What about the fish?

Improving fish passage through wetland flow control structures in the lower River Murray

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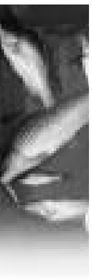
Dean Gilligan - New South Wales Fisheries

Natural Heritage Trust

Acknowledgements



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Australian Landscape Trust was contracted to Bookmark Supporters Community Group to undertake the project based at Calperum Station Renmark, South Australia.

Scott Nichols (Australian Landscape Trust) was the project officer, undertaking field sampling, report writing, and liaising with NSW Fisheries on methodology and data analysis.

Dr Dean Gilligan from NSW Fisheries undertook all statistical investigation for this project. Dr Dean Gilligan and Scott Nichols jointly interpreted the results.

Scott Nichols and Prudence Tucker compiled the literature review for this report.

Tracey Steggles reviewed drafts of this report.

Australian Landscape Trust staff (based at Calperum Station) Mike Harper, Sonia Dominelli, Andy McQuie and Prudence Tucker undertook field sampling during the high river flow in November-December 2000.

University of Adelaide Engineering students contributed laboratory investigations on fish swimming ability, species specific behavioural deterrents, structure management, and environmental conditions affecting fish movement through the Lock Six fishway.

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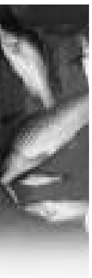

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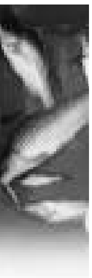

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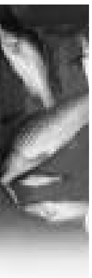
SUMMARY AND RECOMMENDATIONS



General remarks

Sampling for this project has revealed fish communities occurring within wetlands differ between wetlands and between different habitats sampled within each wetland system. This finding adds an additional layer of complexity to wetland (and fish) management, indicating that there will not be a “one size fits all” solution. Instead, a “precautionary principle” approach is required until baseline data is collected on the fish fauna of a particular site. Unfortunately, degradation of the river system is occurring at a rapid rate, with mistakes made early on in its management only now beginning to show. It is therefore imperative that collection of baseline data on fish populations and their basic biology occur in order to be able to manage the fish fauna in an appropriate, and ecologically sensitive manner.

This study has shown that, based on size class data and entry and exit of fish from wetlands, the wetlands surveyed were not acting as significant recruitment areas for any fish species analysed. For some species, wetlands appear to be acting as sinks for the population, with significantly more individuals recorded moving into wetlands than were moving out at various seasons. However due to limitations of the sampling equipment used, larval fish were not sampled. As a result it is possible that spawning may have occurred within wetlands, with larval fish dispersing back into the river at sizes too small to be sampled. Lastly, wetlands may act as grow-out (nursery) habitats with larger size classes of Australian smelt (*Retropinna semoni*), bony bream (*Nematalosa erebi*), callop (*Macquaria ambigua*), and goldfish (*Carassius auratus*), exiting wetlands than entering. As well as this occurring for some of the native species (including western carp gudgeon, *Hypseleotris klunzingeri*; and Lake’s carp gudgeons, *Hypseleotris sp5*; crimson spotted rainbowfish, *Melanotaenia fluviatilis*; and Australian smelt), significantly more carp (*Cyprinus carpio*) were recorded entering wetlands than leaving them in summer, and significantly more gambusia (*Gambusia holbrooki*) entered wetlands than left in autumn and spring.

Both of these findings have ramifications for wetland management, particularly for fish attempting to move out of wetlands and back into the mainstream habitat. For those species using the wetland as a grow-out area, management of the inlet structures should be undertaken to accommodate them and allow for movement of fish back into the mainstream. For those native species where wetlands are acting as a sink for their population, wetland management may need to be changed in order to sustain the population. In the case of introduced fish (carp in particular), removal of the population is a desirable outcome, and wetland management should be continued or changed so that their removal is enhanced.

