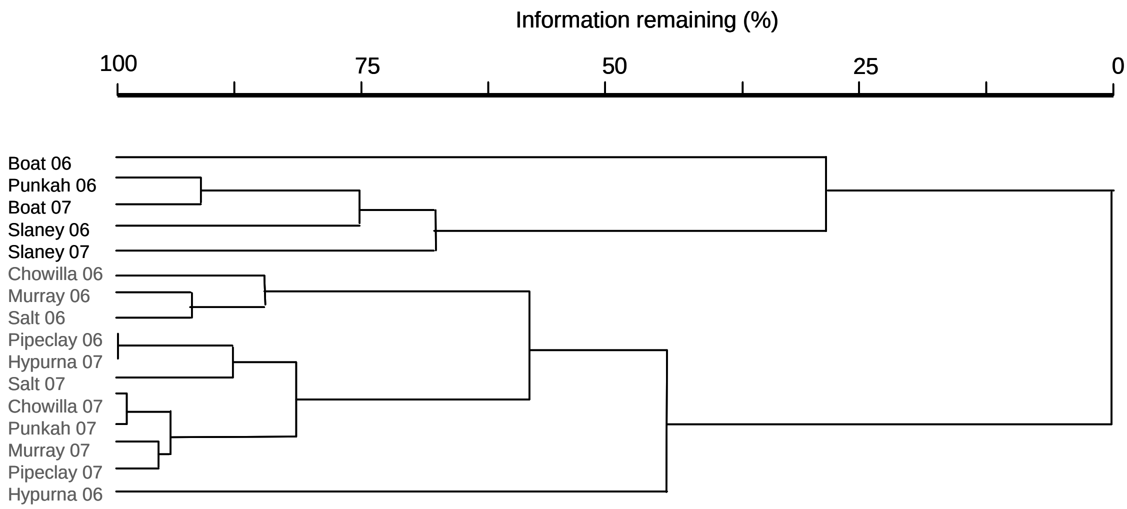


Figure 4-4 UPGMA cluster dendrogram of sites based on total CPUE abundances for each year. The dendrogram was timed at 25% similarity to produce two groups with significantly different larval fish assemblages.

Table 4-5 Indicator species analyses comparing the relative abundance of fish species between sites. A significant difference (*P* < 0.05) indicates that a species occurs in higher abundances in a particular group (group 1 or 2 identified by cluster analysis). Values that are not significant indicate that a species was sampled in similar abundances in both groups (W = widespread).

Species	Group	*P*-value
Unspecked hardyhead	2	0.161 (W)
Common carp	2	**0.037**
Gudgeon	2	**<0.001**
Golden perch	1	0.780 (W)
Murray cod	2	0.534 (W)
Murray rainbowfish	2	0.1814 (W)
Bony herring	2	**0.001**
Australian smelt	2	**0.004**
Redfin perch	2	0.350 (W)

The grouping of sites based on cluster analysis is further supported by a comparison of larval fish relative abundance between aquatic mesohabitats (MRPP, A = 0.0377, P < 0.0001). Fast-flowing mesohabitats had significantly different larval communities from both slow-flowing (SF) and main channel (MC) habitats but slow and main channel habitats did not differ (FF ≠ SF = MC). Indicator species analysis revealed that gudgeons, bony herring and Australian smelt occurred in significantly higher abundances in slow-flowing mesohabitats (Table 4-6).

Table 4-6 Indicator species analyses comparing the relative abundance of fish species in three aquatic mesohabitat categories. A significant difference (P < 0.05) indicates that a species occurs in higher abundances at a particular mesohabitat type. Values that are not significant indicate that a species was either sampled in low numbers (U = uncommon) or was sampled in similar abundances in both mesohabitats (W = widespread).

Species	Mesohabitat type	*P*-value
Unspecked hardyhead	Slow-flowing	0.297 (W)
Common carp	Slow-flowing	0.065 (W)
Gudgeons	Slow-flowing	**0.002**
Golden perch	Fast-flowing	0.445 (W)
Murray cod	Slow-flowing	0.485 (W)
Murray rainbowfish	Slow-flowing	0.344 (W)
Bony herring	Slow-flowing	**0.009**
Australian smelt	Slow-flowing	**0.012**
Redfin perch	Slow-flowing	0.447 (W)

4.3.3 Microhabitat Availability

There was a greater percent cover of submergent and floating aquatic macrophytes in both the slow-flowing sites and Murray River site than in fast-flowing sites (Figure 4-5). Emergent aquatic macrophytes, however, constituted a greater percent cover in fast-flowing sites (Figure 4-5). The percent cover of woody debris (all types) was similar across mesohabitats although the percent cover of CWD 3 was slightly higher in fast-flowing sites.

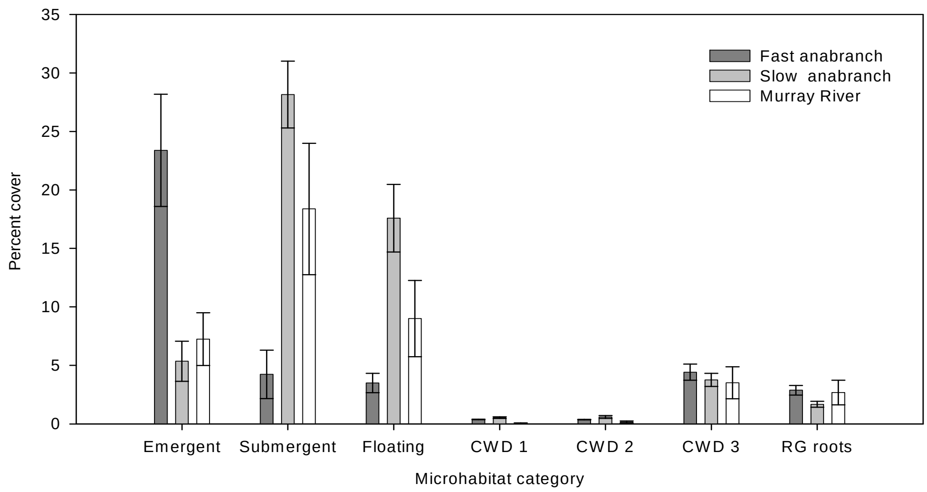


Figure 4-5 Percent cover of each microhabitat category present within three mesohabitat types, namely fast and slow-flowing mesohabitats and the adjacent Murray River.

4.4 Discussion

4.4.1 Pilot study

Eight species of freshwater fish (six native and two non-native) were captured as larvae as part of the pilot study within the Chowilla system and adjacent Murray River. Three species were not captured as larvae despite their presence as adults in the region, namely Murray cod, golden perch and sliver perch.

The eight species captured were represented using each sampling method; nevertheless, the effectiveness of each sampling technique differed for individual species. Drift nets were particularly efficient at capturing Australian smelt, gudgeons, common carp, freshwater catfish and bony herring. Hardyhead, Murray rainbowfish and gambusia although present in drift nets were more strongly represented in the SNEF samples. Hence the species captured could be categorised as larvae with a significant larval drift phase (drift nets) or larvae with a short or non-existent drift phase (SNEF).

During the pilot study we observed for the first time the downstream drift of larval freshwater catfish. Freshwater catfish larvae were captured in drift net and SNEF samples from Slaney Creek and the Murray River. Larvae were 15 – 20 mm in length and were estimated to be

23 days post hatching (Lake 1967). Adult freshwater catfish are considered non-migratory but larval drift may facilitate the dispersal of this species in the lower Murray River.

4.4.2 Larval fish assemblage

Nine species of fish (seven native and two non-native) were recorded as larvae in the study of spatial and temporal variation in larval assemblages (2005/2006 and 2006/2007 sampling) with gudgeons and Australian smelt the most abundant species in both years. Unlike the pilot study, Murray cod, golden perch and redfin perch were captured in 2005/2006 and/or 2006/2007 but freshwater catfish (*Tandanus tandanus*) and gambusia (*Gambusia holbrooki*) were absent.

All species collected as larvae, have also been collected as juveniles and/or adults in the region (Zampatti *et al.* 2006). However, silver perch (*Bidyanus bidyanus*), which have been collected as adults were not collected as larvae. Silver perch are considered to be a flow cued spawner (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003) and they may have been expected to be present during the same period when larval golden perch (also a flow cued spawner) were collected. Silver perch larvae, however, were collected by a separate investigation in the Murray River (Cheshire and Ye 2008) following the 2005/2006 flow event suggesting that they may have been absent, or present in very low abundances, in the Chowilla system.

4.4.3 Inter-annual variation

The relative abundance of larvae in 2006/2007 was greater than in 2005/2006, due primarily to significantly higher abundances of Australian smelt. This result was also observed in similar larval studies undertaken in the mid Murray, in the Barmah-Millewa region (King *et al.* 2007) and the main channel of the Murray River in South Australia (Cheshire and Ye 2008). Both studies collected substantially higher numbers of Australian smelt in 2006/2007 compared to 2005/2006. The mechanism for this increase in abundance of Australian smelt larvae is unclear. Nevertheless, Australian smelt typically inhabit slow-flowing or lentic habitats in high abundances (Lintermans 2007). Due to low flows in 2006/2007 these habitats were more common in the Chowilla system and may have resulted in increased spawning success for this species.

Golden perch larvae were only collected from the Chowilla region in 2005/2006, in association with a small but prolonged increase in discharge over the spring/early summer period. Golden perch larvae were also collected in the main channel of the Murray River in South Australia during the same period (Cheshire and Ye 2008). Golden perch is recognised as a flow cued spawner (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003) and the presence of larvae in Chowilla and the Murray River supports the notion that this species may spawn on relatively small increases in discharge. Nevertheless, the relationship between flow and recruitment to the adult population remains uncertain. The success of such a spawning event will ultimately be determined by larval survival and subsequent contribution to the adult population. Therefore we recommend monitoring the age structure of the adult population in conjunction with larval studies to investigate recruitment.

It also remains unclear if the golden perch larvae captured within the Chowilla system occurred as a result of a spawning event within the system or were drifting larvae spawned further upstream. Regardless of spawning site, however, it is likely that the Chowilla system provides an ideal habitat for growth and development because of the diverse aquatic habitats available within the system.

Redfin perch larvae were only collected in 2006/2007, from all three aquatic mesohabitat types. Redfin perch have been conspicuous in their absence from the juvenile/adult fish community in the Chowilla system (Zampatti unpublished data) and little is documented on their ecology in the lower Murray River. The absence or low abundance of redfin perch larvae may result from the current low abundance of this species within the region. Engledow and Vilizzi (2006) only recorded redfin perch larvae in one year (2005/2006) of a five year investigation of larval fish in the Lindsay-Mullaroo system in the lower reaches of the Murray River. Consequently it appears that redfin perch spawning and/or survival to the larval stage may not occur annually in the lower Murray River.

4.4.4 Intra-annual variation

Most species, with the exception of golden perch and redfin perch, spawned each year and the timing and duration of occurrence of larvae for each species was relatively consistent between years. There was, however, considerable inter-specific variation in the timing and duration of larvae present in any given year. Species could generally be grouped as having a discrete or prolonged and an early or late spawning season. Species present early in the sampling season (September) were gudgeons, Australian smelt and carp. Gudgeons and Australian smelt were generally present for the entire sampling season (September to February) and can be considered as having the most prolonged spawning season of the species collected. Common carp larvae were present from September until December but may have been present prior to the start of sampling thus suggesting they have an early commencing, prolonged spawning season.

Unspecked hardyhead, Murray rainbowfish and bony herring had a late commencing, prolonged spawning season. These species were first collected in October – November and thereafter until sampling ceased in February. The species with the most discrete periods of occurrence were Murray cod, golden perch (in 2005/2006) and redfin perch (in 2006/2007). The timing and duration of occurrence of Murray cod larvae has been well documented in the mid reaches of the Murray River and several tributaries (Humphries *et al.* 2002; Humphries 2005; King *et al.* 2005; Koehn and Harrington 2006). Larvae have been documented as beginning to drift early in November and extending until mid December. In the Chowilla system, however, Murray cod larvae were collected in the drift by mid October, thus suggesting that Murray cod may spawn earlier in the lower reaches of the Murray River. Water temperature may be an important stimulus for Murray cod spawning and a threshold of approximately 15 ºC has been proposed (Humphries 2005; Koehn and Harrington 2006). This water temperature was reached by early September in 2005/2006 and 2006/2007 in the Chowilla system and may result in earlier spawning than the mid reaches of the Murray River.

Low numbers of golden perch larvae were only collected in 2005/2006, in association with a small but prolonged within-channel rise in discharge. Golden perch larvae were present in the catch for approximately a two month period, from late November to mid January. Unlike Murray cod, golden perch do not appear to spawn annually and instead appear to rely on a hydrological cue (Humphries *et al.* 1999; Mallen-Cooper and Stuart 2003).

Redfin perch larvae were only collected for a brief period between October and November 2006/2007. Humphries (2002) observed a similarly discrete period of occurrence for redfin perch larvae in the Campaspe and Broken Rivers (tributaries of the mid reaches of the Murray River) from October till November on an annual basis (over 4 years).

The initial timing of occurrence of larvae for a number of species appears earlier in the Chowilla and Lindsay systems than in the mid reaches of the Murray River (Humphries *et al.* 2002; Meredith *et al.* 2002; Engledow and Vilizzi 2006; King, *et al.* 2007) and may be a result of water reaching optimal spawning temperature earlier in the lower reaches of the Murray River.

4.4.5 Spatial variation in the larval fish assemblage

Species richness and diversity of larval fish was similar across all sites and most species were widespread. Nevertheless, slow-flowing sites had significantly different abundances than fast-flowing sites. An exception was Punkah Creek (typically a slow-flowing habitat) that had similar larval abundances to the fast-flowing creeks (Slaney and Boat) in 2005/2006. This may be due to the increase in discharge in 2005/2006 altering the hydraulics of Punkah Creek to more closely resemble those of a fast-flowing creek.

Generalist species, such as gudgeons, bony herring and Australian smelt were captured in significantly higher abundances in slow-flowing mesohabitats (including the Murray River site). The use of still or slow-flowing areas by fish larvae has been widely documented (Scheidegger and Bain 1995; Merigoux and Ponton 1999). Research within the Lindsay Island region, an anabranch system immediately upstream of the Chowilla system, identified a similar trend in species composition and larval abundance in still/slow-flowing environments (Meredith *et al.* 2002; Engledow and Villizzi 2006). Humphries *et al.* (1999) suggests that such environments provide ideal habitats for larval fish due to greater densities of food items and less turbulence. Our data also indicate that slow-flowing habitats and the Murray River, were characterised by a greater percent cover of submerged aquatic macrophytes than fast-flowing mesohabitats. Submerged aquatic macrophytes are considered an important spawning and rearing habitat for small-bodied species such as gudgeons and Australian smelt and may help explain the significantly greater abundance of larvae in this hydraulic mesohabitat.

Common carp larvae were also found to be significantly associated with sites grouped as slow-flowing habitats. Adult and juvenile carp prefer slow-flowing and backwater habitats, and have been shown to be significantly associated with areas with a high percent cover of submerged aquatic macrophytes (*Vallisneria americana* and *Potamogeton crispus*) within the Chowilla Anabranch system (Zampatti *et al.* 2006). These findings suggest that slow-flowing environments in the Chowilla system are potential spawning and recruitment habitats for this species.

Murray cod and golden perch were captured in low abundances and were not significantly associated with a mesohabitat type, although abundances of both these species were generally higher in fast-flowing habitats and Chowilla Creek. Adult Murray cod occur in significantly higher abundances in the fast-flowing mesohabitats (e.g. Slaney Creek) of the Chowilla system (Zampatti *et al.* 2006). We propose that spawning takes place in these creeks and the larvae are then transported to the slow-flowing Chowilla Creek. Such slow-flowing environments are less turbulent and potentially more productive thus providing abundant zooplankton as a food source for larval fish (Humphries *et al.* 1999). This spatial separation of habitats is a permanent feature of the Chowilla system and represents a process that would normally be temporally defined during floods in the Murray River.

5 Murray Cod Distribution and Spawning

A juvenile Murray cod (*Maccullochella peelii*) captured in Slaney Creek.

5.1 Introduction

Murray cod (*Maccullochella peelii*) is the largest fish in the Murray-Darling Basin (MDB) reaching a potential maximum total length (TL) of 1.8 m and weight of 113 kg (Harris and Rowland 1996). It is an iconic species and has great cultural significance to indigenous and non-indigenous Australians. Murray cod distribution and abundance have declined significantly since European settlement and the species is now considered nationally vulnerable to extinction under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This decline has primarily been attributed to habitat loss and degradation, barriers to fish passage, flow regulation, cold water releases and fishing (MDBC 2005). Nevertheless, the ecological mechanisms behind these threats are not often described.

The South Australian commercial catch of Murray cod declined dramatically from a peak of > 140 tonnes/annum in 1957/1958 to < 10 tonnes/annum in the mid 1970s. Annual landings remained at this level until a moratorium on the catch of Murray cod was instituted in January 1990. The moratorium was lifted in 1993 and the catch reached a maximum of ~ 29 tonnes/annum prior to the closure of the native fish fishery in the SA Murray River in July 2003.

Pierce (1990) suggested that in the late 1980s, juvenile Murray cod were rarely seen in the lower Murray River thus indicating low levels of recruitment or recruitment failure. During the same period, however, juvenile Murray cod were present in the Chowilla system and Pierce (1990) proposed that Chowilla system was a known breeding and rearing habitat for Murray cod. Unfortunately, data to support these conclusions are scarce.

Information on the biology and ecology of Murray cod in the lower Murray River is lacking, nevertheless, extensive data have been collected in the mid to upper reaches of the Murray and its tributaries (Lake 1967; Langtry in Cadwallader 1977; Rowland 1985; Rowland 1998; Gooley *et al.* 1995; Humphries *et al.* 2002; Humphries 2005; Koehn and Harrington 2006). Murray cod spawn annually over a relatively short, well defined breeding season (spring – early summer) most likely cued by increasing photoperiod and water temperature (recorded range 15 – 23.5ºC). Despite being an annual spawner, length and age frequency data from the lower Murray River, Edward, Wakool and Murrumbidgee Rivers indicate that Murray cod recruitment is strongest when the breeding season coincides with high river flows, both within-channel and overbank (Rowland 1998; Ye *et al.* 2000).

To effectively manage Murray cod in the lower Murray River, and specifically in the Chowilla system, an understanding is required of its life history including biology and the environmental factors that influence recruitment. Most of the published information on Murray cod biology and ecology comes from the mid reaches or tributaries of the Murray River, or from populations in isolated lakes (e.g. Lake Charlegrark, Victoria). Murray cod populations from different habitats and regions in the MDB are likely to exhibit differences in biology (e.g. timing of spawning, growth rates, etc.) (Anderson *et al.* 1992) and it is important to take account of these regional differences when managing Murray cod.

This chapter is a synthesis of data collected from 2004 – 2007 on the spatial distribution, micro and mesohabitat preferences, spawning and size distribution of Murray cod in the Chowilla Anabranch system and adjacent Murray River in South Australia. It is intended to provide preliminary data to inform the management of Murray cod in this region and guide future investigations.

5.2 Methods

5.2.1 Spatial Distribution and Habitat Preferences

Murray cod were collected during annual (2005 – 2007) electrofishing surveys of 16 sites in the Chowilla system (see Chapter 2) and during a number of ad hoc electrofishing operations. Micro and mesohabitat associations were determined as described in Chapter 4.

5.2.2 Spawning

Murray cod undergo direct development without a true larval phase (Balon 1984); nevertheless, we have used the term larvae to describe 'free embryos' (Humphries 2005) and immediate 'post larval' life stages (Koehn and Harrington 2006). The presence of larval Murray cod was used as an indicator of spawning. Larval Murray cod were collected during surveys of larval fish assemblages throughout the Chowilla system and adjacent Murray River as described in Chapter 4. Larval Murray cod distribution and abundance was determined over two years in the spring/summer spawning seasons of 2005/2006 and 2006/2007. The age of larval Murray cod was estimated by comparing body size and morphological features, specifically yolk sac size as well as head and body shape with hatchery reared known age fish obtained from the Narrandera Fisheries Centre, New South Wales. Gross morphological features have been used by Koehn and Harrington (2006) and Humphries (2005) and are considered to be comparable to otolith interpretation and a relatively accurate method of determining the age of this species during the early life history stage. The age of larval Murray cod was then used to back-calculate an approximate spawning date for adult Murray cod.

5.2.3 Temporal and spatial variation in size distribution

Length frequency data for Murray cod was collated from four years (2004 – 2007) of annual electrofishing surveys of 16 sites in the Chowilla system and adjacent Murray River (see Chapter 2) and from a number of ad hoc electrofishing operations. Data were also obtained for the main channel from the lower Murray River in the vicinity of Locks 1 – 3. (Baumgartner *et al.* 2008; Zampatti unpubl. data). Fish were sampled by consistent methods, using a boat-mounted 5 or 7.5 kW Smith Root Model GPP electrofishing system. Electrofishing incorporated 12 (6 on each bank) or 16 (8 on each bank) x 90 second (power on time) electrofishing shots during daylight hours. All Murray cod were measured (total length, L_T) and returned to the water at the place of capture. Due to the low numbers of fish encountered, data from four years were combined for length-frequency analysis.

5.3 Results

5.3.1 Spatial Distribution and Habitat Preferences

From 2005 – 2007 Murray cod were generally wide spread but patchily distributed in the Chowilla system and adjacent Murray River. Extensive electrofishing surveys indicated that Murray cod were only sampled from Murray River mesohabitats and fast-flowing mesohabitats in the Chowilla system. Specifically, Murray cod were sampled from Chowilla, Boat, Pipeclay, Slaney, Salt and Swiftys Creek, and the Murray River upstream and downstream of Lock 6.

Based on standardised electrofishing data from 16 sites across the Chowilla system (from 2005 – 2007) abundances of Murray cod were greatest in Chowilla Creek immediately upstream of Boat Creek, Slaney Creek downstream of Salt Creek Junction and Slaney Creek downstream of Slaney Weir (Figure 5-1). A similar pattern is observed in total abundances calculated from all available electrofishing data from 2005 – 2007 (Figure 5-2).

Murray cod are a significant ($p < 0.001$) 'indicator species' (Dufrene and Legendre, 1997) for fast-flowing mesohabitats in the Chowilla system, as they only occur, and are ubiquitously distributed, in this mesohabitat. At the microhabitat scale Murray cod were significantly associated with large snags (branches and trunks > 5 cm diameter), river red gum (*Eucalyptus camaldulensis*) roots, lignum (*Muehlenbeckia florulenta*) and the emergent macrophytes *Phragmites australis* and *Juncus usitatus*. This vegetation generally characterised the riparian zone of fast-flowing mesohabitats and along with flowing water and large snags created considerable structural, hydraulic and geomorphological heterogeneity in these habitats.

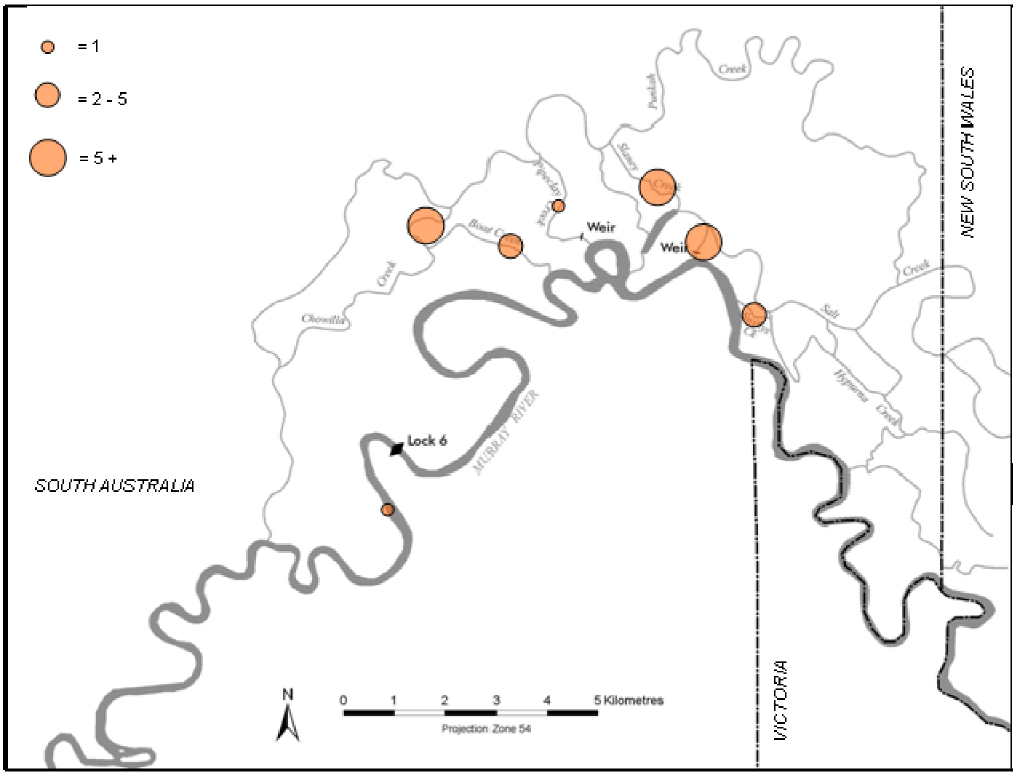


Figure 5-1 Spatial variability in Murray cod abundance (coloured circles represent total number of fish) from 2004 – 2007 using standardised electrofishing data from 16 sites across the Chowilla system.

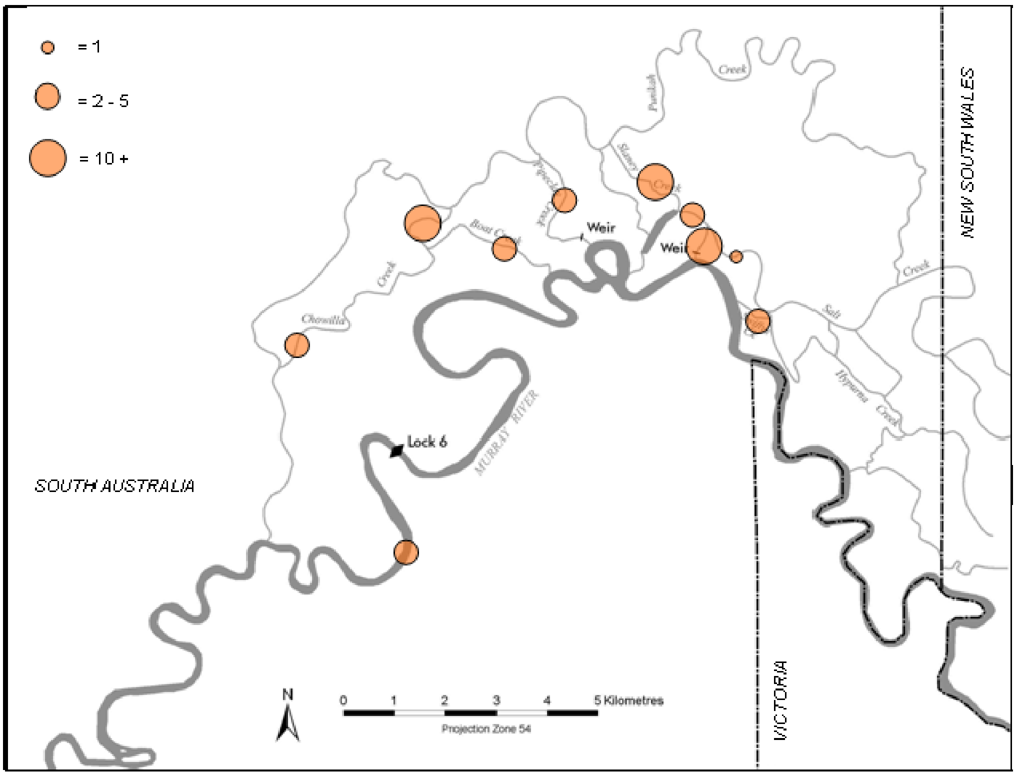


Figure 5-2 Spatial variability in Murray cod abundance (coloured circles represent total number of fish) from 2004 – 2007 using all available electrofishing data.

5.3.2 Spawning

Murray cod larvae were captured from seven sites within the Chowilla system and the Murray River downstream of Lock 6 (Table 5-1). No Murray cod larvae were captured from Hypurna and Salt creeks. In general, the highest numbers of larvae were captured within Chowilla, Slaney and Pipeclay creeks.

Larvae were collected from 19th October – 17th November in 2005 and from 16th October – 20th November in 2006 (Figure 5-3). During this period water temperature in Chowilla Creek was consistent between years, increasing from ~ 20 to 24ºC (Figure 5-3). Discharge, however, varied between years (Figure 5-3). In 2005, Murray cod larvae were present during a period when discharge into South Australia decreased from 9,000 to 8,000 ML/d before increasing to a peak of 15,000 ML/d. During the same period in 2006 discharge into South Australia was lower and remained constant at ~ 5,000 ML/d.

Murray cod larvae ranged from 10.2 – 12 mm in length and could be categorised into two distinct groups based on the presence of a yolk sac. Larvae in group 1 possessed a small yolk sac. Comparing these fish to known age fish it is likely that they had recently left the parental nest and entered the drift. These larvae were collected from mid October to early November. Larvae in group 2 possessed no visible yolk sac and their body features more closely resembled a juvenile fish (greater pigmentation with head and body shape more defined). Larvae in this group were collected from early to late November.

Based on the size and morphological features of the collected larvae compared with known aged larvae, and life history information, we estimate the age of fish in group 1 to be approximately 10 – 15 days old and group 2 to be 20 – 25 days old. Using these ages the time of spawning can be estimated to be late September / early October.

Table 5-1 The raw number and standardised abundance (larvae/1000m^3 + 12 hr) of Murray cod larvae captured using drift nets and light traps from seven sites in the Chowilla system and one site in the Murray River during the 2005/2006 and 2006/2007 sampling seasons.

Sites	2005/2006 Raw	2005/2006 Standardised	2006/2007 Raw	2006/2007 Standardised
Boat Creek	-	-	1	0.3
Chowilla Creek	9	6.0	18	17.0
Hypurna Creek	-	-	-	-
Murray River	-	-	2	2.4
Pipeclay Creek	2	17.1	5	13.4
Punkah Creek	1	2.2	1	0.7
Salt Creek	-	-	-	-
Slaney Creek	2	0.9	7	3.2
Total	**14**	**26.2**	**34**	**37.0**

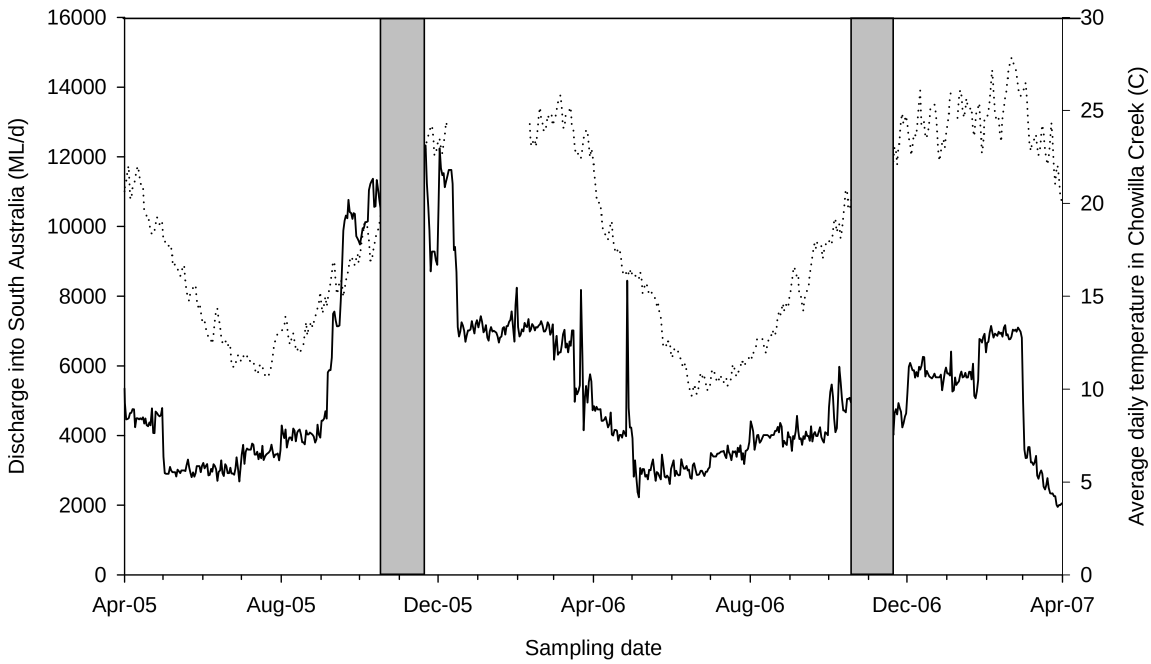


Figure 5-3 Presence of Murray cod larvae (grey bars) within the Chowilla system plotted with discharge into South Australia (solid line) and temperature (dotted line) during the 2005/2006 and 2006/2007 sampling seasons.

5.3.3 Temporal and spatial variation in size distribution

From 2004 – 2007 the sample size for Murray cod was small (*n* = < 25 fish/year), nevertheless, a broad length distribution of fish were collected with fish ranging from 150 mm to 1250 mm. Low numbers of juvenile fish (< 500 mm) were collected every year, with the exception of 2004 when ~ 50% of the sampled fish were < 500 mm (Figure 5-4). In 2004 a bimodal length distribution of fish is present with the cohort of smaller fish ranging from 300 – 550 mm in length. In 2006 and 2007 this mode appears to progress and by 2007 fish < 600 mm were less numerous (Figure 5-4).

The length-frequency distributions of Murray cod collected in 2004 – 2008 differed between the Chowilla system and the main channel of the lower Murray River in the vicinity of Locks 1 – 3 (Figure 5-5). Fish in the lower Murray River ranged from ≥ 350 mm to > 1300 mm L_T; with 98% being ≥ 900 mm L_T. Fish in the Chowilla system were 150 mm to ≥ 1250 mm L_T and, in contrast to the river, 40% were < 600 mm L_T and 35% were ≥ 900 mm L_T (Figure 5-5).

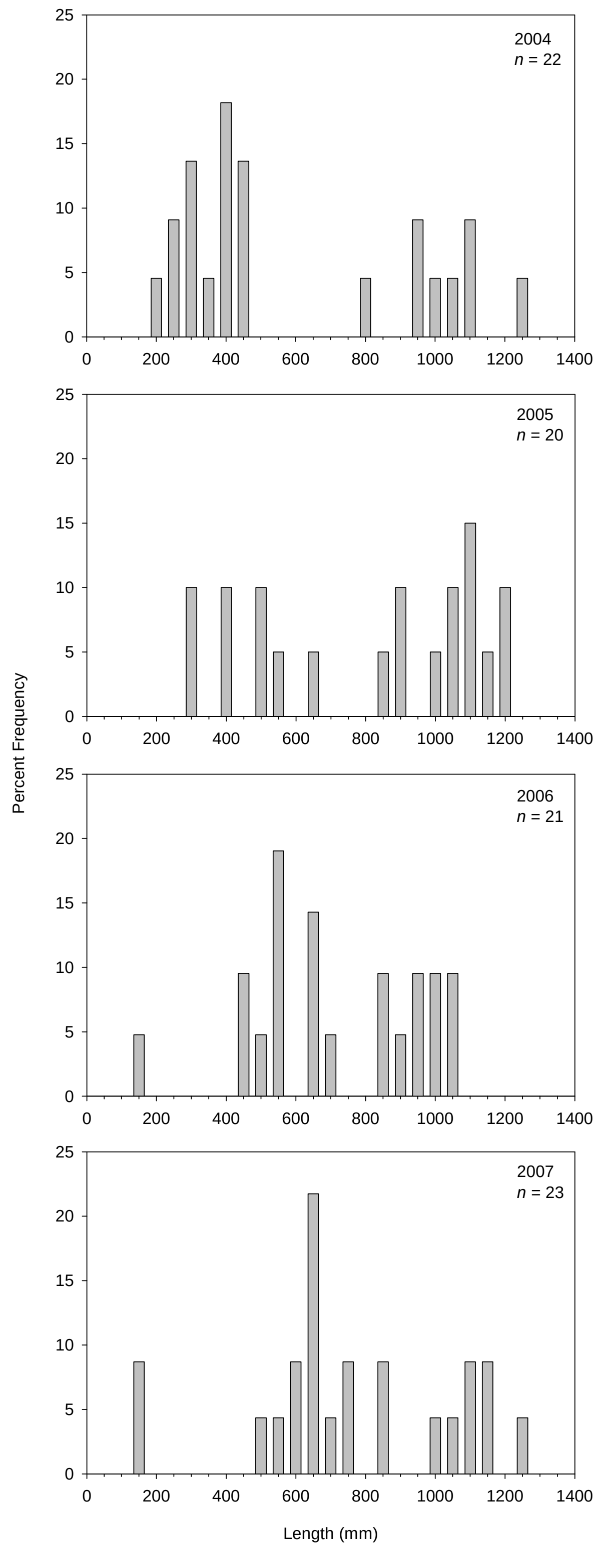


Figure 5-4 Length-frequency distributions of Murray cod collected from the Chowilla system from 2004 – 2007.

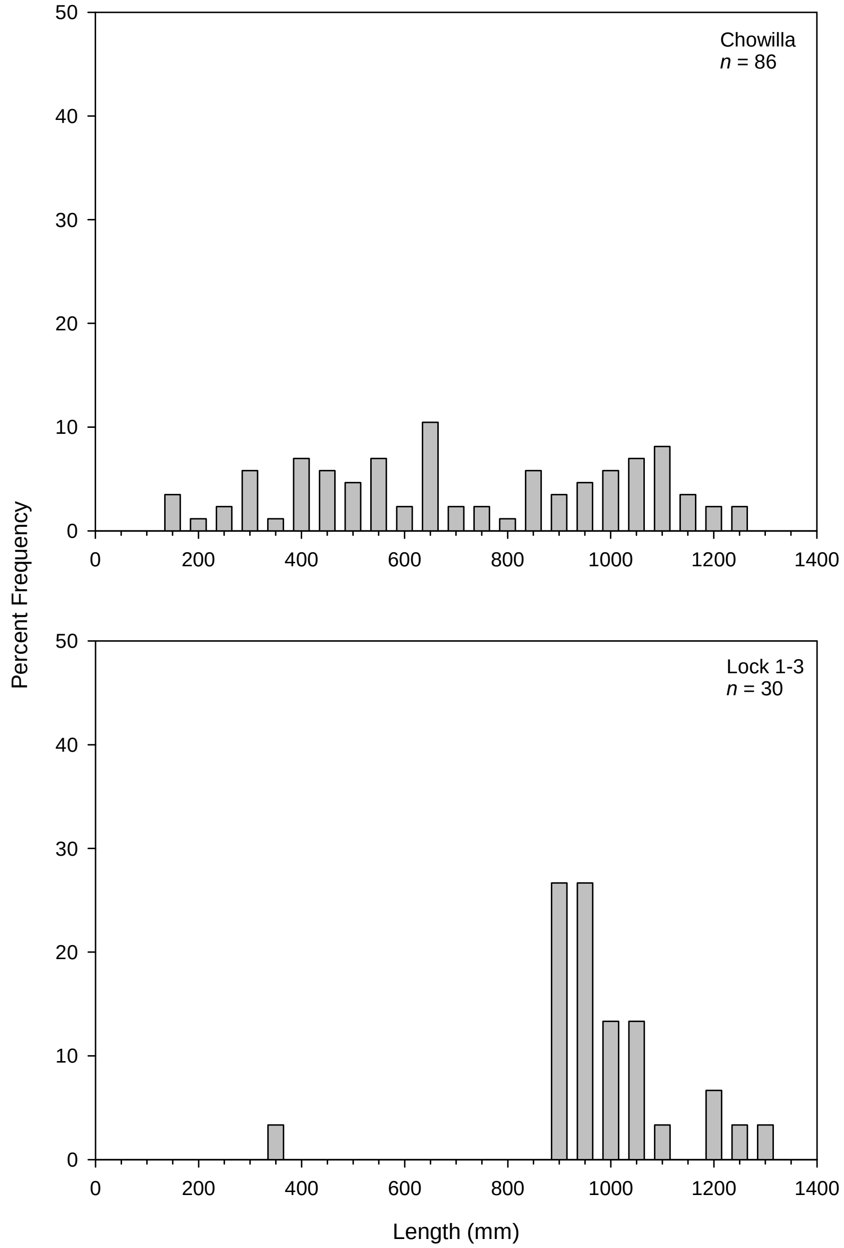


Figure 5-5 Length-frequency distribution of Murray cod from (a) the Chowilla system and (b) the Murray River in the vicinity of Locks 1 – 3 from 2004 – 2007.

5.4 Discussion

Over the three year study period Murray cod were consistently and only collected in fast-flowing mesohabitats of the Chowilla system and in the Murray River. The highest abundances of Murray cod were sampled at three sites in the Chowilla system, namely Chowilla Creek upstream of Boat Creek, Slaney Creek downstream of Slaney Weir and Slaney Creek downstream of Salt Creek Junction. These sites were characterised by average cross-sectional water velocities > 0.18 ms^{-1} and abundant large woody debris; these attributes in combination produced considerable hydraulic and channel (e.g. bedform) complexity. At the microhabitat scale, Murray cod were significantly associated with large wood (snags), river red gum roots, overhanging terrestrial vegetation (lignum) and the emergent macrophytes *Phragmites australis* and *Juncus usitatus.*

Radio-tagged adult (> 450 mm TL) Murray cod in the mid reaches and a tributary of the Murray River have been shown to prefer main river channel and flooded floodplain channel macrohabitats (Koehn 2009). Within these macrohabitats Murray cod selected microhabitats characterised by high levels of structural woody habitat, coefficient of variation in depth and overhanging vegetation (Koehn 2009). Murray cod in the Chowilla system were associated with similar habitat variables and although coefficient of variation in depth was not measured we observed high channel complexity at sites with flowing water and abundant woody habitat. The contiguous, desnagged weir pool habitats of the main channel of the Murray River provide little hydraulic or channel complexity and lack the high levels of structural wood that are found at sites within the Chowilla system. Consequently, specific regions in the Chowilla system provide a unique combination of flowing water and structural woody habitats that support high abundances of adult and juvenile Murray cod. These habitat characteristics are absent or rare in the lower Murray River where Murray cod occur in low abundances.

Murray cod larvae were collected in fast and slow-flowing mesohabitats in the Chowilla system from mid October to mid November in both 2005 and 2006, and from the Murray River only in 2006. Flow velocities in the Murray River were < 0.05 ms^{-1}, so that drift nets were unlikely to be effective. Cheshire and Ye (2008), however, undertook plankton tows in these habitats during the same period and captured Murray cod larvae annually. From these data, spawning was confirmed in main channel and anabranch habitats (with the exception of backwaters) during a small increase in flow, and during stable low flows, at water temperatures of 18 – 20°C. These observations are consistent with other studies, and support the general view that Murray cod spawn annually during a limited season, independent of hydrological conditions and in association with increasing water temperatures (variously reported as > 15 – 20°C) (Rowland 1983; Rowland 1998; Humphries 2005; Koehn and Harrington 2006).

Back calculation of approximate spawning dates, based on a comparison of yolk sac size, and head and body shape, with hatchery reared known age fish (Koehn and Harrington 2006; Humphries 2005) indicated that captured larvae were spawned in late September/early October in both years. This is earlier than timing of spawning (i.e. mid October to early December) reported in the mid reaches and tributaries of the Murray River (Humphries 2005; Koehn and Harrington 2006). If water temperatures of 15°C are an important threshold then this temperature is commonly reached by mid September in the lower Murray River and may explain the earlier onset of spawning. The highest abundances of larvae were collected from fast-flowing mesohabitats in Chowilla, Slaney and Pipeclay creeks. These mesohabitats were characterised by high levels of structural woody habitat, an important adult habitat (Koehn 2009) and spawning substrate for Murray cod (McDowall 1996) and may represent important spawning sites.

Length frequency data indicate some recruitment of Murray cod during the period of our investigations. Fish less than 300 mm total length were rare; nevertheless, fish of this size are generally cryptic, inhabiting complex habitats such hollow logs (Jarod Lyon, Department of Sustainability and Environment, Victoria, pers comm.). Fish residing in these habitats may be difficult to effectively electrofish in turbid lowland rivers. Once fish reach ~ 400 mm, however, their catchability appears to increase (authors' personal observations). Despite generally low annual sample sizes (*n* < 25 fish/year), there appears to be a cohort of fish that progresses from approx 400 – 500 mm in 2005 to 600 – 700 mm in 2007. A similar progression was observed in the Lindsay-Mullaroo Anabranch system during the same period (Villizzi *et al.* 2006). Conversely, fish of this size range were noticeably absent in the lower reaches of the Murray River, particularly in the ~ 500 km of main channel downstream of Lock 5 (Ye and Zampatti 2007). Pierce (1990) observed a similar pattern in the late 1980s with juvenile Murray cod being rare in the main channel of the lower Murray River whilst at the same time being present in the Chowilla system.

Murray cod recruitment in the southern MDB appears to be positively associated with high river flows, both within-channel and overbank (Rowland 1998; Ye *et. al.* 2000). During a prolonged low-flow period (2001 – 2007) in the lower Murray River, recruitment has been negligible and length-frequency data suggest that the last significant recruitment event in the lower Murray River was in the early-mid 1990s (Ye and Zampatti 2007). The capture of a broad size range of Murray cod during the present study, and the observations of Pierce (1990) indicate that the Chowilla system facilitates recruitment of Murray cod during periods of extended low-flow and in the absence of recruitment in the main river. Hence the Chowilla system has provided an important source of recruits to potentially carry over Murray cod populations to the next major recruitment event.

Chowilla provides a complex of physical and hydraulic habitats at both micro and mesohabitat scales. At the micro-scale flowing water provides hydraulic complexity that may ultimately increase larval survival. Humphries (2005) suggested that apparent variations in the year-class strength of Murray cod populations may reflect density-dependent effects, and pointed out that larvae may have an obligate drifting stage. This could counter density-dependent effects, reducing cannibalism, predation and competition between siblings and move larvae to new, potentially more favourable habitats (cf. Robinson *et al.* 1998). Larvae that are spawned in hydraulically homogenous lotic weir pool habitats may not be able to drift and hence may exhibit lower survival.

At the mesoscale the spatial separation of fast-flowing (potential spawning habitats) and slow-flowing (potential rearing habitats, *sensu* Humphries *et al.* 1999) habitats is a permanent feature of the Chowilla system and represents a pattern that would normally be temporally defined during floods in the Murray River. Importantly, the lotic habitats within Chowilla provide drought refugia, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance (Schlosser and Angermeier 1995). Flowing habitats are scarce and unique in the lower Murray River and as such should be afforded special protection along with the Murray cod populations that inhabit them. The mechanisms that facilitate Murray cod recruitment are yet to be explored and form important questions for future research as does the movement of adult and juvenile Murray cod within the Chowilla system and between Chowilla and the Murray River.

6 Golden Perch Spawning and Recruitment

Golden perch (*Macquaria ambigua ambigua*) are common and widespread throughout the Chowilla system.

6.1 Introduction

Flow is a pervasive force in riverine ecosystems. It drives hydrological and geomorphological processes, and determines the types and amount of habitat available to aquatic biota (Poff and Ward 1989). Fish are a prominent indicator of changes to the natural flow regime associated with river regulation. Flow regulation affects fish by decreasing habitat complexity and productivity, impeding movement and disrupting life histories (Junk *et al.* 1989; Poff and Ward 1989). Ultimately, these factors may create conditions that favour generalist and non indigenous species at the expense of locally-adapted native fish (Brown and Ford 2002; Aarts *et al.* 2004; Poff *et al.* 2007). Flow regulation is considered a key threat to native fish in the Murray-Darling Basin (MDB) (Cadwallader 1978; Gehrke *et al.* 1995) and is implicated, along with a range of other factors (e.g. habitat degradation, lowered water quality and alien species) in causing a reduction in native fish levels to approximately 10% of their pre-European levels (Barrett 2004).

An understanding of flow related ecology is critical to the restoration of freshwater fish, in particular to inform the provision of more natural flow regimes in regulated rivers (Arthington and Pusey 2003; Arthington *et al.* 2006). To restore components of the flow regime we need to understand those facets that are important to native fish (Lytle and Poff 2004; Jowett *et. al.* 2005; Humphries *et. al.* 2008). Whilst many studies highlight the potential effects of river regulation on fish few are able draw significant conclusions or make definite links because they are conducted over limited spatial and temporal scales (Humphries *et al.* 2008). Consequently, investigations need to be undertaken under a range of hydrological conditions if they are to inform how hydrology influences fish ecology (Arthington and Pusey 2003; King *et al*. 2009).