Currently, with the exception of Pilby Creek Lagoon which can be actively drained, all wetlands sampled during the study are evaporatively dried. This means that once a management decision is made to dry the wetland, the inlet structure is closed and no further connection to the mainstream is possible. Whilst not a problem to semi-aquatic fauna that can move readily across land in search of new habitat (eg turtles, yabbies or water rats), this management action is particularly disadvantageous to the fish fauna who rely on an open (aquatic) passage to be present to move from the wetland back to the river. As water levels drop in the wetland, fish fall prey to predators or declining water quality and perish. Hence, wetland management is forcing the wetlands to act as a population sink. Where the wetlands are providing grow-out conditions for some fish species, this could be having the detrimental effect of removing young individuals from the population before they reach sexual maturity.

Under natural conditions, fish would also have been stranded in many wetlands as they dried. prior to river regulation, during dry periods some remnant wetland fish would have taken refuge in the river, surviving in the pseudo-wetland habitats created in the river channel as it reverted to a series of pools. However, under current river management, these pseudo-wetland refuge habitats within the river channel no longer exist during dry periods has been lost. Further, lateral migration of fish from riverine refuges and wetlands is now blocked by the presence of flow control structures.

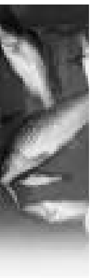
Serious consideration therefore needs to be given to the current method of wetland management, which improves wetland health, but has a negative effect on wetland fish populations. Due thought must be given to ensure that suitable and accessible refuge habitats exist for wetland fish communities when wetlands are dried. This may require a totally artificial process of captive stocks used to reseed wetlands following refilling, synchronised management of a number of wetlands within an area, or significant changes to current riverine flow regimes.

Structure type

Of the structures monitored during this study, under current management, downstream fish passage (into the wetland) was found to be significantly inhibited at Little Duck Lagoon (short pipe) and Loveday Wetlands (box culvert), although this was only slightly obstructed for Loveday. Under current management, downstream fish passage was also obstructed at Pilby Creek Lagoon (open-top box culvert), although this relationship was not significant.

When adjustment was made for changes in the direction of flow at some wetlands, it was shown that Lake Littra (large box culvert) structure facilitated movement of fish into wetlands that was most approximating unmanaged wetlands. Little Duck Lagoon, Lake Merreti (long pipe), and Werta Wert Lagoons (moderate length pipe) were the next most accommodating for fish passage into wetlands when direction of flow was considered, with Loveday Wetlands and Pilby Creek Lagoon structures providing the lowest fish passage efficiency (inhibited at both, although only significantly inhibited at Loveday Wetlands).

For fish passage out of wetlands (upstream movement) under current management, only Lake Littra structure and Werta Wert Lagoons structures were found to allow uninhibited fish passage. The other structures (in order of least inhibitive to most inhibitive to movement): Loveday Wetlands, Little Duck Lagoon, Lake Merreti, and Pilby Creek Lagoon all obstructed fish passage out of wetlands, although this was only significant for the Lake Merreti and Pilby Creek Lagoon structures.



When direction of flow at the time of sampling was taken into account, Loveday Wetlands, Werta Wert Lagoons and Little Duck Lagoon structures were the only structures to not obstruct fish passage out of wetlands. All other structures significantly obstructed fish movement out of wetlands including Lake Littra structure which was not found to inhibit fish movement under current management conditions.

It is unclear why Lake Littra obstructed fish passage out of the wetland. Build up of debris against the fish screens was observed on several occasions, and may have contributed to the obstructed passage out of the wetland. Maintenance of this issue may lead to an improvement in fish movement out of this wetland.

Similarly, it is unclear why Little Duck Lagoon was found to be obstructing fish passage in both directions under current management. $RFP_{structure}$ values improved for movement both into and out of the wetland when consideration was given to the direction of flow at the time of sampling, indicating that this may have been a factor. This structure could be improved through the installation of additional cells in the embankment, to increase the proportion of the structure relative to the cross-sectional area of the inlet channel. This will decrease flow velocities experienced in the culvert and facilitate fish passage.

Loveday Wetlands structure is also likely to be inhibitive to fish movement into the wetland as a result of structure management rather than structure design. Management of this six cell structure in the past has been to allow water exchange to occur through fully opening one or two cells at one time, rather than opening all cells a small amount each. By opening only one or two cells at once, water velocities experienced through the open cells would be increased, possibly limiting fish movement (possibly through behavioural avoidance). It is therefore recommended that future management of this structure utilise all cells within the culvert rather than only one or two so that water velocities encountered can be minimised.

Lake Merreti structure is a poor performer for fish movement out of the wetland due to the long distance fish must swim against laminar flows within the pipe in order to escape. The proportion of cross-sectional area of the inlet channel for this structure is low: by increasing this it is likely that fish passage out of the wetland will improve.

The poor performance of Pilby Creek Lagoon structure for fish movement out of the wetland is likely to be due to a combination of the structure setting and of the initial small fish screen size present. Due to the structure being set quite high in relation to the bed level of the inlet channel (perched), fish movement out of the wetland is limited prior to the fish reaching the structure itself as fish must first negotiate a steep rise. This rise is not a problem when water levels are equal or near equal either side of the structure, but becomes a problem when water levels on the wetland side have dropped below the base of the structure. Draining of this wetland provides an opportunity for fish to escape, however, rocks present on the downstream side of the outlet structure may damage or kill fish as they are flushed out of the wetland. The fish screens ($1cm^2$ mesh) initially present on Pilby Creek Lagoon inlet structure were too small to allow any fish greater than approximately 30mm total length (assuming they swam diagonally through the mesh) to enter or exit the wetland. The fish screens currently in use are likely to improve fish transfer through the structure, and fit with the design recommended by French *et al.* (1999) for inhibiting carp. This screen design (5mm diameter metal rods placed vertically approximately 10mm apart) is still likely to inhibit movement of a number of species, but allows greater access to most of the smaller fish species, and those that are greatly laterally compressed (eg bony bream).

It is recommended that monitoring of fish movement through this structure occur when water levels have equalised either side of the structure. This will enable the effectiveness of these fish screens at passing fish to be determined, eliminating the influence of the structure being perched when considering movement of fish out of the wetland.

It is also recommended that removal of rock rubble and creation of small pools occur on the downstream side of the outlet structure in order to lessen damage to fish that are flushed from the wetland during wetland draining, and erosion from water discharge.

Lastly an open-top box culvert should be installed at another wetland to further investigate the ability of open-topped structures to allow fish movement into and out of a wetland. At Pilby this complicated assessment as the structure was perched, therefore confounding the assessment of the open-topped structure.

Structural characteristics

Structural characteristics measured included depth of water within the structure (cm), flow velocity through the structure (m/s), the height of the invert above the inlet bed (cm), screen mesh size of fish screens (area in cm^2), the width of the apron (cm), the cross-sectional area of the culvert (cm^2), the percentage cross-sectional area of inlet (%) and openness of the structure.

Of the above characteristics, upstream fish movement (out of a wetland) was most influenced by apron width, proportion of the cross-sectional area of the inlet, and flow. A short apron width present and a large cross-sectional area of the culvert were found to be the most important characteristics for movement of fish out through the structures surveyed. It is therefore recommended that these characteristics be considered during future structure design. Flow was also found to be an important factor in passage of fish out of the wetlands surveyed, however fish passage was found to be greatest when higher flows through the structures were experienced. This is the opposite to what would be expected for fish moving against the flow, as it would be thought that low flows would allow fish to travel further against them when inside the structure.

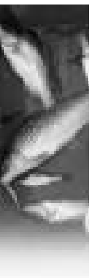
For movement of fish into a wetland, flow within the structure was the only factor found to be significant for the wetlands surveyed, with increasing fish passage occurring with decreasing flow. However, flow only accounted for 27.78% of the variation observed, thus indicating that other factors may be influencing fish movement into the wetlands.

Dooland *et al.* (2000) found that in a laboratory flume, carp drifted or actively swam with the flow when flows were less than 0.4m/sec (Dooland *et al.* 2000). Above this velocity carp were swept through the artificial culvert, employing burst speed repeatedly to fight against it. At 0.4m/sec fish would actively avoid being swept or drift into the culvert. It is therefore recommended that where possible this filling velocity be employed to minimise carp colonisation of wetlands (Dooland *et al.* 2000).