Golden perch (*Macquaria ambigua ambigua*) is a large-bodied (up to 76 cm total length, [TL]) potamodromous fish that is wide spread in the inland rivers of Australia, including the Murray-Darling Basin (MDB), the Lake Eyre Basin and the Dawson and Fitzroy Rivers (Allen *et al.* 2002). Golden perch is an iconic fish in the MDB; it is a major target species for recreational anglers and formed the primary component of a commercial fishery in the Murray River until 2002, when commercial fishing ceased in South Australia (Ye 2004). Golden perch has undergone a range reduction in the MDB but remains common in the lower reaches of the Murray and Darling Rivers. Declines in range and abundance have been primarily attributed to the construction of dams and weirs, altering flow regimes and creating barriers to fish movement (Cadwallader 1978; Gehrke *et al.* 1995; Mallen-Cooper 1996; McDowall 1996). Interestingly the potential impacts of commercial fishing are rarely mentioned.

The lower Murray River and the Darling River flow through predominantly semi-arid or arid landscapes. As such, in their natural states, they experienced highly variable flow regimes (Walker *et al.* 1995; Puckridge *et al.* 1998). River regulation; however, has had a profound impact on total discharge and discharge variability in the lower Murray River (Maheshwari *et al.* 1995; Walker 2006). Mean annual discharge is now approximately 36% of the natural mean, low flows dominate, medium (within-channel pulses) are greatly reduced but big floods remain relatively unchanged.

An understanding of the ecology of key fish species, such as golden perch, is essential to provide guidance on the critical components of flow regimes that need to be protected or reinstated. Golden perch have traditionally been described as flood cued spawners that have a life history that fits the flood-pulse concept described by Junk *et al.* (1989). That is, fish spawn in association with spring floods that inundate floodplains, stimulating the production of abundant food such as zooplankton and facilitating high rates of survival of larval fish (Lake 1967; Gehrke and Harris 1994; Schiller and Harris 2001). This model, however, has been questioned in recent years with researchers determining that spawning may occur in association with increases in flow contained within the river channel or with no increase in flow (Mallen-Cooper and Stuart 2003; King *et al.* 2005; Balcombe *et al.* 2006; Roberts *et al.* 2008) . Furthermore, strong recruitment into the adult population has been associated with within-channel rises in flow (Mallen-Cooper and Stuart 2003). Golden perch in regulated rivers, however, have more variable recruitment (whereby a small number of age classes comprise a large proportion of the population) than in unregulated or lesser regulated rivers where multiple age classes indicate more frequent recruitment (Roberts *et al.* 2008).

The collection of fish larvae provides evidence of when, where and under what environmental conditions a particular fish species has spawned. Furthermore, fish larvae have been suggested as a useful tool to monitor the effects of river regulation and restoration (Humphries and Lake 2000). Numerous studies have collected the drifting eggs or larvae of golden perch but the success of subsequent recruitment in many of these studies remains unclear (King *et al.* 2005; Gilligan and Schiller 2004). The presence of larval fish alone does not predicate recruitment and ultimately recruitment into the reproductive population will be a key to the restoration of native fish communities. Our knowledge on how hydrology influences the population dynamics of golden perch is growing; nevertheless, long-term studies that investigate larval abundance, survival, recruitment and flow have been lacking (King *et al.* 2005; Brown and Wooden 2007).

The Chowilla system has been described as an important recruitment source for golden perch in the South Australian reaches of the Murray River (Pierce 1990; Lloyd 1990). Nevertheless, no data are available on the spawning and recruitment ecology of this species in the region and hence how altered flow regimes or reinstatement of environmental flows may affect this species. In this chapter, we provide evidence that golden perch do spawn on relatively small within-channel rises in flow and that some larvae do survive until at least the 0+ and 1+ age class. Furthermore, investigation of the age structure of golden perch populations in the Chowilla region (including the Murray River) indicates that strong year classes of adult fish are associated with increases in discharge, both within-channel and overbank.

6.2 Methods

6.2.1 Collection of golden perch

Post larval (young-of-year, YOY) golden perch were collected during the larval fish survey of the Chowilla region during the period September 2004 – February 2007 (see Chapter. 4). Additional light traps were set at a site in Chowilla Creek on the 1/12/2005 to collect supplementary golden perch larvae for ageing.

Juvenile and adult golden perch were collected in March over three consecutive years (2005, 2006 and 2007) using a boat mounted 5kW Smith Root Model GPP 5.0 electrofishing unit. Boat electrofishing has been shown to be the least selective fish sampling methodology for both species and size of fish in lowland rivers in south-eastern Australia (Faragher and Rodgers 1997). Golden perch were collected during standardised quantitative surveys of fish assemblages at least 16 sites representing all available meso (e.g. lentic and lotic waters) and micro (e.g. open water, aquatic macrophytes and woody debris) habitats in the Chowilla system and adjacent Murray River. Additional fish were collected during *ad hoc* electrofishing operations throughout the study period. All fish retained for ageing were measured to the nearest mm (total length, TL), sex was determined by examination of gonads and both otoliths were removed.

In order to validate the annual nature of otolith increment formation additional golden perch were collected from a fishway at Lock and Weir No. 6 on the Murray River, adjacent to the Chowilla Anabranch system. From August 2005 to July 2006 golden perch (n = 8 – 15) were collected monthly and processed as above.

6.2.2 Ageing of golden perch

Under a dissecting microscope (x 40) post larval golden perch were measured to the nearest millimetre and otoliths were removed. An earlier validation of daily increment formation of known age larvae identified that the sagittae were preferred to lapilli as they were easier to prepare, revealed an easily interpretable microstructure and provided higher and more confident increment counts (Zampatti *et al.* unpubl. data). Furthermore, transverse sections provided better resolution and regularity of microstructural patterns than other sectioning planes. For preparation of transverse sections, sagittae were embedded in crystal bond™ and ground from both anterior and posterior surfaces to the primordium, with 9 μm imperial lapping film and polished using 0.3 μm alumina slurry to produce sections between 50 and 100 μm thick.

Sections were examined using a compound microscope (x 600) fitted with a digital camera and the *Optimas* image analysis software (version 6.5, Media Cybernetics, Maryland, USA). A drop of immersion oil was used to enhance the clarity of sections. Increments were counted blind with respect to fish length and capture date. Each otolith was examined on a single occasion when three counts of the increments were performed. If these differed by more than 5% the otolith was rejected, but if not the mean was accepted as the best estimate of the count.

Dated increments were back calculated from the capture date to estimate the time of spawning for individuals. Increment counts were considered to represent true age of post larval and juvenile golden perch, from analysis of known age larval/post larval otoliths supplied by Narrandera Fisheries Centre, NSW DPI (Zampatti *et al.* unpublished). Egg development and hatching is known to occur within the first 24 hours post-spawning (Brown and Wooden 2007), increment counts of known age larvae/post larvae exceeded the known age at hatch by one increment, which incorporates egg development before hatch. Therefore the number of increments counted is considered to represent the true age of individuals.

Transverse sections of adult golden perch sagittae display a clear incremental pattern of opaque and translucent zones which form annually (Anderson *et al.* 1992; Stuart and Mallen-Cooper 2003). Whole sagittae dissected from juvenile/adult fish were embedded in clear casting resin and a single 400 to 600 μm transverse section, incorporating the primordium, was prepared using a Gemmasta diamond cutting saw. Sections of sagittae were examined using a dissecting microscope (x 25) under transmitted light. Estimates of age were determined by counting the number of complete or clearly discernable opaque zones from the primordium to the otolith edge. Otoliths were interpreted independently by three readers. Discrepancies in otolith age by one or two readers were due in all instances to the inclusion of a marginal increment (opaque zone at the otolith edge) and were adjusted accordingly to reflect the age with reference to the capture date and the estimated birth date. A suitable birth date was assigned by considering the timing of the formation of a new annulus (opaque zone) and the back calculated spawning dates estimated for post larval fish.

The otolith edge was analysed to identify the seasonal timing of increment formation. Prepared transverse sections were used to determine the seasonality (month) of annulus (opaque zone) formation. The edge of each otolith was analysed and the presence of either an opaque or translucent zone was recorded and the change in relative frequency of each edge zone was plotted across months (Campana 2001). Four categories were used to describe the formation of the opaque zone. The otolith edge was described as either being opaque or translucent. Where the edge was described as translucent, the distance between the last completed increment and the outer edge was further described as being thin, medium or wide. Where the otolith was recorded as having an opaque edge it was noted if the marginal increment was included in the estimate of age.

6.3 Results

6.3.1 Hydrology

The maximum known age of golden perch is 26 years (Stuart 2006) hence a 25 year flow record is considered adequate for an investigation of age structure of golden perch populations in the Chowilla region. Over the last 25 years discharge in the Murray River at the South Australian border has varied considerably, maximum flows of > 110,000 ML/d were recorded in the summer of 1993/1994 and minimum flows of < 1,000 ML/d were recorded more recently in the winter of 2007 (Figure 6-1). The three year study investigating the spawning and recruitment of golden perch was conducted during an unprecedented period (since river regulation in the 1930s) of low-flow. Maximum daily discharges during the study period were approximately 8,500 ML/d, 15,000 ML/d and 7,000 ML/d in 2005, 2006 and 2007 respectively.

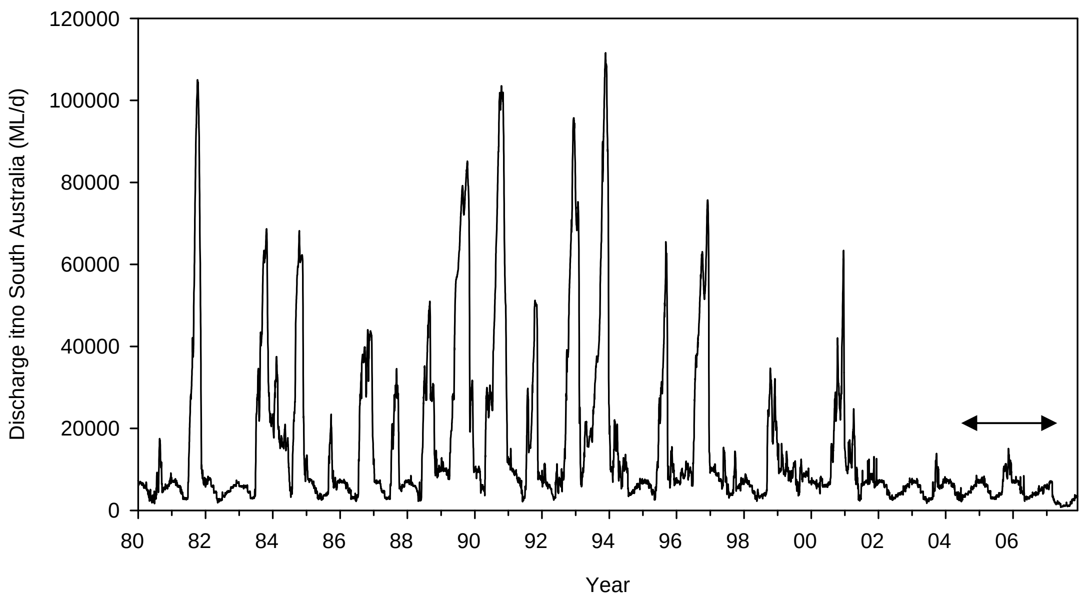


Figure 6-1 Murray River discharge into SA (ML/d) from 1980 to 2007. Black arrow represents study period.

6.3.2 Temporal and spatial variation in occurrence of larvae

No larval or post larval golden perch were collected in the 2004/2005 sampling season, 14 post larval golden perch were sampled in 2005/2006 (between 29th November and the 14th December 2005) and no larvae/post larvae were collected in 2006/2007 (Figure 6-2). Post larval golden perch collected in 2005 had a mean length of 11.2 mm (range 8 - 14 mm) and were collected in both slow-flowing and fast-flowing aquatic mesohabitats. Low numbers of fish were collected from five creeks in the Chowilla system, namely Boat, Chowilla, Hypurna, Salt and Slaney Creeks.

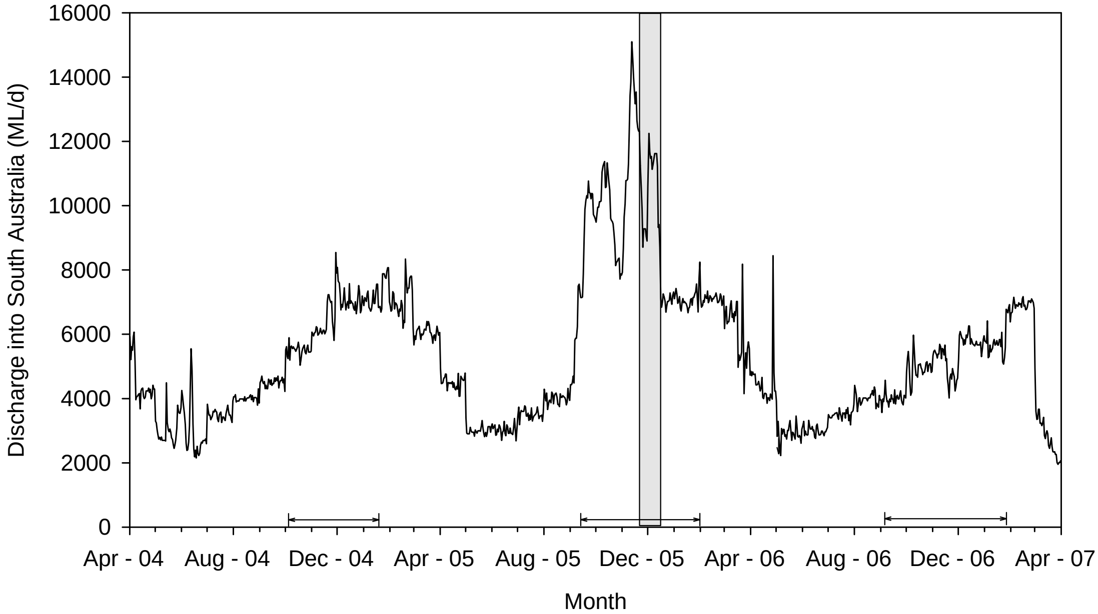


Figure 6-2 Presence of larval golden perch (represented by the grey bar) plotted against Murray River discharge into SA (ML/d) over the period April 2004 – April 2007. Arrows indicate period of larval sampling.

6.3.3 Length frequency structure

The size distribution of juvenile and adult golden perch ranged between 50 and 500 mm TL for samples collected between 2005 and 2007. In 2005 the length frequency was unimodal with fish ranging in length from 240 – 440 mm (Figure 6-3). A bimodal distribution was observed in 2006, with a small mode of fish ranging from 50 – 80 mm and a mode of larger individuals ranging from 240 – 450 mm. A similar bimodal size distribution was evident in 2007 where the size distribution of the first mode progressed from fish ranging in length from 50 - 80 mm in 2006 to 120 – 300 mm in 2007. The second mode progressed slightly from fish ranging in length from 240 – 450 mm in 2006 to 340 – 500 mm in 2007.

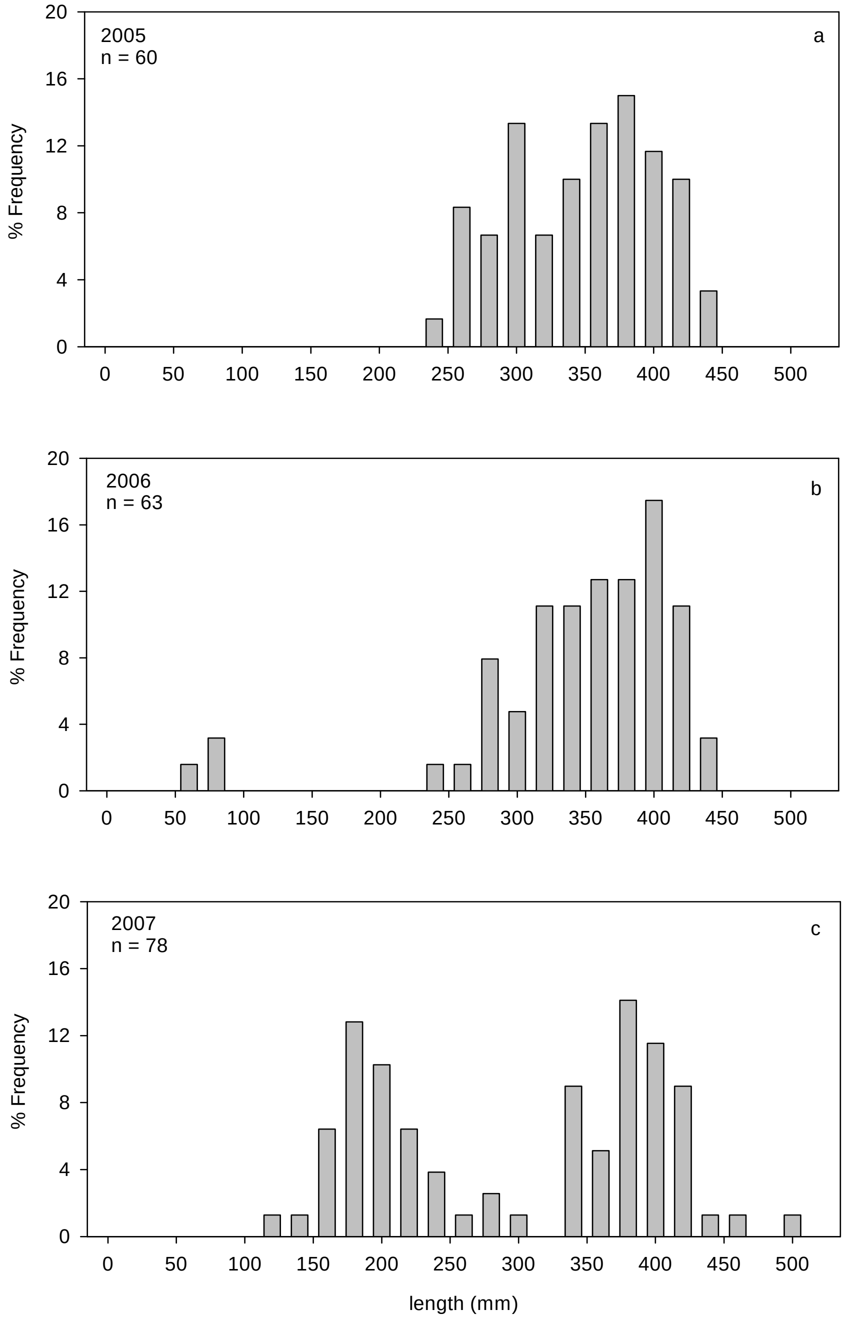


Figure 6-3 Length frequency distribution of golden perch captured from the Chowilla region in March/April (a) 2005, (b) 2006 and (c) 2007.

6.3.4 Age structure

The mean age of post larval fish captured during the 2005/2006 sampling season was 27 days (range 22 – 38 days). Back-calculated ages suggest that these fish were spawned in late October/early November. Spawning at this time coincided with a water temperature of approximately 21 to 23 ºC and a small (5,000 – 15,000 ML/d) but prolonged (~ 3 months) increase in discharge in the Murray River (Figure 6-4).

The age estimates for the three juvenile fish (0+) collected on the 25th January, 26th January and 4th March 2006, were 52, 78 and 147 days respectively. With the exception of the 52 day old fish (spawned early in December) this corresponds to the estimated spawning period (late October/early November) for all post larval fish collected in 2005 (Figure 6-4).

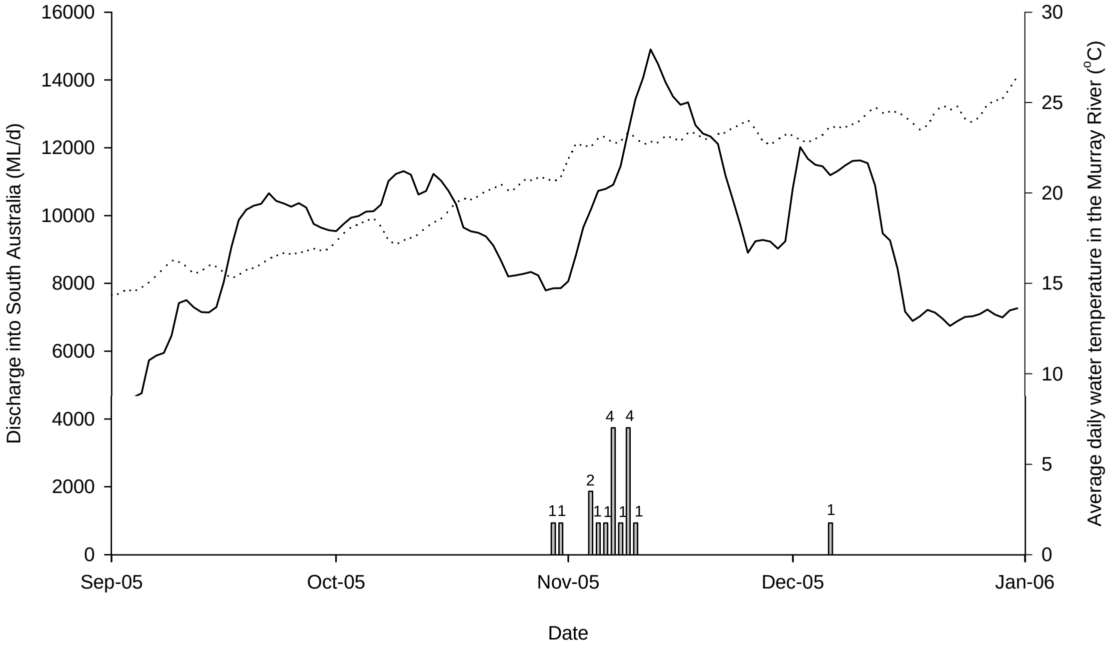


Figure 6-4 Back-calculated spawning dates for post larval and juvenile (0+) golden perch captured in the Chowilla region during the 2005/2006 sampling season plotted against discharge (ML/d) (solid line) and water temperature (°C) (dotted line) in the Murray River. Numbers above bars indicate number of fish back calculated as spawning on that day.

The marginal increments (opaque zone) of adult golden perch otoliths collected between August 2005 and July 2006 displayed an annual sinusoidal cycle when plotted against season. Opaque zones were evident in samples from October – December indicating spring and early summer formation (Figure 6-5). During November and December a high proportion of otolith edges were classified as translucent and thin indicating that the opaque zone had been recently completed. By February all opaque zones had been completely deposited. From February to July 2006 and August to September 2005 all otoliths were classified as having translucent edges. During February to April 2006 thin to mid translucent zones were observed, progressing to mid to wide during May 2006 to September 2005 indicating that the next opaque zone was soon to appear. After considering the timing of the formation of a new annulus (opaque zone) and the back calculated spawning dates of post larval fish we assigned a theoretical birth date of November 1st.

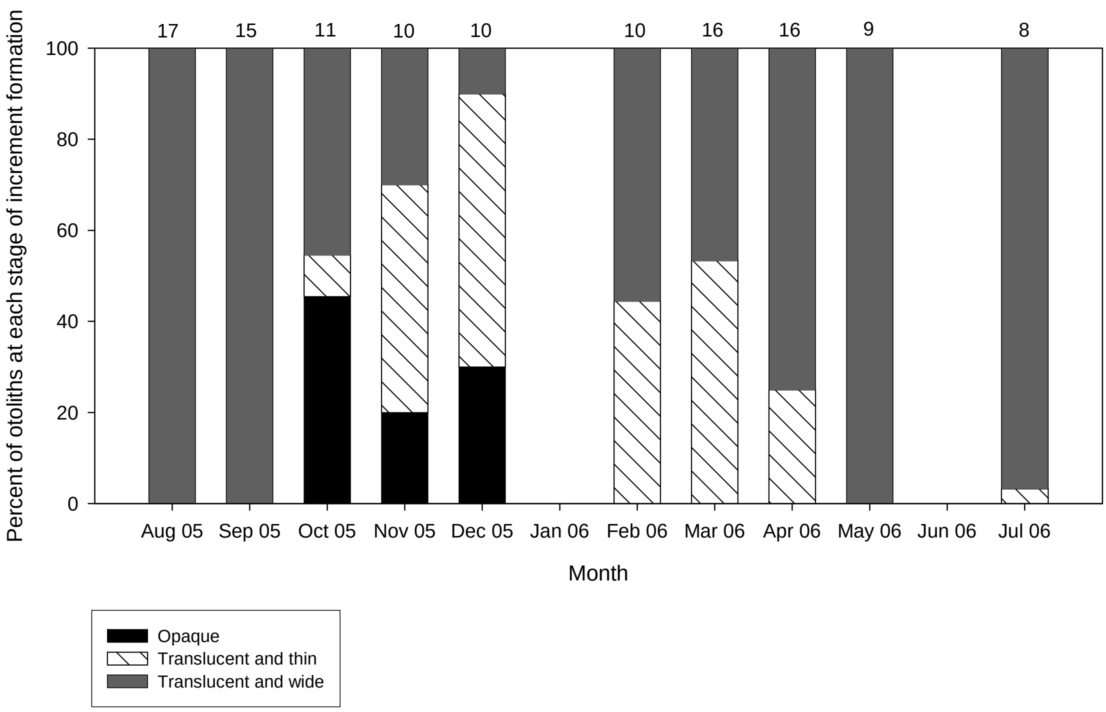


Figure 6-5 Proportion of golden perch otoliths at each marginal increment stage. Otoliths were collected monthly from the Chowilla region from August 2005 to July 2006. Numbers above bars indicate the sample size.