Fish screens

The use of fish screens on managed wetlands needs consideration. Results from this study indicate that both the abundance and biomass of carp in managed wetlands with fish screens were not different to wetlands without fish screens (managed or unmanaged). When wetlands were investigated individually, size class analyses showed that a greater number of small carp (50-200mm) occurred in all wetlands studied

except Gurra Control Wetland. However, no significant differences were found between river and wetland systems for fish 250-300mm, except at Loveday Wetlands where a greater number of large carp occurred in the wetlands.
These findings indicate that, although carp greater than 300mm are excluded from wetlands, fish screens are not effective to stop small carp and fish up to 300mm in size from entering. As carp can reach 200mm in their first year (Brown 1996), and management of many wetlands is for it to remain wet for longer than one year, consideration is needed as to the usefulness of fish screens on wetland inlet structures when carp of the this size are present in equivalent frequencies whether a fish screen is present or not.



Management of fish screens, along with management of the structure itself needs to be improved. This study has shown that carp, goldfish and callop are nocturnal or crepuscular in their activity, indicating that fish screens could potentially be managed on a daily basis in order to minimise carp movement into wetlands and maximise native fish thoroughfare. Although callop were also found to be nocturnal or crepuscular in their movements, their use of wetlands as adults appears minimal, allowing for fish screens to be used if deemed necessary to control carp access.

Structure management and maintenance

In addition to structural characteristics, management of the structure is a very important factor in facilitating fish movement into and out of wetlands. Regular structure maintenance is required to ensure structures remain operational in the manner for which they were constructed. This includes regular cleaning of debris from the culvert (especially from fish screens where present) to ensure headlosses are minimized across the structures and fish passage is not blocked (Northcote 1998). It also includes monitoring the effectiveness of the structure itself (eg checking for the presence of leaks that may attract fish to danger areas) to ensure it is acting correctly.

Correct operation of the structure is also important, and may be as important as the design of the structures themselves (Dooland *et al.* 2000). A structure that has an approximate cross-sectional area equal to the surrounding inlet channel, but is only managed to use one or two of the cells present within the structure, will not be effective at allowing fish movement through the structure. All cells present should be employed to facilitate water and fish movement.

It is recommended by Dooland *et al.* (2000) that filling velocities within the structure remain at around 0.4m/sec in order to minimise carp influx into wetlands (Dooland *et al.* 2000).

Where fish screens are present, these should be employed at the times when carp are most active. On a daily basis carp are more active at night, dusk and dawn, meaning that to minimise carp access into wetlands, fish screens should be in place at these times. On a seasonal basis, carp are known to have a major breeding event in spring (mainly in October, but extending from August to February), therefore where screens are employed, they should be in place at this time, and at water temperatures are below 20ºC (when native fish begin breeding activity) (Mallen-Cooper 1996, Dooland *et al.* 2000).

Water quality parameters should also be monitored as a part of wetland management. Increasing water temperature and conductivity were found to be important factors stimulating fish movement into wetlands. When native fish were isolated for analysis, increasing water temperature, conductivity and decreasing flow in wetland inlets were found to stimulate native fish movement into wetlands. For introduced fish, increasing water temperature, conductivity and flow in the inlet channel, with decreasing turbidity were found to stimulate movement into wetlands. These factors only explained 41% or less of the variation for movement into wetlands, indicating other factors are also involved, however, changes in these parameters do allow for a prediction of fish activity which can be used to benefit structure management.

No water quality or environmental parameters were found to explain movement of the entire fish community or introduced fish out of wetlands. When native fish were analysed alone, however, increasing turbidity and flow at the nearest lock were found to be significant, although only explained 10% of the variation indicating other factors are involved. Therefore turbidity and increasing flow at the nearest lock can be used as predictors for native fish movement out of wetlands, allowing management of the inlet structure to occur accordingly.

Use of attractant flows

Preliminary investigations conducted as part of this project indicate that the use of attractant flows to encourage fish movement out of wetlands prior to undertaking a drying event may be beneficial. The validity of this requires further investigation however, with practicalities needing to be taken into account such as if fish are unable to move themselves out of a wetland, how they would be removed prior to drying (manually or mechanically).

Use of deterrents

Dooland *et al.* (2000) and Champion *et al.* (2001) undertook laboratory investigations on carp responses to various deterrents, and indicated that for most either no response was observed, or habituation to the deterrent occurred quite quickly, limiting their effectiveness (Dooland *et al.* 2000, Champion *et al.* 2001).

Presence of coarse substrate either side of a culvert did not elicit any response in carp moving through it in the laboratory (Champion *et al.* 2001).

Although carp were found to prefer a darkened environment, the presence of a strong light source at the culvert did not completely inhibit movement through the culvert, but did increase the time taken before fish darted through (Dooland *et al.* 2000, Champion *et al.* 2001).

The use of an acoustic device found that carp were most deterred by frequencies of 10 and 20Hz, with the greatest effect observed at 20Hz. Results varied between single fish and groups with and without a leader (single larger fish), less effect was observed in groups fish without a leader fish (Champion *et al.* 2001).

In combination, the use of light and sound was not found to increase the effect on fish, but the remained at the same level (Champion *et al.* 2001).

As with light and sound deterrents, the use of a bubble curtain did not inhibit carp movement through the culvert in the laboratory, although increased the amount of time taken before fish darted through (Champion *et al.* 2001). All these deterrents have limited application in the field as a result of the highly turbid waters present in the lower River Murray (light) and energy or maintenance requirements (sound, light, bubble curtain) to run.

A fifth deterrent investigated, the half barrier, may hold more promise however. This sloping chicken wire mesh structure that decreased the water depth available for fish to move through effectively stopped carp from crossing it throughout the test period.

Although this experiment was conducted under no flow conditions (flow is essential for carp to jump: Stuart *pers. com.* 2003), this barrier warrants further investigation into its effectiveness and its effects on native species. As there are no moving parts or energy requirements, it is potentially very useful for the field with cleaning of debris the only issue.

Dooland *et al.* (2000)'s finding that carp actively avoided moving through a laboratory culvert at flows of 0.4m/sec could also be employed as a management tool to deter or minimise carp movement into wetlands (Dooland *et al.* 2000).

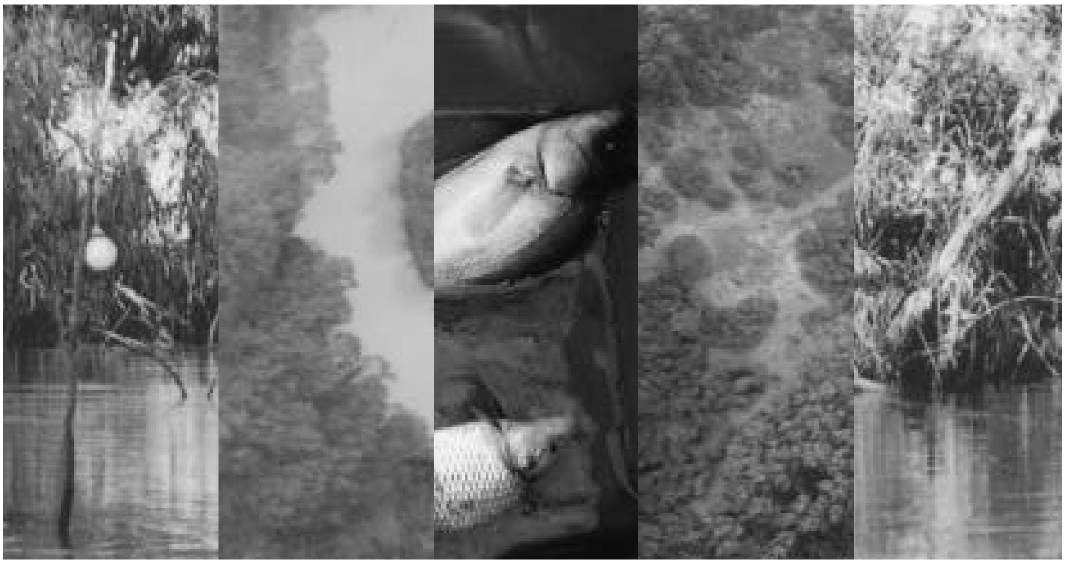
Future investigations

It is recommended that if this study were to be repeated, more unmanaged wetlands should be included in the survey to overcome inherent differences found between wetlands.