The age frequency data for fish collected in 2005 show three strong age classes, namely, 4, 6 and 8 year olds (Figure 6-6). A clear annual progression is evident in the age structure from 2005 to 2007 where strong age classes remain dominant. The proportion that 6 and 8 year old fish contributed to the age structure declined significantly over the sampling period, whilst the 4 year olds remained relatively stable. In 2007 a new strong age class is also present as 1 year olds, suggesting successful recruitment of fish spawned in 2005.

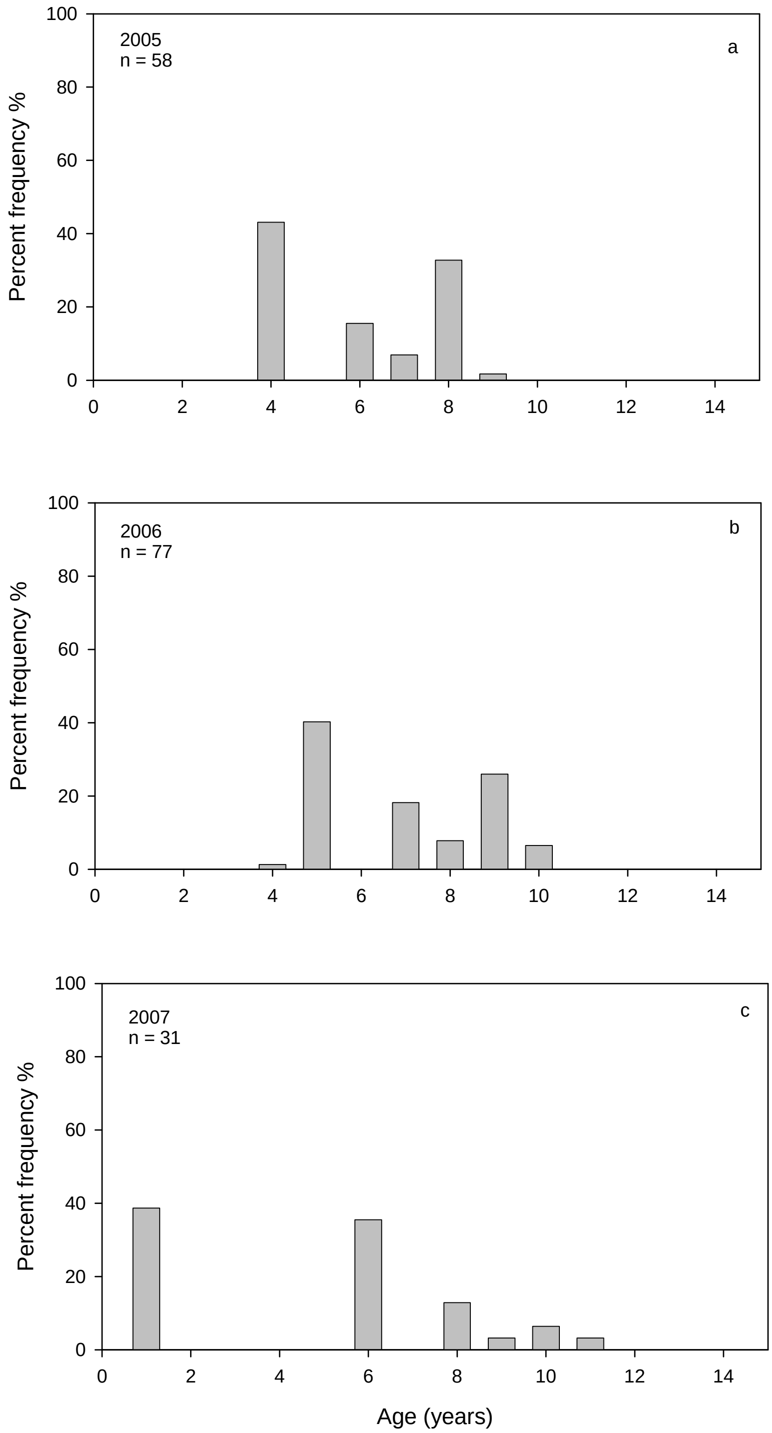


Figure 6-6 Age frequency distribution of golden perch captured within the Chowilla region in (a) 2005, (b) 2006 and (c) 2007.

Backdated spawning dates of fish sampled in 2005 show three strong year classes associated with increased discharge in years 2000 (4 year olds), 1998 (6 year olds) and 1996 (8 year olds) (Figure 6-7). A similar pattern is observed for fish captured in 2006 and 2007 (Figure 6-7), however the contribution of older year classes, particularly 1997 and 1999 becomes less dominant in successive years. The presence of a new strong year class in 2007 indicates successful recruitment to age 1+ for fish spawned during increased flow in spring/summer 2005/2006.

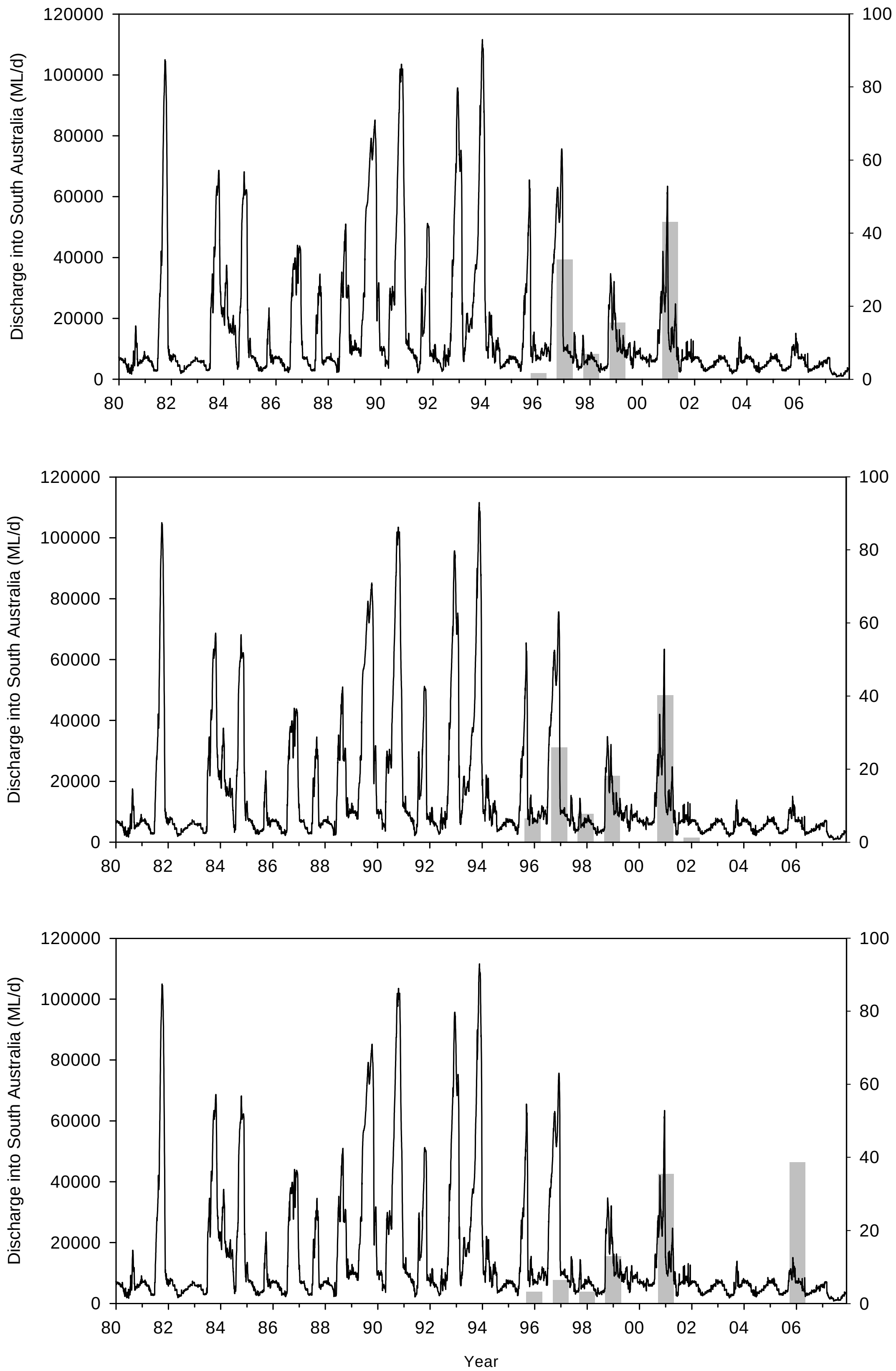


Figure 6-7 Backdated spawning dates shown as the percent frequency each age group contributed to the age structure in (a) 2005, (b) 2006 and (c) 2007 shown with discharge into South Australia (ML/d).

6.4 Discussion

The importance of floodplains and flooding in the life cycle of native fish in the Murray-Darling Basin has received considerable attention in the past decade (Humphries *et al.* 1999; King *et al.* 2003; Mallen-Cooper and Stuart 2003; Graham and Harris 2005; Ebner *et al.* 2009). Nevertheless, regional differences remain unclear, particularly between the hydrologically distinct mid and lower reaches of the Murray River, and multi-scale approaches that investigate spawning and recruitment over long temporal scales are lacking (Harris and Gehrke 1994; Humphries *et al.* 2008). In order to investigate golden perch recruitment ecology in the Chowilla system and lower Murray River we conducted a three year study which incorporated early life history and population age structure data to elucidate patterns in recruitment and river flow. The study period spanned two years of low stable discharge and one year of elevated spring/summer discharge.

Golden perch larvae were only collected during a small but prolonged within-channel rise in discharge in spring/summer 2005. During two years of stable, low discharge (2004 and 2006) no larvae were collected. A low number (n = 6) of YOY golden perch were also collected from January to March 2006 but no YOY fish were collected in 2005 or 2007. The back calculated spawning dates of the YOY fish collected in 2006 corresponded with the spawning period determined for post larval golden perch collected in late November and December 2005. As such these YOY fish had recruited from the spring 2005 spawning event.

It is unclear whether the post larval golden perch collected captured from Chowilla were actually spawned in the region; nevertheless, the age of the larvae at collection and the habitats they were collected in (e.g. large woody debris in the littoral zone) suggest that the Chowilla system is at least a nursery area for juvenile golden perch as proposed by Lloyd (1990) and Pierce (1990). This proposition is further supported by the YOY and 1+ fish that were subsequently collected in the system in 2006 and 2007. Importantly YOY and 1+ golden perch were collected both in Chowilla Creek and the main channel of the Murray River thus supporting the proposition that river channels provide suitable nursery or rearing habitats for juvenile golden perch that are spawned during low or within-channel flows (Mallen-Cooper and Stuart 2003).

Back calculation of spawning dates of post larval and YOY golden perch using daily growth increments in otolith microstructure revealed spawning occurred in late October/early November 2005. During this period discharge was variable; nevertheless, it appears that most of the fish were spawned on the ascending limb of the second flow peak of the September to

December flow event. A few fish, however, appear to have been spawned during a small decrease in discharge between two flow peaks. Water temperatures during this period ranged from 21 – 24°C.

These discharge and water temperature conditions are consistent with those proposed for golden perch spawning by Lake (1967). Furthermore, the spawning event coincided with an early November 2005 spawning event in the Barmah region of the Murray River that also occurred on the second peak of the flow event and at similar water temperatures (King *et al.* 2008). These data support the notion that golden perch is indeed a flow cued spawner, nevertheless, the component of the flow event that triggered spawning remains unclear. Spawning occurred both during a rise and fall in the hydrograph hence variability in the flow peak is likely to be important when recommending flow regimes that stimulate golden perch spawning and benefit native fish in general.

Length frequency data collected from 2005 – 2007 provide some indication of recruitment but offer little accurate information on the actual age structure of the population. Precise age determination is essential to accurately investigate the relationship between recruitment success and environmental variables (Campana 2001). Consequently we used thin-sectioned otoliths to validate the periodicity of annuli formation and determine the subsequent age of individuals. In 2005, the golden perch population in Chowilla and the adjacent Murray River was dominated by three strong year classes (4, 6 and 8 year olds) which would have been spawned in 2000, 1998 and 1996 respectively. In each of these years substantial within-channel or overbank increases in discharge occurred during the spawning period for golden perch (October – December).

The strong year classes observed in 2005 progressed to 5, 7 and 9 year olds in 2006 with no addition of further year classes. In 2007, an additional strong year class of 1 year old fish appeared, following successful spawning and recruitment of golden perch during a small but prolonged within-channel increase in discharge in spring/summer 2005. Overall our data support the proposition of Mallen-Cooper and Stuart (2003) that strong golden perch recruitment is not reliant on flood flows (i.e. over-bank) and that even relatively small within-channel flow events may support significant recruitment. There still exists considerable conjecture on the role of overbank flows in golden perch recruitment (Mallen-Cooper and Stuart 2003; King *et al.* 2008; Ebner *et al.* 2009). Whilst it appears that there is consensus that spawning and recruitment may occur during both within-channel and overbank flows, some investigations suggest spawning intensity and recruitment may be strongest during overbank floods. Nevertheless, investigations of golden perch spawning have yet to be undertaken during a major overbank flow (i.e. > 60,000 ML/d) in the MDB.

Age structure data from the Chowilla system and adjacent Murray River indicate that there have been two successful recruitment events for golden perch in the in the lower Murray River region in the period 2000 – 2007, namely 2000 and 2005. In these years, spawning and recruitment corresponded with maximum discharges of approximately 60,000 and 15,000 ML/d respectively. Recruitment appears negligible in all other years when flows were relatively low and stable. There was one medium sized flow event in 2003 of ~ 15,000 ML/d; however, the duration of this event was relatively short.

Whilst overbank flooding may be important, particularly from a primary productivity perspective (Junk *et al.* 1989) the fact that within-channel flows can support strong recruitment has important implications for flow management in the lower Murray River. Medium sized flow events are the component of the flow regime that has been most significantly altered by river regulation in the lower Murray River (Walker 2006). Furthermore, it is these size events (e.g. 15 – 25,000 ML/d) that could practically be restored within the current constraints of system operation. Importantly, restoration of these within-channel flow events may lead to more frequent golden perch recruitment.

Discharge data for the Murray River at the South Australian border indicate that since 2000 flows of a magnitude potentially suitable for golden perch spawning/recruitment (i.e. > 14,000 ML/d) occurred in two years out of the past eight (Figure 6-8). In comparison, modelled 'unregulated' flow data indicate that under natural conditions they would have occurred in seven out of the past eight years (Figure 6-8). Golden perch is long-lived (> 20 years) and hence adapted to coping with a highly variable environment that may lead to variable recruitment. Roberts *et al.* (2008) observed that golden perch recruitment in coastal rivers in eastern Australia was more variable (i.e. low numbers of dominant year classes) in rivers with higher levels of regulation compared to less regulated rivers. This is also evident in the lower Murray River where episodic recruitment results in only a few strong year classes dominating the population. Modelled 'unregulated' flow data, however, indicate that discharges of the magnitude potentially conducive to spawning and recruitment may have been more frequent in the unregulated Murray River and hence may have resulted in more consistent recruitment.

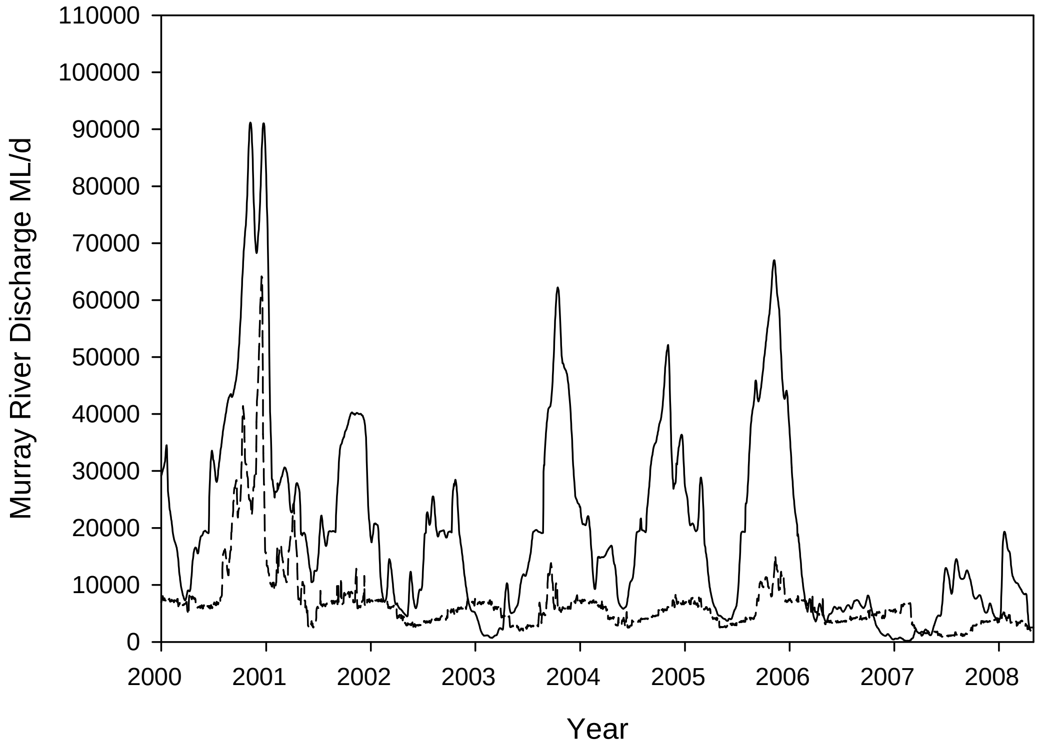


Figure 6-8 Modelled 'unregulated' (solid line) and actual (dashed line) Murray River discharge into South Australia from 2000 – 2008**.**

Age structure data also indicate that the number of older fish in the Chowilla region decreases over time. Golden perch is known to live to 26 years (Stuart 2006); nevertheless, no fish older than 11 years were collected in the Chowilla region or adjacent Murray River during our study period. The fate of these older fish is unknown but potential causes may include fishing pressure or emigration of older fish from the region (see Chapter 8). Selective removal or emigration of large old individuals may ultimately contribute to serious population depletion for species with variable recruitment (Longhurst 2002).

This study is the first documented account of golden perch spawning and subsequent recruitment of fish, to at least the 1+ age class, in the lower Murray River. Importantly it incorporates early life history data with age structure data on the adult fish population to elucidate patterns in recruitment and river flow. These data provide an important ecological basis for flow restoration in the MDB.

7 Impacts of Slaney and Pipeclay Weirs on Downstream Fish Assemblages

Pipeclay Creek Weir regulates flow from the Lock 6 weir pool into Pipeclay and Chowilla Creek.

7.1 Introduction

Movement of freshwater fish is an adaptive strategy to optimise feeding, avoid unfavourable conditions, maximise spawning success and enhance colonisation (Northcote 1978). In the Murray-Darling Basin (MDB), unrestricted movement is a critical component in the life history of all freshwater fish species (Mallen-Cooper 1996; Koehn and Nicol 1998; Harris 2001) and a major objective for the restoration of native fish populations as a part of the Murray-Darling Basin Commission's (MDBC) Native Fish Strategy (MDBC 2003).

The 33 species of freshwater fish that inhabit the rivers of the MDB all migrate to some extent. Movements for spawning, recolonisation and habitat selection range from longitudinal migrations of hundreds of kilometres to small-scale lateral movements onto the floodplain (Reynolds 1983; Koehn and O'Connor 1990; Nichols and Gilligan 2004). Barriers to such movements have been implicated in declining fish populations through restricting access to spawning grounds and preferred habitats, preventing dispersal and recolonisation, and disrupting the lateral and longitudinal connectivity of river systems (Cadwallader 1978; Mallen-Cooper 1996; Gehrke *et al.* 1995).

As a component of a multifaceted program to restore native fish populations in the MDB, the MDBC is restoring fish passage along the Murray River from the sea to Hume Dam, a distance of 2,225 km (Barrett and Mallen-Cooper 2006). The program aims to facilitate fish passage for the whole fish community (target size range, 40 – 1000 mm) on 15 weirs and barrages along the main channel of the river. Whilst the main channel of the Murray River is likely to be a primary conduit for the migration of freshwater fish, under low flows a large proportion of Murray River flow actually bypasses Lock 6 and flows through Chowilla. Under this scenario, fish movement through the Chowilla system may be substantial and, as Slaney and Pipeclay Creeks constitute the major regulated inflows to Chowilla Creek, these weirs may present major barriers to the upstream migration of native fish.

Based on the recommendations of a preliminary barrier prioritisation project (Zampatti and Leigh 2005) we investigated the potential impact of Slaney and Pipeclay weirs on fish community composition and relative abundance immediately downstream of each barrier (i.e. within 1 km) and at two control sites. We also investigated fish community composition and relative fish abundance downstream of Lock 6 on the Murray River.

7.2 Methods

Lock and Weir No. 6 on the Murray River was constructed from 1927 – 1930. During the same period weirs were also constructed on Pipeclay and Slaney Creek to assist with the maintenance of the weir pool at Lock 6. All structures are of an overshot stop-log design with head differentials ≥ 2.5 m (see photo above, Pipeclay Creek Weir).

Sites were sampled immediately downstream (within 1 km) of Slaney Weir, Pipeclay Weir and Lock 6 and a corresponding control site was located at least 4 km downstream of each weir (Table 7-1 and Figure 7-1). We propose that the control sites were far enough downstream so that fish movement would not be impeded by the regulating structures (i.e. cause an accumulation of fish). Due to the short length of Pipeclay Creek the control site for Pipeclay Weir was located in Chowilla Creek downstream of the Pipeclay confluence (Figure 7-1). Control sites were selected to have similar stream morphology, hydrology and habitat (e.g. large woody debris loads) to their corresponding weir site.

Table 7-1 Location of sites sampled downstream of weirs and corresponding control sites.

Site Number	Waterway	Location
1	Slaney Creek	Immediately downstream Slaney Weir
2	Slaney Creek	Upstream of Slaney/Chowilla Junction
3	Pipeclay Creek	Immediately downstream Pipeclay Weir
4	Chowilla Creek	Immediately upstream of Boat Creek
5	Murray River	Immediately downstream of Lock 6
6	Murray River	10 km downstream of Lock 6

Sampling was conducted monthly from October – December 2004 and in March 2005. Fish were sampled using a boat mounted 5kW Smith Root Model GPP electrofishing system. Electrofishing incorporated 12 (6 on each bank) x 90 second (power on time) electrofishing shots during daylight hours. All fish were dip netted and placed in a recirculating well. Fish from each shot were identified and a sub sample of 20 individuals was measured for length (caudal fork or total length, mm). Any positively identified fish unable to be dip netted were recorded as "observed".

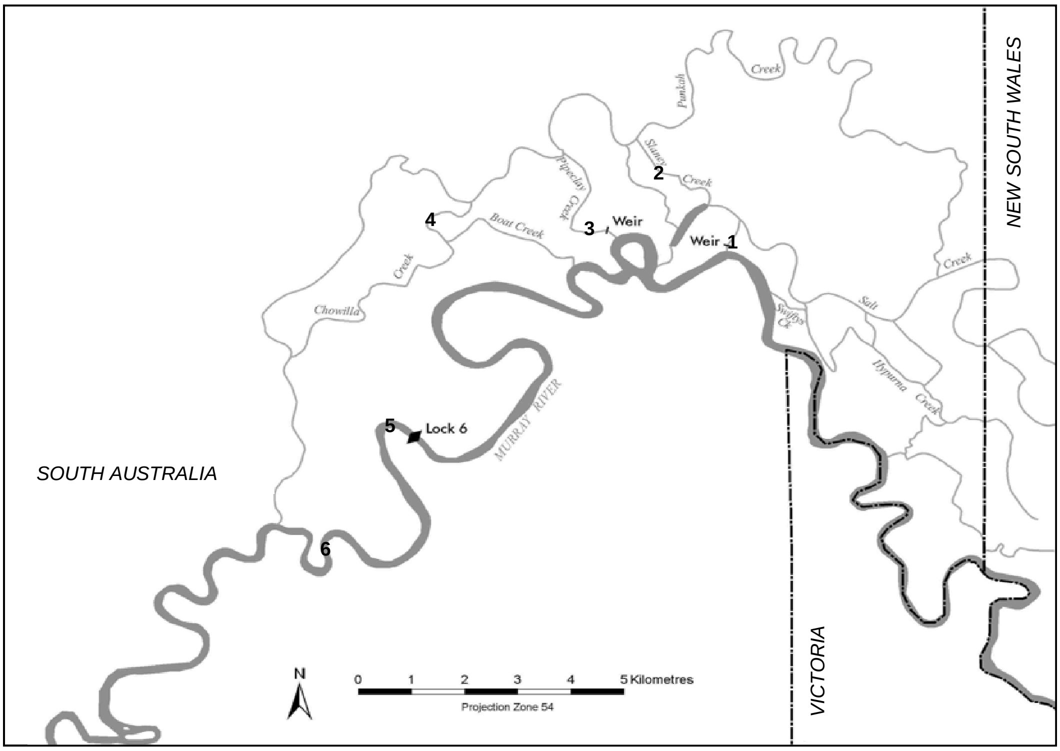


Figure 7-1 Map of the sites sampled downstream of weirs and the corresponding control sites.

Two-factor non-parametric multivariate analysis of variance (PERMANOVA) (site, month and site x month) (Anderson, 2001) was used to compare the relative abundance of species between weir and control sites and between months (October, November, December and March). A posteriori multiple comparisons tests were performed and the alpha level was adjusted using a Bonferroni correction (Zar 1984). Indicator species analysis (Dufrene and Legendre 1997) was used to identify those species that were significant indicators of weir or control sites by combining information on the relative abundance of species at each site with the faithfulness of occurrence of a species at that site (McCune *et al.* 2002). Indicator species analysis was performed using PCOrd version 5.12 using a Monte Carlo technique with 5,000 randomisations.

Bray-Curtis distances were used to calculate the similarity matrix for all multivariate analyses (Bray and Curtis 1957) and two-dimensional ordination solutions with stress lower than 20% were deemed acceptable. Replicates for each site were pooled for the ordinations for clarity, however PERMANOVA and indicator species analysis were performed on unpooled data. Individual analyses were undertaken for Slaney Creek, Pipeclay Creek and the Murray River.

7.3 Results

7.3.1 General

A total of 10,818 fish from 13 species were sampled from all sites (Table 7-2). The small to medium-bodied native fish unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*) (32.3% of total catch), bony herring (*Nematalosa erebi*) (20.0%) and Australian smelt (*Retropinna semoni*) (19.9%) were sampled in the greatest relative abundance (Table 7-2). Large-bodied fish such as golden perch (*Macquaria ambigua ambigua*) (3.0%), Murray cod (*Maccullocheela peelii*) (0.4%) and common carp (*Cyprinus carpio*) (4.1%) were sampled in lower relative abundances (Table 7-2). Most species were sampled at all sites with the exception of silver perch (*Bidyanus bidyanus*) which was sampled in low numbers from the Slaney Weir site (Site 1) and Murray River control site (Site 6) and dwarf flat-headed gudgeon (*Phylipnodon macrostomus*) which was only collected from the Murray River control site (Site 6).

Table 7-2 Summary of total fish catches from weir and control sites sampled in October (O), November (N) and December (D) 2004, and March (M) 2005. Site 6 was not sampled in October 2004.

	Abundance																								
	Site 1 (weir)				**Site 2 (cont)**				**Site 3 (weir)**				**Site 4 (Cont)**				**Site 5 (weir)**				**Site 6 (Cont)**				**Total number**
Species	**O**	**N**	**D**	**M**	**O**	**N**	**D**	**M**	**O**	**N**	**D**	**M**	**O**	**N**	**D**	**M**	**O**	**N**	**D**	**M**	**O**	**N**	**D**	**M**	
Murray cod	4	6	-	2	3	1	2	2	-	1	1	-	2	6	8	2	-	-	-	-		-	-	-	**40**
Golden perch	29	16	22	9	19	20	3	9	29	27	13	6	27	19	14	7	18	10	5	4		15	6	2	**329**
Silver perch	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1	-	2	**6**
Bony herring	41	59	66	433	5	17	13	89	160	53	35	217	92	110	19	75	9	30	27	325		131	38	124	**2168**
Australian smelt	89	134	377	50	146	92	25	33	216	253	282	20	87	38	16	9	74	7	15	15		112	20	48	**2158**
Murray rainbowfish	18	46	111	27	23	25	21	22	15	25	37	10	21	27	20	16	36	113	32	83		105	46	124	**1003**
Unspecked hardyhead	9	131	32	46	16	15	9	16	214	449	144	259	7	9	23	8	334	279	124	712		210	43	413	**3502**
Carp gudgeon	26	11	51	14	4	4	9	6	11	87	54	19	15	8	37	5	102	20	35	23		28	11	24	**604**
Flat-headed gudgeon	20	41	71	4	9	12	8	3	3	50	10	2	9	14	4	1	60	28	23	12		46	1	10	**441**
Dwarf flat-headed gudgeon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	1	**1**
Common carp	23	22	11	7	32	17	13	9	28	22	24	8	31	25	21	10	16	24	26	16		35	21	6	**447**
Goldfish	8	3	3	1	1	2	1	1	6	3	3	7	4	-	6	1	-	3	2	1		12	2	7	**77**
Gambusia	-	-	2	1	1	-	8	2	-	2	1	8	-	-	-	3	-	1	1	6		-	3	3	**42**
Total fish/sampling occasion	**267**	**471**	**747**	**594**	**259**	**205**	**112**	**192**	**682**	**972**	**604**	**556**	**295**	**256**	**168**	**137**	**649**	**515**	**290**	**1197**		**695**	**191**	**764**	**10818**

7.3.2 Slaney Creek

Fish communities in Slaney Creek differed significantly between the weir and control site and between months (Table 7-3). There was also a significant interaction between site and month (Table 7-3). Fish assemblages differed significantly between the weir and control site in all months sampled (Table 7-4).

Table 7-3 Results of a two-way crossed PERMANOVA comparing relative abundances of fish at the weir and control site in Slaney Creek over four separate months in 2004/2005.

Factor	*df*	*F*	*P*
Site	1, 95	5.7121	0.0002
Month	3, 95	6.7046	0.0002
Site x Month	3, 95	3.383	0.0002

Table 7-4 Pair-wise *a posteriori* comparisons of fish assemblages between the Slaney Creek Weir site and Slaney Creek Control site. Significant results ($P < 0.0125$, Bonferroni adjusted alpha) signify differences in fish assemblages between the two sites.

	Slaney Weir vs Control site	
Month	***t***	***P***
October	1.8926	0.003
November	1.7593	0.0058
December	2.0255	0.0010
March	2.2278	0.0018

Indicator species analysis suggests that significant differences between weir and control sites were always due to higher abundances of fish at the weir sites, specifically bony herring and carp gudgeons in October, unspecked hardyhead and flat-headed gudgeon in November, Murray rainbowfish, bony herring, carp gudgeon, flat-headed gudgeon, golden perch and Australian smelt in December, and bony herring in March (Table 7-5).

Table 7-5 Summary of indicator species analyses showing species that were significantly more abundant at either the Slaney Creek weir or Control (Cont) site in four different months of 2004/2005. A significant difference ($P < 0.05$) indicates that a species occurs in a higher relative abundance at a site and hence is contributing to differences between the fish assemblages of the two sites. Values that are not significant indicate that a species was either sampled in low numbers (uncommon) or was sampled consistently across both sites (widespread).

	Slaney Creek October		**Slaney Creek November**		**Slaney Creek December**		**Slaney Creek March**	
Species	**Site**	**P**	**Site**	**P**	**Site**	**P**	**Site**	**P**
Unspecked hardyhead	Cont	0.367(w)	Weir	**0.01**	Weir	0.136(w)	Weir	0.08(w)
Murray rainbowfish	Cont	0.278(w)	Weir	0.13(w)	Weir	**0.014**	Weir	0.52(w)
Gambusia	Cont	1(u)	Cont	1(u)	Cont	0.141(u)	Cont	0.744(u)
Bony herring	Weir	**0.003**	Weir	0.063(w)	Weir	**0.008**	Weir	**0.0004**
Goldfish	Weir	0.147(u)	Weir	0.795(u)	Weir	0.731(u)	Cont	1(u)
Common carp	Cont	0.891(w)	Weir	0.999(w)	Cont	0.738(w)	Weir	0.211(w)
Carp gudgeon	Weir	**0.001**	Weir	0.068(w)	Weir	**0.013**	Weir	0.342(w)
Flat-headed gudgeon	Weir	0.106(w)	Weir	**0.003**	Weir	**0.0004**	Weir	0.786(u)
Murray cod	Weir	0.775(u)	Weir	0.125(u)	Cont	0.471(u)	Cont	1(u)
Golden perch	Weir	0.145(w)	Cont	0.31(w)	Weir	**0.0002**	Cont	0.558(w)
Silver perch	-	-	Weir	0.494(u)	Weir	1(r)	-	-
Australian smelt	Cont	0.359(w)	Weir	0.447(w)	Weir	**0.001**	weir	0.514(w)

7.3.3 Pipeclay Creek

Fish communities in Pipeclay Creek differed significantly between the weir and the control site and between months (Table 7-6). There was also a significant interaction between site and month (Table 7-6). Fish assemblages differed significantly between the weir and control sites in all months except December (Table 7-7).

Table 7-6 Results of a two-way crossed NP-MANOVA (Non-parametric Multivariate Analysis of Variance) comparing relative abundance of fish at two sites in Pipeclay Creek over four separate months in 2004/2005.

Factor	*df*	*F*	*P*
Site	1, 95	17.9972	0.0002
Month	3, 95	5.1598	0.0002
Site x Month	3, 95	2.2558	0.0016

Table 7-7 Pair-wise *a posteriori* comparisons of fish assemblages between the Pipeclay Creek Weir site and Pipeclay Creek Control site. Significant results ($P < 0.0125$, Bonferroni adjusted alpha) signify differences in fish assemblages between the two sites.

Pipeclay Creek Weir vs Control Site		
Month	***t***	***P***
October	2.1082	0.0004
November	3.3160	0.0002
December	1.5692	0.0258
March	2.8944	0.0002

Indicator species analysis suggests that significant differences between weir and control sites were primarily due to higher abundances of fish at the weir sites, specifically, unspecked hardyhead in October, unspecked hardyhead and Australian smelt in November, Australian smelt in December, and unspecked hardyhead, bony herring and carp gudgeons in March (Table 7-8).

Table 7-8 Summary of indicator species analyses depicting which species were significantly more abundant at either the Pipeclay Creek Weir or Control (Cont) site in four different months in 2004/2005. A significant difference ($P < 0.05$) indicates that a species occurs in a higher relative abundance at a site and hence is contributing to differences between the fish assemblages of the two sites. Values that are not significant indicate that a species was either sampled in low numbers (uncommon) or was sampled consistently across both sites (widespread).

	Pipeclay Creek October		**Pipeclay Creek November**		**Pipeclay Creek December**		**Pipeclay Creek March**	
Species	**Site**	**P**	**Site**	**P**	**Site**	**P**	**Site**	**P**
Unspecked hardyhead	Weir	**0.0004**	Weir	**0.0002**	Weir	0.14(w)	Weir	**0.0002**
Murray rainbow fish	Cont	0.692(w)	Weir	0.817(w)	Weir	0.543(w)	Cont	0.454(w)
Gambusia	-	-	Weir	1(u)	-	-	Weir	0.2(u)
Bony herring	Cont	0.568(w)	Cont	**0.011**	Weir	0.079(w)	Weir	**0.032**
Goldfish	Weir	0.297(u)	Weir	0.219(u)	Cont	0.522(u)	Weir	0.212(u)
Common carp	Cont	0.36(w)	Cont	0.24(w)	Cont	0.976(w)	Cont	0.95(w)
Carp gudgeon	Cont	0.881(w)	Weir	0.11(w)	Weir	0.128(w)	Weir	**0.039**
Flat-headed gudgeon	Cont	0.361(u)	Weir	0.092(w)	Weir	0.068(w)	Weir	1(r)
Murray cod	Cont	1(u)	Cont	0.064(u)	Cont	**0.024**	Cont	0.471(u)
Golden perch	Weir	0.975(w)	Weir	0.259(w)	Weir	0.685(w)	Cont	0.605(w)
Australian smelt	Weir	0.208(w)	Weir	**0.005**	Weir	**0.007**	Weir	0.259(w)

7.3.4 Murray River

Fish assemblages in the Murray River differed significantly between sites and months; nevertheless, there was no significant interaction between sites and months (Table 7-9). Furthermore, *a posteriori* comparisons indicate there was no significant difference in fish assemblages between weir and control sites in any month sampled (Table 7-10).

Table 7-9 Results of a two-way crossed NP-MANOVA (Non-parametric Multivariate Analysis of Variance) obtained from comparisons of relative abundance of fish at two sites in the Murray River over three separate months in 2004/2005. October is excluded as the control site was not sampled in this month.

Factor	*df*	*F*	*P*
Site	1, 71	2.4341	0.0162
Month	2, 71	12.0712	0.0002
Site x Month	2, 71	1.6354	0.0548

Table 7-10 Pair-wise *a posteriori* comparisons of fish assemblages between the Murray River weir site and Murray River control site. Significant results (P < 0.0167, Bonferroni adjusted alpha) signify differences in fish assemblages between the two sites. The control site was not sampled in October consequently comparisons with the weir site cannot be made for this month.

Murray River Weir vs Control site		
Month	***t***	***P***
October	-	-
November	1.3389	0.0856
December	1.3241	0.0686
March	1.4977	0.0760

7.4 Discussion

This study has identified that Slaney and Pipeclay Creek are characterised by diverse fish communities (13 species), including two threatened species, namely Murray cod and silver perch. Significantly higher relative abundances of unspecked hardyhead, bony herring, carp gudgeons, flat-headed gudgeon, golden perch, Australian smelt and Murray rainbowfish were collected downstream of the weirs than at reference sites during the period late spring – autumn 2004/2005. This suggests that these species are accumulating below the weirs and that the weirs may affect the upstream migration of a range of small and large-bodied fish species in Slaney and Pipeclay creek.

Bony herring, Australian smelt and golden perch have all previously been recorded accumulating below weirs and moving through fishways in the MDB and eastern Australian coastal catchments, and are generally accepted as migratory freshwater fish species (Thorncraft and Harris 1996; Mallen-Cooper 1996; Baumgartner 2004; Mallen-Cooper and Brand 2007). The timing of accumulation of Australian smelt and bony herring in Slaney and Pipeclay creeks concurs with that observed by Baumgartner (2004) downstream of Balranald Weir on the Murrumbidgee River and Mallen-Cooper (1996) at Torrumbarry Weir on the Murray River. Like these authors we observed an accumulation of adult bony herring in late spring/early summer followed by an accumulation of YOY bony herring in early autumn.

Only recently has it been recognised that small-bodied species such as Murray rainbowfish, carp gudgeons, flat-headed gudgeon and unspecked hardyhead may undertake larger scale migrations rather than just localised movements (Baumgartner 2004; Stuart *et al.* 2008). Data collected below Slaney and Pipeclay weirs indicate that all the small-bodied species mentioned above are accumulating downstream of the weirs, particularly during late spring and summer. Consequently, fish passage options for the weirs will need to consider the swimming abilities of these species.

Throughout the study period low numbers of Murray cod (n = 1 – 8 fish/month) were collected at both the weir and reference sites in Slaney and Pipeclay Creeks. No Murray cod, however, were collected in the Murray River. In the mid-reaches of the Murray River, Murray cod have been shown to undertake seasonal spawning migrations between main channel and tributary habitats (Koehn *et al.* 2009). Given the abundance of potential spawning habitats (i.e. large wood) in some regions of the Chowilla system (e.g. Slaney Creek) it is likely that Murray cod may undertake movements between the main channel of the Murray River and creeks in the anabranch system. To facilitate the movement of Murray cod between main channel and off-channel mesohabitats, fish passage at Slaney and Pipeclay weirs will need to cater for the passage of large Murray cod up to at least 1000 mm in length.

Silver perch was also only sampled in low numbers with 3 fish collected in both Slaney Creek and in the Murray River. The ecology of silver perch in the lower Murray River remains unstudied yet significant decreases in abundance have been documented since the construction of weirs and regulation of flows in the Murray (Mallen-Cooper and Brand 2007). The current study was undertaken during a period of low, stable flows when silver perch migration may be minimal. Nevertheless, during rises in flow (including within-channel flows), juvenile and adult silver perch have been shown to comprise a large proportion of the migratory fish population in fishways on the Murray River (Mallen-Cooper and Brand 2007).

In the MDB, instream barriers cause downstream accumulations of fish, delay migration, increase predation, competition and disease, and reduce the upstream range of migratory species (Harris 1984; Mallen-Cooper 1996; Stuart and Mallen Cooper 1999; Gehrke *et al.* 2002; Baumgartner 2007; Baumgartner *et al.* 2008). The results from the current investigation of spatio-temporal variation in fish assemblages downstream of Slaney and Pipeclay weirs support the recommendation of Zampatti and Leigh (2005) that these structures should be ranked as high priority in the Chowilla system for the restoration of fish passage. Given the diversity and abundance of fish in Slaney and Pipeclay Creeks restoration of fish passage at Slaney and Pipeclay weirs will need to consider the whole fish community and will require fishways of similar or better functionality to those being constructed on the locks and weirs of the Murray River (Stuart *et al.* 2008). The construction of low velocity and low turbulence vertical-slot fishways (Barrett and Mallen-Cooper 2006), or similar, at these sites should have a measurable effect on mitigating accumulations of fish downstream of the weirs.

8 Golden Perch Movement in Chowilla and the lower Murray River

A golden perch tagged with a radio transmitter (trailing wire antenna near anal fin) and a coloured external dart tag (near dorsal fin).

8.1 Introduction

Conservation of migratory fish and the mitigation of barriers to fish passage need to be based on a thorough understanding of fish life history and movement patterns (Gatz and Adams 1994; Albanese *et al.* 2004). The 33 species of freshwater fish that inhabit the rivers of the MDB all move to some extent. Movements for spawning, recolonisation and habitat selection range from longitudinal migrations of hundreds of kilometres to small-scale lateral movements onto the floodplain (Reynolds 1983; Koehn and O'Connor 1990; Nichols and Gilligan 2004). Barriers to such movements have been implicated in declining fish populations through restricting access to spawning grounds and preferred habitats, preventing dispersal and recolonisation, and disrupting lateral and longitudinal connectivity (Cadwallader 1978; Mallen-Cooper 1996; Gehrke *et al.* 1995).

Golden perch (*Macquaria ambigua ambigua*) is a large-bodied (up to 76 cm total length, [TL]) potamodromous fish (i.e. migrates wholly within freshwater) that is wide spread in the MDB, with subspecies also occurring in the Lake Eyre Basin and the Dawson and Fitzroy Rivers in Queensland (Allen *et al.* 2002). Golden perch is an iconic fish in the MDB; it is a major target species for recreational anglers and formed the primary component of a commercial fishery in the Murray River until 2002, when commercial fishing ceased in the Murray River upstream of Wellington, South Australia (Ye 2004). Golden perch has undergone reductions in range and abundance in the MDB (Cadwallader 1978; Walker 1979; Brumley 1987). These declines have been primarily attributed to the construction of dams and weirs altering flow regimes and creating barriers to movement (Cadwallader 1978; Gehrke *et al.* 1995; Mallen-Cooper 1996; McDowall 1996).

Golden perch exhibit a range of migration patterns from strong home range fidelity (Crook 2004) to large-scale (100s – 1000s km) movements upstream and downstream (Reynolds 1983; O'Connor *et al.* 2005). In general, long-distance movements in spring and early summer, both in an upstream and downstream direction, have been associated with spawning, but spawning locations and evidence of spawning are yet to be detected. In a tag and recapture study undertaken in the lower Murray River, golden perch were recorded travelling > 1000 km in an upstream direction and > 450 km downstream (Reynolds 1983). Reynolds (1983) proposed that long-distance upstream migrations were a spawning movement being undertaken by mature golden perch to ensure that pelagic eggs would not drift into saline water and die. Large numbers of reproductively mature and juvenile (age 1+) golden perch have also been recorded moving upstream through fishways in the lower and mid-Murray (Mallen-Cooper 1996; Stuart *et al.* 2008).

Biotelemetry techniques have been used to investigate the movement of golden perch in the main channel and tributaries of the mid reaches of the Murray River (Crook 2004a and b; O'Connor *et al.* 2005; O'Connor *et al.* 2006). O'Connor (2005) utilised radio telemetry to investigate the movement of adult golden perch in a relatively unobstructed 500 km lotic reach of the mid Murray River. Fish were observed to move both downstream and upstream during a rising spring flow to distinct reaches of the Murray River before making return homing movements. These movements were considered to be associated with reproduction (O'Connor *et al.* 2005).

In contrast to the large-scale movements observed in the Murray River, radio-tagged golden perch in a constrained reach of a tributary in the mid reaches of the Murray River exhibited restricted movement, strong site fidelity and established home ranges predominantly in pool habitats (Crook 2004a and b). This study, however, was undertaken over a short timeframe (four months) during a non spawning period in a geomorphically constrained section of river.

The Chowilla system provides important and unique lotic habitats (at least in South Australia) for fish such as golden perch, and it has been proposed as an important region for spawning (Pierce 1990; Lloyd 1990). The Chowilla system, however, is also constrained by a number of weirs that influence stream hydrology and hydraulics, and may impede fish movement. An improved understanding of the movement and habitat use of golden perch in the Chowilla system and lower Murray River is required to identify meso and macrohabitats that may be important for conservation, identify significant barriers to fish migration and determine the spatio-temporal response of golden perch to flow alteration. Such information would also enable a comparison of golden perch ecology in the lower Murray River with the hydrologically distinct mid reaches of the Murray River.

In 2004/2005, data collected using standardised quantified electrofishing showed that a significantly higher abundance of golden perch was collected immediately downstream of Slaney Weir during December in comparison to a control site (Chapter 7). These data suggest that golden perch, which are known to undertake extensive migrations during spring and early summer (O'Connor *et al.* 2005), may have been accumulating downstream of Slaney Weir. Nevertheless, abundance data does not provide temporal and spatial data on the actual movement of fish.

From 2005 – 2007 we further investigated the movement of golden perch in the Chowilla system using radio telemetry techniques. This investigation was designed to provide data on the aquatic macrohabitats used by golden perch, timing of movement, and response to environmental variables such as flow and water temperature. This investigation will aid in the mitigation of barriers to fish passage in the Chowilla system and provide important data on the ecology of golden perch in the lower Murray River.

8.2 Methods

8.2.1 Transmitters

Radio transmitters were cylindrical 150 MHz, internal radio transmitters with 30 cm (0.7 mm diameter) trailing antenna (Advanced Telemetry Systems (ATS), Insanti, MN, USA). Two sizes of transmitter were used; models F1840 and F1845, weighing 14 and 21 g respectively in air and having a warranted battery life of 260 and 300 days respectively. The functional life of the transmitter batteries was maximised by incorporating a duty cycle of 5 periods on and 7 periods off. Transmitters were also fitted with a mortality circuit that activated if the fish (transmitter) did not move for a period of 8 hours.

8.2.2 Fish capture and transmitter implantation

A total of 52 golden perch [395 ± 29 mm TL, 874 ± 219 g (mean± S.D.), 6.4:1 (male:female)] were captured in August 2005 and May/July 2006 using a Smith-Root® 7.5 KVA boat mounted electrofishing unit. Fish were collected from the lower reaches of Chowilla Creek between the Murray River confluence and Pipeclay Creek, a distance of ~ 12 km (Figure 8-1). In order to not compromise fish buoyancy fish selected for transmitter implantation were of a large enough size to ensure that transmitter weight was ≤ 2% of body weight.

Prior to transmitter implantation golden perch were anesthetised using 0.75 ml of Alfaxin per 10L of river water. The length (L_T, mm) and weight (g) of the fish was measured and the fish was inverted onto a v-shaped cradle. The gills of the fish were irrigated continuously throughout the surgery with a 50% dilute solution of Alfaxin and river water. A 2 – 3 cm incision was made through the ventral wall slightly dorsally of the midventral line beginning adjacent the pelvic fin and extending towards the anus. The sex of the fish was determined and the transmitter inserted into the abdominal cavity.

A shielded needle technique (Adams *et al.* 1998) or a plastic catheter was used to guide the trailing antenna through the lateral body wall posterior to the incision. The incision was closed with two internal and three external sutures. The fish was then injected in the dorsal musculature with a long-term (2 weeks) antibiotic (Baytril) at a dose of 0.1 ml/kg. To enable external visual identification fish were dart tagged between the dorsal spines and inserted with a passive integrated transponder (PIT) tag in the dorsal musculature. PIT tagging enabled radio-tagged fish to be detected by PIT tag readers on fishways on the Murray River (Barrett and Mallen-Cooper 2006; Stuart *et al.* 2008). Following recovery in aerated river water fish were released at their capture location.

8.2.3 Monitoring

Golden perch were manually tracked by boat once every 2 – 4 weeks using an ATS radio receiver/logger (model No. RC4500C). Signals could be detected from approximately 400 m and the position each fish, as determined by the point of greatest signal strength, was recorded by GPS. Trials with hidden transmitters indicated that using this technique, transmitters could be located consistently to within an area of 3 m^2.

Five fixed logging stations (ATS radio receiver/loggers model No. RC4500C) were located on major tributaries of Chowilla Creek and at the junction of Chowilla Creek and the Murray River (Figure 8-1). Three Yagi antennae were positioned on each logging station; one upstream, one downstream and one in the direction of the tributary. The presence of fish in the vicinity of any of the antenna was recorded automatically as a frequency, antenna number, time and signal strength, thus enabling the direction of movement of fish to be established.

Fish moving upstream in the Murray River were detected by interrogating PIT tag reader records from fishways at Lock 7 – 10.

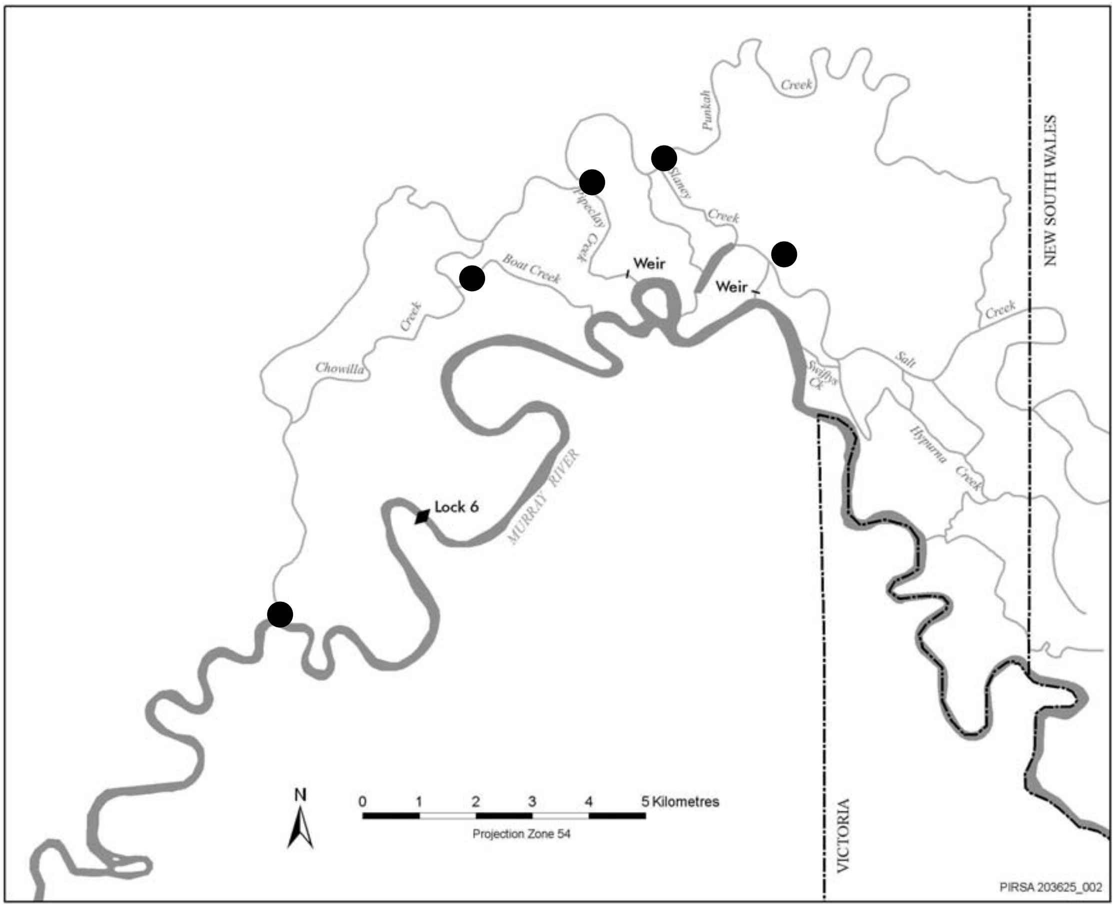


Figure 8-1 Map of the study area showing the location of fixed radio transmitter logging stations (closed circles) in the Chowilla system.

8.3 Results

8.3.1 General movement patterns

This study was undertaken over a two year period from August 2005 to August 2007. Data were collected for all 52 fish tagged with radio transmitters, over periods ranging from 153 – 680 days (Table 8-1). Golden perch movement could be categorised into three broad categories based on the total linear range (km) and macrohabitats utilised during the study period:

1. Strong home range fidelity (total linear range 0 – 2 km)
2. Small – medium-scale movements within the Chowilla Anabranch system and adjacent Murray River (total linear range 2 – 20 km)
3. Long-distance unidirectional movements (total linear range 20 – > 270 km).

Strong home range fidelity and/or residency was exhibited by at least 20 golden perch which moved < 1 km from their original capture and release location (Figure 8-2a). Furthermore, many fish that undertook exploratory movements within the Chowilla system or long-distance movements up the Murray River exhibited strong home range fidelity prior to and/or following these movements (Figure 8-2).

Sixteen fish made small (2 – 10 km) or medium-scale (10 – 20 km) movements within the Chowilla system or between Chowilla and the adjacent Murray River (Table 8-1). Small-scale movements were often one-off and followed long-term residency at a site in Chowilla Creek and return to this site (*n* = 3) or establishment of residency at an alternative site in Chowilla Creek (*n* = 2), Monoman Creek (*n* = 3) or Piggy Creek (*n* = 1).

Medium-scale movements involved fish moving down Chowilla Creek and up the Murray River to Lock 6 (*n* = 2) or fish travelling up Chowilla Creek, Slaney Creek and Salt Creek (*n* = 5) and not being detected again by manual radio tracking (in the Chowilla system or Murray River) or PIT tag readers on the fishways at Locks 7 – 10. These fish were assumed to have moved upstream out of the Chowilla system into the Murray River via Swiftys Creek but were not present on the 7 – 10 fishway PIT reader data due to large gaps in the data record.

One radio-tagged golden perch (193-22) exhibited behaviour that incorporated both the observed medium-scale movement patterns. This fish was resident at its capture location in lower Chowilla Creek from 30th May 2006 until 4th December 2006. It then moved down Chowilla Creek into the Murray River and was located immediately downstream of Lock and

Table 8-1 Radio transmitter and fish details. Total linear range is defined as the distance between the two outermost positions the fish occupied.

Freq.	Length (mm)	Weight (g)	Sex	Observation period	Days at liberty	No. of locations	Total linear range (km)
017-20	360	666	f	23/8/05-10/12/06	474	111	150.3
017-21	400	930	f	23/8/05-21/6/06	302	31	199.4
017-22	355	570	f	18/8/05-30/1/07	530	24	0.55
017-23	415	1014	f	24/7/06-26/6/07	337	12	0.14
017-24	432	1168	m	23/7/06-26/6/07	334	62	0
035-20	397	769	f	18/8/05-29/11/06	468	31	155.0
035-21	379	700	f	23/8/05-17/10/06	420	17	0.12
035-22	357	641	f	24/8/05-26/2/06	186	15	33.3
035-23	446	1299	f	23/8/05-14/2/07	540	24	0.28
035-24	450	1308	f	30/5/06-31/1/07	246	14	1.4
057-20	380	735	f	24/8/05-20/9/06	392	21	1.92
057-21	396	915	f	23/8/05-11/10/06	414	25	149.15
057-22	354	634	f	24/5/05-8/1/07	592	39	92.80
057-23	449	1206	f	3/7/06-27/6/07	357	176	0.60
076-20	360	591	f	16/8/05-14/2/07	547	27	7.60
076-21	384	818	f	16/8/05-13/4/07	605	26	1.10
076-22	373	724	f	18/8/05-13/12/05	117	10	7.35
097-20	400	895	f	17/8/05-21/9/06	400	16	191.3
097-21	385	824	m	16/8/05-14/2/07	547	32	18.10
097-22	381	835	f	17/8/05-14/11/06	454	27	153.85
097-23	485	1754	m	4/7/06-27/6/07	358	23	7.8
112-20	397	947	f	17/8/05-27/11/06	467	58	14.2
112-21	394	897	f	16/8/05-24/3/06	220	17	16.1
112-22	390	745	f	16/8/05-31/1/07	533	24	3.0
112-23	395	828	f	17/8/05-13/2/07	545	60	13.67
112-24	367	669	f	17/8/05-9/1/07	510	24	5.3
112-26	407	901	f	4/7/06-4/12/06	153	9	0.63
113-21	397	742	f	31/5/06-27/6/07	392	14	1.5
133-20	387	732	f	17/8/05-9/1/07	510	24	0.13
133-21	351	648	m	24/8/05-19/8/06	360	18	1.0
133-22	364	658	f	16/8/05-13/4/07	605	28	0
133-23	365	659	f	18/8/05-5/2/07	536	30	10.22
133-24	362	572	f	16/8/05-27/6/07	680	28	1.0
133-25	367	865	f	4/7/06-3/12/06	152	12	10.7
133-26	370	780	f	4/7/06-27/6/07	446	16	1.25
156-20	382	786	f	23/8/05-4/12/06	468	31	151.41
156-21	381	749	f	17/8/05-17/10/06	426	19	8.2
156-22	393	822	f	17/8/05-14/1/07	415	28	14.73
156-23	380	790	f	18/8/05-27/12/06	496	27	264.5
156-24	376	780	f	23/8/05-19/12/06	483	38	1.16
156-26	400	873	f	4/7/06-27/6/07	440	17	3.47
173-20	420	1015	f	23/8/05-27/6/07	673	28	0.23
173-21	409	940	m	18/8/05-13/4/07	603	25	0.10
173-22	421	1041	m	17/8/05-18/2/07	550	26	268.40
173-23	408	941	f	23/8/05-30/11/06	464	110	81.75
173-24	438	1216	f	30/5/06-30/11/06	184	13	271.6
193-20	429	959	f	30/5/06-27/6/07	403	14	0.110
193-21	422	1081	m	30/5/06-24/5/07	359	24	214.26
193-22	396	1031	f	30/5/06-12/12/06	196	19	21.2
193-23	410	950	m	23/8/05-27/6/07	673	35	2.28
193-24	423	1025	?	18/8/05-21/6/06	307	15	208.60
156-20*	387	813	f	30/5/06-27/6/07	403	21	4.85

Weir No. 6 on the 6th December 2006. On the 8th December this fish moved back down the Murray River and proceeded to travel up Chowilla Creek, Slaney Creek and Salt Creek. It was last recorded on the Salt Creek logger on the 12th December 2006. The fish was not recorded again and most likely left the Chowilla system via Swiftys Creek and continued migrating upstream in the Murray River

A small number of fish (*n* = 4) made exploratory movements into Boat Creek (*n* = 2), Piggy Creek (*n* = 1) and Slaney Billabong (*n* = 1) during the small but prolonged increase in discharge and water levels in spring/summer 2005 (Chapter 1, Figure 1-2) (Figure 8-2c). These fish continued to make repeat movements between these habitats and Chowilla Creek over the course of the study. The fish that moved into Slaney Billabong (017-21), however, resided in this macrohabitat for approximately two months before rapidly moving into Salt Creek on 8th December 2005, then up Swifty's Creek and into the Murray River. This fish was next located downstream of Lock 10 on the 16th February 2006 and remained there until it was last tracked on the 21st June 2006.

The 52 radio-tagged golden perch were located on a total of 1,618 occasions in all major mesohabitats in the Chowilla system and the Murray River. No fish, however, were located in Punkah Creek or Hypurna Creek. Over 84% of detections were in Chowilla Creek and detections in other mesohabitats constituted between 0.2% (Pipeclay Creek) and 3.7% (Murray River) of total (Table 8-2). Movements of a low number of fish into Monoman Creek, Boat Creek and Piggy Creek were associated with exploratory behaviour and residency. In contrast, golden perch located in Salt Creek and Slaney Creek were generally undertaking transitionary movements between the Chowilla system and the Murray River.

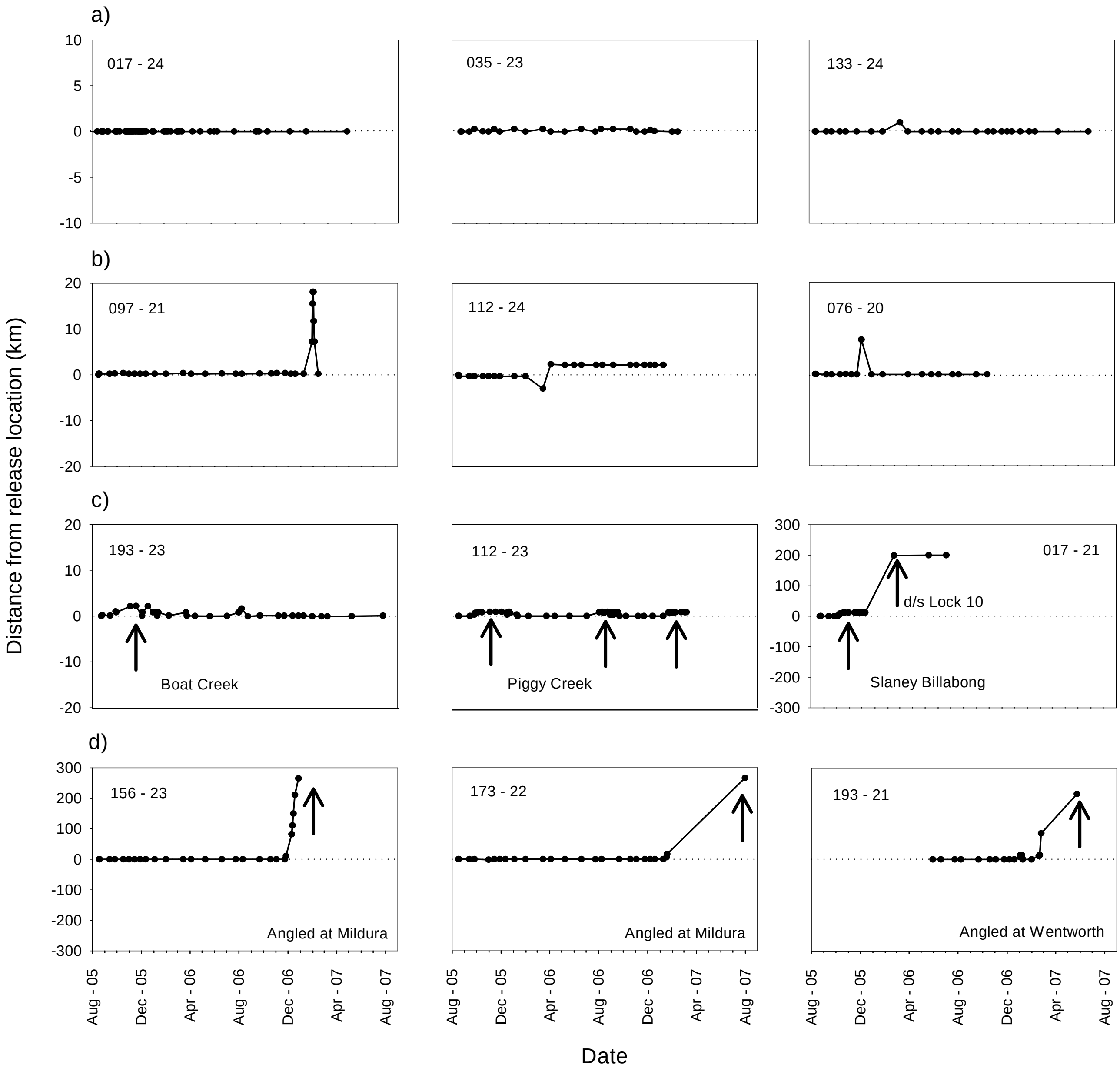


Figure 8-2 Locations of selected radio-tagged golden perch within the Chowilla system and lower Murray River over the duration of the study. Four general movement patterns were displayed: (a) fish that displayed strong site fidelity/residency to sites in Chowilla Creek, (b) fish that undertook small (2 – 10 km) and medium-scale (< 20) km movements within the Chowilla Creek system, (c) fish that moved into tributaries or backwaters of Chowilla Creek and (d) fish that undertook long-distance (> 20 km) unidirectional movement out of Chowilla and up the Murray River. Black arrows indicate residence in habitats other the Chowilla Creek.

Table 8-2 Percentage use of mesohabitats by golden perch, based on the total number of individual locations for all fish over the study period.

Mesohabitat	Number of detections	% of total
Chowilla Creek	1368	84.5
Murray River	60	3.7
Monoman Creek	41	2.5
Slaney Creek	39	2.4
Salt Creek	38	2.3
Boat Creek	29	1.8
Piggy Creek	21	1.3
Slaney Billabong	19	1.2
Pipeclay Creek	3	0.2
Total	**1618**	**100**

Seventeen golden perch undertook long-distance unidirectional upstream movements out of the Chowilla system and up the Murray River (Table 8-1, Figure 8-2). An additional five fish were last detected moving upstream in Salt Creek and were not located again. These fish were assumed to have also left the Chowilla system. All fish followed the same route from lower Chowilla Creek, up Slaney Creek, Salt Creek and Swiftys Creek into the Murray River (Figure 8-3). Once in the Murray River fish continued to move upstream until they were constrained by a Lock and Weir without a fishway or were caught by an angler (n = 10). The furthest upstream golden perch could move during the study period was to the tailwater of Lock and Weir No. 11 at Mildura a distance of 265 km along the Murray River. The mean speed of upstream movement was 0.50 ± 0.19 km/h S.D. with a range of 0.34 – 0.83 km/h (n = 13). Importantly, no return downstream movements were detected by radio tracking or PIT readers on the Lock and Weir fishways.

There was no significant difference (t-test, t = 0.28, P > 0.3) in size (L_T) between those fish that undertook long-distance upstream movements and those that remained in the Chowilla Anabranch system. Furthermore, both male (n = 2) and female (n = 17) fish undertook upstream movements in a ratio not significantly different ($\chi2$ = 0.724, df = 1, P > 0.05) from the ratio that remained in the Chowilla system.

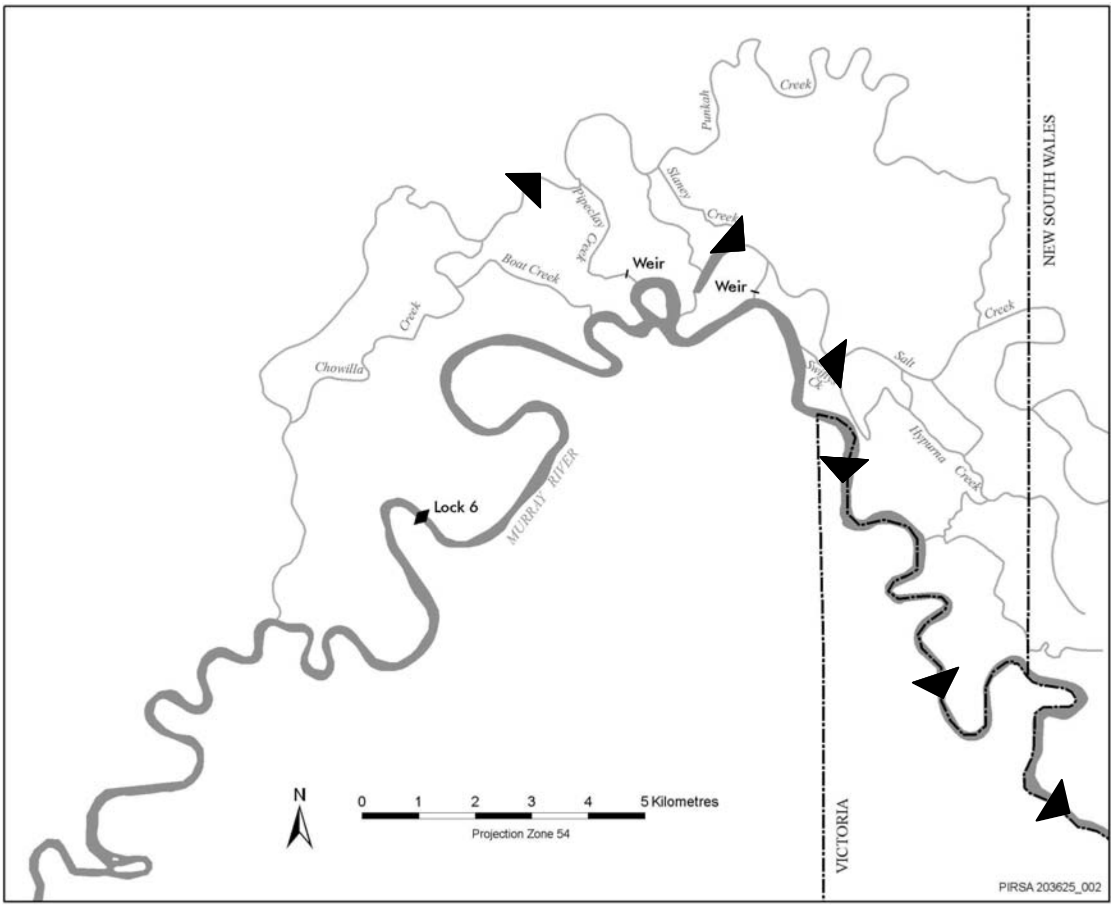


Figure 8-3 Route and direction of movement (black arrows) of 17 radio-tagged golden perch that moved out of the Chowilla system and up the Murray River.

Long-distance movements out of the Chowilla system occurred individually, without apparent schooling, during summer and autumn in 2005/2006 and through late spring, summer and autumn in 2006/2007 (Figure 8-4). Movements occurred both on the receding limb of a small within-channel increase in discharge (2005/2006) and during a period of relatively stable discharge (2006/2007) (Figure 8-4). Water temperatures during the study period ranged between 10 and 27°C but movement was only recorded at temperatures above approximately 17°C.

8.3.2 Recapture of radio-tagged golden perch

Up until July 2007, 10 radio-tagged fish had been caught by anglers; eight in the Murray River and two in Chowilla Creek. Six of the radio-tagged golden perch caught by anglers in the Murray River were caught immediately downstream of Lock 10 at Wentworth or Lock 11 at Mildura.

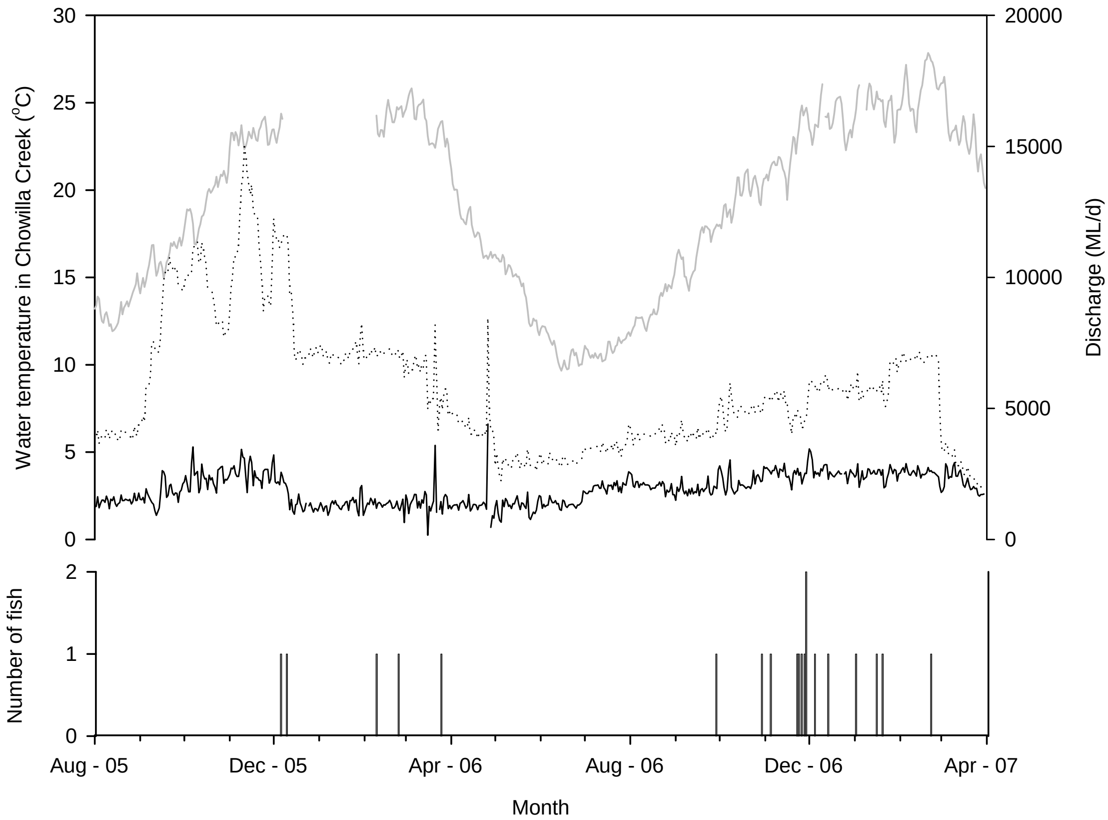


Figure 8-4 Timing of golden perch movement out of the Chowilla system and upstream into the Murray River. Mean daily water temperature in Chowilla Creek (grey line), discharge in Chowilla Creek (black line) and discharge in the Murray River (dotted line).

8.4 Discussion

In this study adult golden perch displayed considerable spatio-temporal variability in movement patterns with three distinct movement patterns emerging: 1) small-scale (< 1 km) non-directional activity within a limited home range, 2) small – medium-scale movements (~2 –20 km) involving exploratory behaviour and potential establishment of new home ranges and 3) rapid, long-distance unidirectional movements (~20 – > 250 km). These movements encompass three discrete types of animal movement which have previously been described as foraging, ranging and migration (Dingle and Drake 2007).

The earliest investigation of golden perch movements by Reynolds (1983) in the lower Murray River, using t-bar tags recovered by fishers, showed that 20% of tag-returned fish did not move from their original capture location, 33% moved < 10 km, 8% moved between 60 and 200 km, and 6% moved over 200 km, generally in high flows. Recent investigations of golden perch movements using radio telemetry have observed limited movement (< 5 km) and strong home range fidelity during low, stable flows in the non-spawning season (from late summer to winter (Crook 2004b; O'Connor *et al.* 2005) or a short intense period of upstream (≤ 35 km) and downstream (≤ 290 km) migration of 74% of tagged fish (n = 15) during high flows (25,000 ML/d) in the spawning season (spring), that was often followed by return movments (O'Connor *et al.* 2005). During the same period, however, 26% of fish moved < 5 km (O'Connor *et al.* 2005).

In the current study most (94%, n = 49) golden perch exhibited periods of strong site fidelity and limited movement extending for 2 to 24 months. Over 50% of fish maintained their home site throughout the study, including the spawning season (spring and summer) and during a small increase in discharge in spring/early summer (2005/2006). Several fish (n = 9) that initially exhibited strong site fidelity and occupied small home ranges subsequently undertook exploratory/ranging movements and returned to their original home range or, alternatively, selected new home ranges. These data support the 'home range shift' model (Crook 2004b), which is potentially driven by the 'profitability' of habitats encountered.

Mobility may be related to habitat quality and complexity with fish in low quality homogenous habitats exhibiting greater mobility than those in heterogeneous environments (Bruylants *et al.* 1986). The strong site fidelity and limited movement of many golden perch in Chowilla Creek may be a reflection of heterogeneous hydraulic environments and associated habitat complexity that characterise the Chowilla system and are absent from the highly regulated main channel of the lower Murray River (Walker 2006).

Changing environmental conditions may stimulate exploratory behaviour (ranging) which may enable fish to opportunistically exploit available resources (Louca *et al.* 2008). Fish that exhibited exploratory behaviour into fast-flowing mesohabitats in secondary creeks (e.g. Boat Creek and Piggy Creek) and backwater mesohabitats (e.g. Slaney Billabong) in late 2005/early 2006 may have been responding to a small increase in discharge and water level that subsequently inundated or made accessible new habitats. These habitats (e.g. newly inundated littoral zones) may have provided additional food resources such as macrocrustaceans, an important food source for golden perch (Baumgartner 2007).

Ranging behaviour can also be a response to changing resource condition or inter or intra specific competition and generally ceases once a suitable new home range is found (Gowan and Fausch 1996). Golden perch generally occupied habitat patches that were characterised by the presence of large woody debris (predominantly river red gum, *Eucalyptus camaldulensis* Dehnh.), and emergent aquatic macrophytes *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha domingensis* (Pers.). These habitats occur throughout Chowilla Creek and when shifting home range golden perch commonly selected the same habitat attributes at an alternative location, suggesting that competition rather than a change in resource condition may have been the stimulus to move. Woody debris and aquatic macrophytes are important habitats for freshwater fish and the frequency and distribution of these habitat patches may influence the spatio-temporal scale of fish movement (Belica and Rahel 2008).

Golden perch exhibiting long-distance upstream movements (n = 17) over an extended period from spring – autumn in 2005/2006 and 2006/2007 followed the same route out of the Chowilla system and up the Murray River. In complex hydrodynamic environments migrating fish navigate using hydraulic cues that may not be described by simple qualitative descriptions of depth and velocity (Nestler *et al.* 2008). Nevertheless, golden perch initiating long-distance upstream movements in the Chowilla system consistently followed the path of greatest discharge, potentially following a velocity gradient or integrating area and velocity. Consequently, manipulation of discharge (e.g. by the operation of regulators) through any of the creeks in the Chowilla system may influence the route taken by emigrating fish. As such, fish passage at regulating structures needs to be considered.

Golden perch undertaking long-distance upstream migrations moved as far upstream in the Murray River as possible before being constrained by a weir without a fishway. Rates of movement were of a similar magnitude to those observed by O'Connor *et al.* (2005) in the mid reaches of the Murray River and suggest that fish were undertaking a more purposeful movement than ranging. Ultimately, fish accumulated downstream of Lock 11 and were subject to substantial angling mortality, a common impact of barriers to fish migration (Gehrke *et al.* 2002).

Radio-tagged golden perch in the lotic middle reaches of the Murray River have been observed to undertake long-distance upstream and downstream movements in spring in association with large increases river discharge (25,000 ML/d), which were often followed by return movements to homes sites (O'Connor *et al.,* 2005). Furthermore, large numbers of adult golden perch may move upstream though fishways during spring (Mallen-Cooper 1996). These movements have generally been considered to be spawning related (Reynolds 1983; Mallen-Cooper 1996; O'Connor *et al.* 2005), as golden perch spawn pelagic eggs that give rise to drifting larvae in spring/summer in association with increases in water temperature and discharge (Lake 1967; King *et al.* 2008).

High river flows were not experienced in the present study but the data indicate that long-distance upstream movements of golden perch in the lower Murray River may occur anytime from spring to autumn and these movements may be undertaken during periods of low, stable flow or small within-channel increases in discharge. In addition, long-distance upstream movements in the lower Murray River may not be accompanied by a corresponding downstream homing movement.

Homing behaviour in golden perch under taking migratory movements has been observed in the relatively unconstrained lotic mid reaches of the Murray River (O'Connor *et al.* 2005). In the highly regulated lower Murray River, however, serial weirs may inhibit downstream homing movements following upstream migration. Golden perch may show reluctance to move downstream over regulating structures and, whilst many weirs do have fishways, these generally provide limited downstream passage (O'Connor *et al.* 2006). Furthermore, weirs and lentic weir pool environments may also interrupt the downstream drifting phase of pelagic eggs and larvae.

Restoration of connectivity for riverine fish should facilitate the active movement and displacement of all life stages (Kraabøl *et al.* 2009). The construction of fishways on all Locks and Weirs on the main channel of the Murray River has facilitated the upstream movement of migrating fish (Barrett and Mallen-Cooper 2006); nevertheless, the fate of downstream migrants, particularly larvae, warrants further investigation. Importantly, restoration of lotic habitats in the lower Murray River may assist the downstream displacement of egg, larval and juvenile life stages thus replenishing downstream populations.

It is unclear whether fish migrating out of the Chowilla system were undertaking voluntary movements in response to changes in environmental conditions or resource needs, or innate movements in response to some external cue or endogenous clock (McMahon and Matter 2006). Both male and female fish undertook long-distance movements and there was no difference in size (L_T) between migratory and non-migratory fish. Nevertheless, this does not preclude there being age differences as length is a poor indicator of the age of golden perch due to large variability in length at age (Anderson *et al.* 1992). Consequently, it is possible that fish emigrating from Chowilla were responding to some endogenous cue. Why fish emigrate from the Chowilla system and what triggers this emigration form important questions for further exploration.

Rates of emigration, along with immigration, births and deaths, govern populations (Begon *et al.* 1996) and population dynamics ultimately rely on the behaviour of individuals (Sutherland 1996). Small-scale studies on individual fish have previously been considered a limitation to the association of individual behaviours to population dynamics (Lowe 2003). Whilst the radio telemetry results from this study support the observations of Crook (2004a,b) that golden perch may exhibit restricted movement and strong site fidelity, they also highlight the limitations of spatially and temporally constrained investigations and the tradeoffs of using individual techniques (Lucas and Baras 2001).

In order to understand how the riverscape influences fish population dynamics large-scale investigations are imperative (Fausch *et al.* 2002). In this study a combined radio transmitter and PIT tag approach enabled the differentiation of short – medium distance home range and exploratory movements (radio transmitters) from long-distance migration (PIT tags) at spatial and temporal scales that enable individual behaviours to be linked to population-level response. This investigation has contributed new knowledge on golden perch behaviour in the Chowilla system during an extended period of low within-channel flows and will assist in the site-scale management of this species. In addition, the PIT tagging component of the study has elucidated behaviour that may influence the population dynamics of golden perch in the lower Murray River. This study highlights the spatio-temporal variability of golden perch movement and the need for investigations to be undertaken over broad spatial (100s of km) and temporal (years) scales for long-lived potamodromous fish.

The Murray River is over 2,000 km long and the impacts of river regulation vary along its length (Walker 1985, 2006). Management and conservation strategies for golden perch must consider the spatio-temporal variability observed in golden perch behaviour and movement. Conceptual models of golden perch movement need to be adaptable to account for the plasticity observed in golden perch behaviour, including restricted home ranges, strong site fidelity, exploratory movements and home range shift, potential large-scale spawning migrations and homing behaviour, and large spatial scale emigration. These models also need to account for the substantial temporal variability in the presentation of these behaviours. The high spatio-temporal variability in golden perch behaviour and movement in the MDB highlights the need for a river basin scale approach to native fish management, a scale that is relevant to golden perch and not constrained by human perspectives of artificially delineated sites or state boundaries.

9 Synthesis

Slaney Creek in the Chowilla system. Flowing water and abundant large woody debris (snags) make this creek a unique aquatic habitat in the lower Murray River.

The Chowilla region is the largest remaining region of floodplain habitat in the lower Murray River and in 1987 was listed as a *Wetland of International Importance* under the Ramsar Convention (as part of the Riverland Ramsar site, which stretches from Renmark to the New South Wales border) recognising its unique birdlife and the extent of river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*) woodlands. The floodplain in this region is 5 – 10 km wide and is characterised by a complex of perennial and ephemeral waterbodies consisting of creeks, backwaters, billabongs and lakes.

Due to the head differential (~ 3 m) created by Lock and Weir No. 6 on the Murray River, the Chowilla system exhibits permanent lotic habitats in what previously would have been a combination of perennial and ephemeral streams. Given Sturt's 1830 description of the Murray River in this region it appears that regulation of the Murray River has shifted lotic waters from the main channel into the anabranch system. Lotic habitats are now uncommon in the South Australian section of the Murray River, as the construction of locks and weirs has generally created a series of lentic (still water) habitats (Walker, 2006).

The uniqueness of the Chowilla region has been recognised by numerous studies and the lotic environments are considered to maintain remnant populations of endangered flora and fauna that are uncommon or extinct elsewhere in the lower Murray (O'Malley and Sheldon 1990; Pierce 1990; Sharley and Huggan 1995). Nevertheless, for what is considered to be a region of high conservation value in the lower Murray River, few documented investigations have been undertaken on the aquatic flora and fauna of the area.

The overarching objective of this project was to undertake a range of investigations to assist in determining the current status and ecological requirements of native fish and aquatic macrophytes in the Chowilla system. The outputs of the project were to be used primarily in the development of management strategies for achieving the ecological targets specified in the Chowilla Asset and Environmental Plan (AEMP) (DWLBC, 2006).

The specific aims of the project were to:

1. Determine the distribution and community structure of native fish assemblages in the Chowilla Anabranch system.
2. Determine the distribution and community structure of aquatic macrophyte assemblages in the Chowilla Anabranch system.
3. Investigate the ecology of native fish, particularly Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua ambigua*) in the Chowilla Anabranch system.
4. Assess the impacts to fish passage caused by barriers identified in the "structure assessment project".
5. Facilitate knowledge transfer to inform operation and modification of existing and new flow regulation structures.

Our investigations were undertaken over a four year period (September 2004 – June 2007) characterised by an unprecedented (since river regulation) period of low-flow in the Murray River. Following the last overbank flood in late 2000, discharge in the lower Murray River has been highly regulated with the delivery of summer (7,500 ML/d) and winter (3,000 ML/d) entitlement flows for six consecutive years with only two minor within-channel increases in discharge (peaking at approximately 15,000 ML/d) in spring/summer 2003 and 2005 (Figure 1-1). All flows recorded during the study period were well below a bankfull or flood-flow threshold of approximately 50,000 ML/d.

Fish assemblages

Total fish species richness (14 species) in the Chowilla system and adjacent Murray River was similar to that reported in other recent investigations of fish assemblages in the lower Murray River main channel and anabranch systems (e.g. the Lindsay-Mullaroo system) (Villizzi *et al.* 2006; Baumgartner *et al.* 2008; Davies *et al.* 2008) with no species being found exclusively in the Chowilla system. Unfortunately, despite extensive surveys, four species considered potentially present in the Chowilla system by Pierce (1990), namely trout cod, river blackfish, southern purple-spotted gudgeon and southern pygmy perch, were not collected.

Species richness was highest in fast-flowing mesohabitats and the Murray River and lowest in slow-flowing and backwater mesohabitats. Fast-flowing habitats tended to be characterised by greater habitat complexity (e.g. large woody debris, variable channel form, diverse aquatic vegetation and heterogeneous hydraulic environments) whilst slow-flowing and backwater mesohabitats were less complex. Significant differences in fish assemblages were detected between mesohabitats with fast-flowing mesohabitats being characterised by large-bodied native species such as Murray cod and golden perch, backwater mesohabitats by native carp gudgeon and non-native common carp and goldfish, and main channel Murray River mesohabitats by the 'wetland specialists' unspecked hardyhead and Murray rainbowfish. The high abundances of these species collected in Murray River sites reflects the highly regulated nature of weir pools in the lower Murray River and an extended period of low flows. Such conditions have transformed a lotic riverine environment to a lentic wetland type environment with little hydraulic complexity and abundant submerged aquatic macrophytes thus favouring generalist and wetland fish species.

Fast-flowing mesohabitats in the Chowilla system were hydraulically complex and contained a mosaic of fast-flowing, slow-flowing and backwater/lentic microhabitats. These attributes in combination with diverse instream structure have the potential to facilitate the habitat requirements of a large range of species. Habitat heterogeneity and hydraulic complexity may promote a more productive aquatic ecosystem with a greater ability to support a range of life stages and life history processes of native fish (Thorp *et al.* 2006). Importantly, such lotic habitats may represent fragmented relicts of the hydrodynamically complex unregulated Murray River.

Determining the use of physical habitats by stream fish is important for the development of conservation measures to aid in species recovery, particularly habitat restoration (Rice 2005). In the Chowilla system and adjacent Murray River small-bodied native fish and non-native fish such as common carp and goldfish were often significantly associated with vegetated edge habitats where the vegetation was comprised of emergent, floating and submerged macrophytes. These vegetation complexes were wide spread across mesohabitats and provide structurally complex regions important for reproduction; food resources and refuge from predators (Pusey *et al.* 1993; Weaver *et al.* 1997).

Coarse woody debris (CWD) and associated river red gum root masses were identified as a significant instream habitat for Murray cod and silver perch. Large wood has also been identified as an important structural habitat for trout cod and Murray cod in the mid reaches of the Murray River (Nicol *et al.* 2007; Koehn 2009). Large wood provides important structural habitat and creates a diversity of physical habitats in rivers (Crook and Robertson 1999).

Species assemblages in each mesohabitat remained relatively consistent from 2005 – 2007. Abundance of individual species, however, did vary between years. Most notably, in 2006, non-native common carp were sampled in significantly higher abundances in backwater and slow-flowing habitats. This increase in abundance was likely to be a result of strong recruitment of young-of-year fish following the within-channel flow event in spring/summer 2005. During this event water levels rose approximately 0.5 m and negligible floodplain habitat was inundated. Consequently, despite floodplain inundation being proposed as a key mechanism for carp recruitment in the MDB (Brown *et al.* 2005; Balcombe *et al.* 2006), our results suggest that within-channel rises in flow may also promote significant recruitment, particularly in the permanently inundated lentic habitats of the lower Murray River.

Aquatic macrophytes assemblages

A total of 91 plant species (including 24 non-natives) were recorded at sites throughout the study period. This number, however, is an underestimate of total plant species richness of the Chowilla system because the surveys undertaken were designed to maximise statistical power, thus a large number of small quadrats were used, which tends to underestimate species richness. Since 1988, 405 taxa have been recorded in the Chowilla system (Nicol *et al.* 2010a).

Areas vegetated with perennial species (e.g. littoral zones and permanently inundated areas) or dominated by bare soil did not change significantly over the study period, which was probably due to stable conditions, brought about by largely stable water levels. High abundances of native submergent, floating, amphibious and emergent species were present in and around permanently inundated areas. In contrast, the floodplain and many temporary wetlands, prior to the commencement of environmental watering, were dominated by terrestrial species, salt tolerant species and bare soil. Whilst there were no significant short-term seasonal changes in the plant community over the study period, in permanently inundated areas or the floodplain, there were localised changes in the plant community in response to the within-channel rise in water level in spring 2005, and longer-term (2006 – 2010) changes across the floodplain (Gehrig *et al.* 2010).

The within-channel water level rise in spring 2005 inundated the fringes of permanent waterbodies and provided an opportunity for floodplain and amphibious taxa to recruit; although the response was patchy. There was a significant increase in the abundance of floodplain and amphibious taxa on the edges of losing reaches (areas of groundwater recharge), whereas there was no change in the plant community in gaining reaches (areas of groundwater discharge).

The remainder of the floodplain, except areas where there were interventions (Gehrig *et al.* 2010; Nicol *et al.* 2010b), showed signs of severe degradation. After the completion of data collection for this project, floodplain condition further declined (i.e. decreased species richness coupled with increased cover of bare soil and salt tolerant taxa) from 2006 – 2009, except in areas where there were interventions (Gehrig *et al.* 2010; Nicol *et al.* 2010b). Changes in floristic composition due to the high water levels in spring 2005 and interventions show the plant community has the capacity to recover; although, how long the system will remain resilient is unknown.

Murray cod ecology

Over the three year study period, adult Murray cod were consistently and only collected in fast-flowing mesohabitats of the Chowilla system and in the Murray River. These mesohabitats were characterised by average cross-sectional water velocities > 0.18 ms^{-1} and abundant large woody debris, and these attributes in combination produced considerable hydraulic and channel (e.g. bedform) complexity. At the microhabitat scale, Murray cod were significantly associated with large wood (snags), river red gum roots, overhanging terrestrial vegetation (lignum, *Muehlenbeckia florulenta*) and the emergent macrophytes *Phragmites australis* and *Juncus usitatus*.

Radio-tagged Murray cod in the mid reaches and a tributary of the Murray River have been shown to prefer main river channel and flooded floodplain channel macrohabitats (Koehn 2009). Within these macrohabitats Murray cod selected microhabitats characterised by high levels of structural woody habitat, higher variation in depth and greater overhanging vegetation (Koehn 2009). Murray cod in the Chowilla system were associated with similar habitat variables and although coefficient of variation in depth was not measured, we observed high channel complexity at sites with flowing water and abundant woody habitat. The contiguous, desnagged weir pool habitats of the main channel of the lower Murray River provide little hydraulic or channel complexity and lack the high levels of structural wood that are found at sites within the Chowilla Anabranch system. Consequently, specific regions in the Chowilla Anabranch system provide a unique combination of flowing water and structural woody habitats that support high abundances of adult and juvenile Murray cod.

Murray cod larvae were collected in fast and slow-flowing mesohabitats in the Chowilla system from mid October to mid November in both 2005 and 2006. Spawning was confirmed in main channel and anabranch habitats (with the exception of backwaters) during a small increase in flow, and during stable low flows, at water temperatures of 18 – 20°C. These observations are consistent with other studies, and support the general view that Murray cod spawn annually during a limited season, independent of hydrological conditions and in association with increasing water temperatures (variously reported as > 15 – 20°C) (Rowland 1983; Rowland 1998; Humphries 2005; Koehn and Harrington 2006).

Back calculation of approximate spawning dates indicated that captured larvae were spawned in late September/early October in both years. This is earlier than the timing of spawning (i.e. mid October to early December) reported in the mid reaches and tributaries of the Murray River (Humphries 2005; Koehn and Harrington 2006). If water temperatures of 15°C are an important threshold then this temperature is commonly reached by mid September in the lower Murray River and may explain the earlier onset of spawning. The highest abundances of larvae were collected from fast-flowing mesohabitats in Chowilla, Slaney and Pipeclay creeks. These mesohabitats were characterised by high levels of structural woody habitat, an important adult habitat (Koehn 2009) and spawning substrate for Murray cod (McDowall 1996), and may represent important spawning sites.

Murray cod recruitment in the southern MDB appears to be positively associated with high river flows, both within-channel and overbank (Rowland 1998; Ye *et al.* 2000). During a prolonged low-flow period (2001 – 2007) in the lower Murray River, recruitment has been negligible (Ye and Zampatti 2007). The capture of a broad size range of Murray cod during the present study, and the observations of Pierce (1990), indicate that the Chowilla system facilitates recruitment of Murray cod during periods of extended low-flow and in the absence of recruitment in the main channel of the Murray River. Importantly, the lotic anabranch habitats at Chowilla provide drought refugia, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance (Schlosser and Angermeier 1995). Flowing anabranch habitats are scarce and unique in the lower Murray River and as such should be afforded special protection along with the Murray cod populations that inhabit them. The mechanisms that facilitate Murray cod recruitment are yet to be explored and form important questions for future research, as does the movement of adult and juvenile Murray cod within the Chowilla system and between Chowilla and the Murray River.

Golden perch ecology

In order to investigate golden perch recruitment ecology in the Chowilla system and the lower Murray River we conducted a three year study which incorporated early life history and population age structure data to elucidate patterns in recruitment and river flow. The study period spanned two years of low stable discharge and one year of elevated spring/summer discharge. Post larval golden perch were only collected during a small but prolonged within-channel rise in discharge in spring/summer 2005 and YOY golden perch were collected in March 2006. It is unclear whether the post larval and YOY golden perch collected in Chowilla were actually spawned in the region; nevertheless, the age of the larvae at collection and the habitats they were collected in (e.g. large woody debris in the littoral zone) suggest that the Chowilla region is at least a nursery area for juvenile golden perch as proposed by Lloyd (1990) and Pierce (1990). Importantly YOY and 1+ golden perch were collected both in Chowilla Creek and the main channel of the Murray River, in 2006 and 2007 respectively, thus confirming that river channels provide suitable nursery or rearing habitats for juvenile golden perch that are spawned during low or within-channel flow events (Mallen-Cooper and Stuart 2003).

Back calculation of spawning dates of post larval and YOY golden perch using daily growth increments in otolith microstructure revealed spawning occurred in late October/early November 2005. During this period, discharge was variable and it appears that most of the fish were spawned on the ascending limb of the second flow peak of the September to December flow event during which time water temperatures ranged from 21 – 24°C. These discharge and water temperature conditions are consistent with those proposed for golden perch spawning by Lake (1967). Furthermore, the spawning event coincided with an early November 2005 spawning event in the Barmah region of the Murray River that also occurred on the second peak of flow event and at similar water temperatures (King *et al.* 2008). These data support the notion that golden perch is indeed a flow-cued spawner, nevertheless, the component of the flow event that triggered spawning remains unclear. It is possible that a combined temperature and flow cue is required for spawning, i.e. spawning will occur in conjunction with a flow event but only once a threshold water temperature is reached.

We used thin-sectioned otoliths to validate the periodicity of annuli formation and determine the age of juvenile and adult golden perch collected in the Chowilla system and adjacent Murray River. In 2005, the golden perch population was dominated by three strong year classes (4, 6 and 8 year olds) which would have been spawned in 2000, 1998 and 1996 respectively. In each of these years substantial within-channel or overbank increases in discharge occurred during the spawning period for golden perch (October – December). The strong year classes observed in 2005 progressed to 5, 7 and 9 year olds in 2006 with no addition of further year classes. In 2007, an additional strong year class of 1 year old fish appeared, following successful spawning and recruitment of golden perch during a small but prolonged within-channel increase in discharge in spring/summer 2005.

Overall our data support the proposition of Mallen-Cooper and Stuart (2003) that strong golden perch recruitment is not reliant on flood flows (i.e. overbank) and that even relatively small within-channel flow events may support significant recruitment. There still exists considerable conjecture on the role of overbank flows in golden perch recruitment (Mallen-Cooper and Stuart 2003; King *et al.* 2008; Ebner *et al.* 2009). Whilst it appears that there is consensus that spawning and recruitment may occur during both within-channel and overbank flows, some investigations suggest spawning intensity and recruitment may be strongest during overbank floods. Investigations of golden perch spawning, however, have yet to be undertaken during a major overbank flow (i.e. > 60,000 ML/d) in the Murray-Darling Basin.

Whilst overbank flooding may be important, particularly from a primary productivity perspective (Junk *et al.*, 1989) the fact that within-channel flows can support strong recruitment has important implications for flow management in the lower Murray River. Medium sized flow events are the component of the flow regime that has been most significantly altered by river regulation in the lower Murray River (Walker 2006). Furthermore, it is these size events (e.g. 15 – 25,000 ML/d) that could practically be restored within the current constraints of system operation. Importantly, restoration of these within-channel flow events may lead to more frequent golden perch recruitment. Modelled 'unregulated' flow data, indicate that discharges of the magnitude potentially conducive to spawning and recruitment may have been more frequent in the unregulated Murray River and hence may have resulted in more consistent recruitment. These data provide an important ecological basis for flow restoration in the MDB.

Radio-tagged adult golden perch displayed considerable spatio-temporal variability in movement patterns with three distinct movement patterns emerging: 1) small-scale (< 1 km) non-directional activity within a limited home range (foraging), 2) small – medium-scale movements (~ 2 – 20 km) involving exploratory behaviour and potential establishment of new home ranges (ranging) and 3) rapid, long-distance unidirectional movements (~20 – > 250 km) (migration).

Most golden perch (94%, *n* = 49) exhibited periods of strong site fidelity and limited movement extending for 2 to 24 months. Over 50% of fish maintained their home site throughout the study, including the spawning season (spring and summer) and during a small increase in discharge in spring/early summer (2005/2006). Several fish (*n* = 9) that initially exhibited strong site fidelity and occupied small home ranges subsequently undertook exploratory/ranging movements and returned to their original home range or, alternatively, selected new home ranges. These data support the 'home range shift' model (Crook 2004b), which is potentially driven by the 'profitability' of habitats encountered. Mobility may be related to habitat quality and complexity with fish in low quality homogenous habitats exhibiting greater mobility than those in heterogeneous environments (Bruylants *et al.* 1986). The strong site fidelity and limited movement of many golden perch in Chowilla Creek may be a reflection of heterogeneous hydraulic environments and associated habitat complexity that characterise the Chowilla system.

Ranging behaviour can be a response to changing resource condition or inter or intra specific competition and generally ceases once a suitable new home range is found (Gowan and Fausch 1996). Golden perch generally occupied habitat patches that were characterised by the presence of large woody debris (predominantly river red gum, *Eucalyptus camaldulensis* Dehnh.), and emergent aquatic macrophytes *Phragmites australis* (Cav.) Trin. ex Steud. and *Typha domingensis* (Pers.). These habitats occur throughout Chowilla Creek and when shifting home range golden perch commonly selected the same habitat attributes at an alternative location, suggesting that competition rather than a change in resource condition may have been the stimulus to move.

Golden perch exhibiting long-distance upstream movements (*n* = 17) over an extended period from spring-autumn in 2005/2006 and 2006/2007 followed the same route out of the Chowilla system and up the Murray River. When undertaking these movements golden perch consistently followed the path of greatest discharge, potentially following a velocity gradient or integrating area and velocity. Consequently, manipulation of discharge (e.g. by the operation of regulators) through any of the creeks in the Chowilla system may influence the route taken by emigrating fish. As such, fish passage at regulating structures needs to be considered.

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This study highlights the spatio-temporal variability of golden perch movement and the need for investigations to be undertaken over broad spatial (100s of km) and temporal (years) scales for long-lived potamodromous fish. The Murray River is over 2000 km long and the impacts of river regulation vary along its length (Walker 1985; 2006). Management and conservation strategies for golden perch must consider the spatio-temporal variability observed in golden perch behaviour and movement. Importantly, conceptual models of golden perch movement need to be adaptable to account for the plasticity observed in golden perch behaviour and the substantial temporal variability in the presentation of these behaviours.

Impact of weirs on fish assemblage structure

In the MDB, instream barriers cause downstream accumulations of fish, delay migration, increase predation, competition and disease, and reduce the upstream range of migratory species (Harris 1984; Mallen-Cooper 1996; Stuart and Mallen Cooper 1999; Gehrke *et al.* 2002; Baumgartner 2007; Baumgartner *et al.* 2008). In Slaney and Pipeclay Creek, two major conduits of water to Chowilla Creek, significantly higher relative abundances of unspecked hardyhead, bony herring, carp gudgeons, flat-headed gudgeon, golden perch, Australian smelt and Murray rainbowfish were collected downstream of the weirs than at reference sites during the period late spring – autumn 2004/2005. These results indicated that these species were Slaney and Pipeclay weir may impede the upstream migration of a range of small and large-bodied fish species.

These findings support the recommendation of Zampatti and Leigh (2005) that Slaney and Pipeclay weir should be ranked as high priority in the Chowilla system for the restoration of fish passage. Given the diversity and abundance of fish in the creeks, restoration of fish passage at Slaney and Pipeclay weirs will need to consider the whole fish community and will require fishways of similar or better functionality to those being constructed on the locks and weirs of the Murray River (Stuart *et al.* 2008). The construction of low velocity and low turbulence vertical-slot fishways (Barrett and Mallen-Cooper 2006), or similar, at these sites should have a measurable effect on mitigating accumulations of fish downstream of the weirs.

Only low numbers of Murray cod were collected and there was no significant difference in the relative abundance of Murray cod between weir and control sites. Nevertheless, Slaney Creek is characterised by high abundances of potential spawning habitats (i.e. large wood) for Murray cod and it is likely that Murray cod may undertake movements between the main channel of the Murray River and creeks in the anabranch system to spawn. Consequently, to facilitate the movement of Murray cod between main channel and anabranch mesohabitats, fishways at Slaney and Pipeclay weirs will need to cater for the passage of large Murray cod up to at least 1000 mm in length.

Conclusions

In the highly regulated lower Murray River, the fast-flowing aquatic habitats of the Chowilla system have long been regarded as unique regions of high biological significance (O'Malley and Sheldon 1990). Furthermore, the aquatic habitat diversity of the Chowilla system, including fast and slow-flowing anabranches, backwaters and temporary billabongs, is unmatched in the lower Murray River, downstream of the Darling River junction. The Chowilla system, however, has not escaped the major impacts of river regulation in the Murray-Darling Basin particularly flow modification, habitat degradation, barriers to migration and invasion by non-native species. These are globally recognised threats to freshwater biodiversity that often have combined and interacting influences on aquatic ecosystems (Dudgeon *et al.* 2006).

Ultimately, the conservation of aquatic ecosystems relies on knowledge of the natural histories of the component biota. This information has been lacking for the fish of the Chowilla system; although both Pierce (1990) and Lloyd (1990) proposed the region to be a major spawning and recruitment site for golden perch and Murray cod. Investigations from 2004 – 2007 have shown that the Chowilla system is characterised by a diverse freshwater fish assemblage and that the distinct aquatic mesohabitats of the system support significantly different fish assemblages. Regulating structures, however, impede the movement of fish between mesohabitats, particularly between Slaney and Pipeclay Creek and the Murray River.

In the case of high conservation value species, such as Murray cod, the fast-flowing aquatic mesohabitats of creeks in the Chowilla system are characterised by significantly higher relative abundances of Murray cod than other available mesohabitats in the lower Murray River. Furthermore, the broad size range of Murray cod, compared to that observed in main channel of the Murray River, indicates that the Chowilla system sustains recruitment of Murray cod during periods of low-flow. Consequently, Chowilla provides a drought refuge, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance.

Tributaries that maintain elements of the natural flow regime of modified main channel rivers may be important for the spawning and recruitment success of fish (Moyle and Mount 2007; Pracheil *et al.* 2009). In the lower Murray River, where significant unregulated tributaries do not exist, major anabranches such as the Chowilla system may be important contributors to the functioning of the river ecosystem. As such, the conservation and potential restoration of these unique habitats will play an important role in meeting the 50 year goal of the MDBC's native fish strategy to rehabilitate all native fish species in the Basin back to 60% or better of their estimated pre-European settlement population levels (Barrett 2004).

The Chowilla system, however, cannot be managed as an isolated site in the landscape. Restoration of riverine fish communities needs to consider the spatio-temporal variability of fish life history and movement patterns. Investigation of golden perch recruitment and movement in the Chowilla region indicates the need to account for the magnitude and frequency of flow events required for spawning, the origin and scale of downstream displacement of larvae, and the broad spatial scale and temporal variability in the movement of adult golden perch. The high spatio-temporal variability in golden perch behaviour and movement in the MDB highlights the need for a river basin scale approach to native fish management, a scale that is relevant to the life histories of the constituent fish fauna and not constrained by human perspectives of artificially delineated sites or state boundaries.

At the completion of this investigation the anabranch creeks of the Chowilla system and Murray River have been hydrologically isolated from their surrounding floodplain for at least seven years. The long-term impacts of this isolation are unknown, as are the ecological responses (e.g. spawning, habitat use and movement) of fish of the Chowilla system and the adjacent Murray River, to large overbank floods. In general, the role of the floodplain and overbank flows in the ecology of large-bodied fish in the lower Murray River remains little explored and forms an important question for further investigation when such conditions next occur.

In closing, the Chowilla system is characterised by a complex of physical and hydraulic habitats that support a range of life history phases of native and non-native fish species. The hydraulic heterogeneity and, for some species, the separation of spawning and potential rearing habitats at the micro and mesohabitat scale are facets of the Chowilla system that are now absent from the homogeneous weir pool habitats of the lower Murray River, particularly under non-flood flows. The conservation of the diverse aquatic mesohabitats in the Chowilla system, along with restoration of a more variable flow regime, and the promotion of physical and hydrological connectivity at the river-scale, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

10 Management and Research Priorities

Key research and management priorities arising from the fish and aquatic macrophyte investigations undertaken from 2004 – 2007 are summarised below.

10.1 Research

- The 2004 – 2007 studies were undertaken during a period of generally low, stable, within-channel flows in the lower Murray River. Patterns in fish distribution, relative abundance and recruitment, however, may be significantly different during times of flooding and overbank flows when floodplain habitats (e.g. Lake Littra) are inundated. To develop a more complete understanding of fish ecology in the lower Murray River and Chowilla region, additional investigations of fish ecology should be undertaken during a period of overbank flows.

- Lotic habitats in the Chowilla system facilitated recruitment of Murray cod during periods of extended low-flow and in the absence of recruitment in the main channel of the Murray River. The mechanisms that facilitate Murray cod recruitment are yet to be explored and form important questions for future research as does the movement of adult and juvenile Murray cod within the Chowilla system and between Chowilla and the Murray River.

- It is unclear whether the post larval golden perch collected captured from Chowilla in 2005 were actually spawned in the region or were spawned further upstream in the Murray River or adjacent habitats (e.g. Rufus River). Determining the natal origin of juvenile golden perch would allow further consideration of the environmental conditions (e.g. discharge) that prevailed at the time of spawning and hence assist in the determination of environmental flow regimes to benefit native fish.

- Freshwater catfish were only collected in fast-flowing and Murray River mesohabitats but would be expected to occupy a broad range of mesohabitats in the Chowilla system. Freshwater catfish are not efficiently sampled by electrofishing (authors' personal observations) and the relative abundance of this species in the Chowilla system may have been underestimated. More specific surveys for freshwater catfish are recommended.

- It is unknown whether golden perch migrating out of the Chowilla system were undertaking voluntary movements in response to changes in environmental conditions or resource needs, or innate movements in response to some external or endogenous cue. Why golden perch, and potentially other fish species, emigrate from the Chowilla system and what triggers this, form important questions for further exploration.

- Generally, the plant communities in the permanently inundated areas of the Chowilla system are dominated by native species and could be regarded as in good condition. However, the littoral zone (the area dominated by amphibious and floodplain species) has contracted to a narrow band fringing permanent water bodies. Nicol *et al.* (2010b) reported that amphibious and floodplain species recruited in response to watering and will probably respond to flooding (regulated or natural). How long the floodplain and amphibious plant community remains resilient in the absence of flooding, and whether the current littoral zone and areas watered act as refuges, are unknown.

10.2 Management

- Specific regions in the Chowilla system provide a unique combination of flowing water and structural woody habitat that support high abundances of adult and juvenile Murray cod. Furthermore, the lotic anabranch habitats at Chowilla provide drought refugia, conferring resilience on the regional Murray cod population by maintaining population structure and providing a source of colonists after disturbance. As such these habitats should be afforded special protection along with the Murray cod populations that inhabit them.

- Overall, our data support the proposition of Mallen-Cooper and Stuart (2003) that strong golden perch recruitment is not reliant on flood flows (i.e. over-bank) and that even relatively small within-channel flow events may support significant recruitment. Whilst overbank flooding may be important, particularly from a primary productivity perspective (Junk *et al.*, 1989) the fact that within-channel flows can support strong recruitment has important implications for flow management in the lower Murray River. Small - medium sized flow events are the component of the flow regime that has been most significantly altered by river regulation in the lower Murray River; nevertheless, it is these size events (e.g. 15 – 25,000 ML/d) that could practically be restored within the current constraints of system operation.

- Slaney and Pipeclay weir should be ranked as high priority in the Chowilla system for the restoration of fish passage. Whilst the main channel of the Murray River is likely to be a primary conduit for the migration of freshwater fish, under low-flows a large proportion of Murray River flow bypasses Lock 6 and flows through Chowilla. Under this scenario, fish movement through the Chowilla system may be substantial and, as Slaney and Pipeclay Creeks constitute the major regulated inflows to Chowilla Creek, these weirs may present major barriers to the upstream migration of native fish. Given the diversity and abundance of fish in these creeks, restoration of fish passage will need to consider the whole fish community and will require fishways of similar or better functionality to those being constructed on the locks and weirs of the Murray River (Stuart *et al.* 2008).

- Restoration of riverine fish communities needs to consider the spatio-temporal variability of fish life history strategies and movement patterns. The high spatio-temporal variability in golden perch behaviour and movement in the MDB, and the hydrological process that facilitate spawning and recruitment, highlight the need for a river basin scale approach to native fish management. Effective management needs to be relevant to the life histories of the constituent fish fauna and not constrained by human perspectives of artificially delineated sites or state boundaries.

- Recognising the need to manage native fish populations over appropriate spatio-temporal scales, opportunities should be explored for appropriately scaled research and monitoring of movement and recruitment. The passive integrated transponder (PIT) tag system developed as part of the MDBA Sea to Hume Dam fishway program should be expanded to include the installation of PIT tag readers on any fishway constructed as part of infrastructure upgrades or new infrastructure in the Chowilla system. With the high potential for fish to use Chowilla as an alternative migratory route to the main channel of the Murray River, not installing readers leaves a large "black hole" in the current PIT reader network. Furthermore PIT readers on fishways at key regulator sites will provide valuable information on fish movement (including immigration and emigration) in response to water management and interventions in the Chowilla system. With regards to the recruitment of long-lived native fish, ongoing monitoring of the age structure of golden perch, and potentially silver perch and Murray cod populations are required to investigate the response of these species to natural flow events and flow management/restoration in the Chowilla system.

- In the highly regulated lower Murray River serial weirs may inhibit downstream homing movements of large-bodied native fish (e.g. golden perch) following upstream migration. Furthermore, weirs and lentic weir pool environments may interrupt the downstream drifting phase of pelagic eggs and larvae. The construction of fishways on all Locks and Weirs on the main channel of the Murray River has facilitated the upstream movement of migrating fish; nevertheless, the fate of downstream migrants (adults and larvae/juveniles) warrants further investigation. Importantly, restoration of lotic habitats in the lower Murray River may assist the downstream displacement of egg, larval and juvenile life stages thus replenishing downstream populations.

- The hydraulically and structurally complex lotic habitats of the Chowilla system represent fragmented relicts of the hydrodynamically complex unregulated Murray River. In the highly regulated lower Murray River such habitats may now be important contributors to the functioning of the river ecosystem. Consequently, the conservation and potential restoration of these unique habitats will play an important role in the rehabilitation of native fish populations and the broader aquatic ecosystem.

- The Chowilla system is characterised by a complex of physical and hydraulic habitats that support a range of life history phases of native and non-native fish species. The hydraulic heterogeneity and, for some species, the separation of spawning and potential rearing habitats at the micro and mesohabitat scale are facets of the Chowilla system that are now absent from the homogeneous weir pool habitats of the lower Murray River, particularly under non-flood flows. The conservation of the diverse aquatic mesohabitats in the Chowilla system, along with restoration of a more variable flow regime, and the promotion of physical and hydrological connectivity at the river scale, will aid in maintaining and potentially restoring native fish populations in the lower Murray River.

- During periods of low-flow numerous temporary wetlands have been inundated by pumping primarily to improve overstorey condition. Results from the within-channel rise in spring 2005 have shown that there is the potential for flood dependent and amphibious understorey recruitment in watering sites. These watering sites may be important refuges for flood dependent and amphibious understorey during periods when there are no overbank flows and may be important for recolonisation during natural floods.

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12 Appendices

Appendix 1 Vegetation site GPS coordinates (UTM format, WGS84).

Site	Easting	Northing
Boat Creek Bridge	490520	6242470
Boat Creek Larvae	492153	6242204
Chowilla Creek Fish Accumulation 01	490201	6242258
Chowilla Creek Fish Assemblages 01	487368	6238627
Chowilla Creek Fish Assemblages 02	489861	6242705
Chowilla Creek Fish Assemblages 03	463262	6244946
Chowilla Creek Larvae 01	490138	6241869
Chowilla Creek Larvae 02	490173	6241914
Hancock Creek 01	492108	6245954
Hancock Creek 02	492857	6246312
Hancock Creek 03	493543	6247083
Hancock Creek 04	494596	6247568
Hypurna Creek Fish Assemblages 01	497612	6240087
Hypurna Creek Fish Assemblages 02	498373	6239850
Isle of Man Backwater Fish Assemblages	493934	6242350
Lake Limbra 01	495333	6248147
Lake Limbra 02	495397	6248560
Lake Limbra 03	495412	6248991
Lock 6 DS	489538	6238361
Monoman Creek Fish Assemblages 01	486965	6241057
Monoman Creek Fish Assemblages 02	490260	6243262
Murray River Fish Assemblages 01	485526	6235344
Murray River Fish Assemblages 02	491678	6238994
Murray River Fish Assemblages 03	494854	6241519
Murray River Larvae 01	488220	6236217
Murray River Larvae 02	488833	6235508
Pilby Creek Fish Assemblages 01A	489898	6239180
Pilby Creek Fish Assemblages 01B	489778	6238823
Pipe Clay Creek Larvae 01	492982	6242381
Pipe Clay Creek Larvae 02	492775	6242396
Pipe Clay Creek Larvae 03	492725	6242978
Pipe Clay Creek Larvae 04	492904	6243329
Pipe Clay Creek Larvae 05	492713	6243838
Punkah Creek Fish Assemblages 01	499532	6244193
Punkah Creek Fish Assemblages 02	495604	6246521
Punkah Creek Larvae	494144	6244750
Punkah Island Horseshoe 01	497476	6242482
Punkah Island Horseshoe 02	497670	6241977
Salt Creek Fish Assemblages	497660	6241160
Slaney Backwater	494596	6242678
Slaney Creek Fish Assemblages	496732	6241790
Slaney Creek Larvae 01	494035	6243942
Slaney Creek Larvae 02	494389	6243725
Slaney Creek Weir	495481	6242224
Woolshed Creek 01	485587	6236197
Woolshed Creek 02	485919	6237151

Appendix 2 List of species recorded in the vegetation surveys (*denotes non-native species).

Acacia stenophylla
Agrostis avenacea
Alternanthera denticulata
Ammania multiflora
*Aster subulatus**
Atriplex spp.
Azolla filiculoides
Bolboschoenus caldwellii
Carpobrotus rossii.
Centipeda minima
Centaurea sp.*
Chara sp.
Chenopodium pumilio
*Conyza bonariensis**
Cotula coronopifolia
Crassula helmsii
Crassula sieberana
*Cuscuta campestris**
Cyperus exaltatus
Cyperus gymnocaulos
*Echium plantagineum**
Eleocharis acuta
*Elodea canadensis**
Enchylaena tomentosa
Epaltes australis
Eragrostis australasica
Eucalyptus camaldulensis var. *camaldulensis*
Eucalyptus largiflorens
Euphorbia drummondii
Glinus lotoides
Glycyrrhiza acanthocarpa
Psuedognaphalium luteo-album
Haloragis aspera
Halosarcia pergranulata ssp. *pergranulata*
*Heliotropium amplexicaule**
*Heliotropium curassivicum**
*Heliotropium europaeaum**
Hydrilla verticillata
*Hypochoeris radicata**
Iseotopsis graminifolia
Isolepis australiensis
Isolepis hookeriana
Juncus usitatus
*Lactuca saligna**
*Lactuca serriola**
Limosella australis
Lemna sp.
Ludwigia peploides ssp. *montevidensis*
Lythrum hyssopifolia
*Malva parviflora**
Maireana macrocarpa
Medicago spp.*
*Mesembryanthemum crystallinum**
Muehlenbeckia cunninghamii
Mimulus repens
Mollugo cerviana
Morgania floribunda
Myriophyllum verucossum
Nitella sp.
Paspalum distichum
Persicaria lapathifolium
Phragmites australis
*Phyla canescens**
*Polygonum aviculare**
Polygonum plebium
*Polypogon monspeliensis**
Potamogeton tricarinatus
Potamogeton crispus
*Ranunculus scleratus**
Rorippa islandica
*Rorippa palustris**
Rumex bidens
*Salix babylonica**
Sclerolaena brachyptera
Sclerolaena divaricata
Selliera radicans
Senecio runcifolius
Senecio sp.
*Solanum nigrum**
Solanum oligacanthum
*Sonchus oleraceus**
Sporobolus mitchelli
Swainsona greyana
Tetragonia tetragonoides
Trachymene cyanopetula
Typha domingensis
Typha orientalis
Vallisneria americana
Wahlenbergia fluminalis
Xanthium spp.*
Zannichellia palustris