It is recommended that further monitoring of the open-top box culvert (Pilby Creek Lagoon) occur at times when water has equalised either side of the structure to determine upstream fish passage capacity at these times. In addition, it is recommended that an additional open-top box culvert be installed on another wetland in the region so that fish passage ability can be determined for a pool level wetland that does not bypass a mainstream weir. Both these recommendations will remove the complicating factor of the poor setting present at Pilby Creek Lagoon inlet structure.

Further investigation should be conducted into the effectiveness of carp deterrents tested (in particular the half barrier) in the field, and the effects of it on native fish passage (in the laboratory and in the field). Development of the acoustic and light deterrent should include development of a low maintenance, inexpensive power source.

The use of attractant flows as a means of minimising fish deaths due to wetland management should be investigated. The practicalities of this management option also needs further investigation, with active removal of fish from the wetland through netting most likely required to enable fish to move out of a wetland once a drying cycle has been initiated.



INTRODUCTION

Background to project

This project was initiated in 2000 to address a major gap in our knowledge of fish behaviour in a wetland and floodplain environment, and in particular if and how wetland rehabilitation projects are affecting this behaviour (if at all).

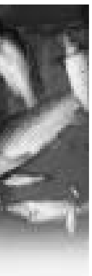
The project examined the requirements / ability / need for all fish captured to move into and out of wetlands with fish and flow control structures present. A number of different structure types were chosen across a range of wetland types to determine which existing structures had minimal effect on fish movement.

This study resulted in the production of wetland specific recommendations on how to manage existing fish and flow control structures to benefit the passage of native fish during lateral migrations between the river and associated floodplain wetlands, and general recommendations for the construction and installation of fish and flow control structures at new wetland rehabilitation sites.

It complements, and has worked closely with, a New South Wales Fisheries project "*Development and testing of national guidelines for "fish and flow friendly" causeway, culvert and wetland inlet structures*" that investigated fish movement through road crossings. Results from these projects have collaboratively formed the scientific basis for a major document and a summary document that outlines fish passage requirements and construction guidelines for waterway crossings (*Fairfull, S. and Witheridge, G. (2003). Why do fish need to cross the road? Fish passage requirements for waterway crossings. NSW Fisheries, Cronulla, 16pp.*).

This project funded two groups of final year Civil and Environmental Engineering students in 2000 and 2001 to undertake additional laboratory investigations, complementary to the project's focus. Their findings have been incorporated into the general findings of this report, and journal articles of their work are presented in Appendix D.

This project was funded by the Natural Heritage Trust MD 2001 Fish Rehab Program through the Department of Agriculture, Fisheries and Forestry – Australia (AFFA) over three years. The staff of the Australian Landscape Trust, Calperum Station, undertook fieldwork and report preparation on behalf of Bookmark Supporters (Friends of Parks Inc). Dr Dean Gilligan of NSW Fisheries developed the sampling strategy, undertook statistical analysis and preliminary interpretation.



Objectives

The following objectives were identified for this project in consultation with the NSW Fisheries project team:

1. Determine the influence of flow rate and flood height on movement of fish between the river and floodplain wetlands.
2. Identify the relative importance of channel versus over-bank flows for fish passage into and out of wetlands.
3. Assess the importance of wetlands for fish recruitment.
4. Determine the impacts of wetland inlet structures on fish passage for native fish.
5. Assist in the development of guidelines to facilitate movement of native fish through inlet structures while excluding carp.
6. Make recommendations on the design of new structures.

Fish in the Murray-Darling Basin

It is widely acknowledged that the distribution and abundance of native fish in the Murray-Darling Basin, has declined as a result of a number of impacts (Cadwallader 1978, Walker 1983, Gehrke *et al.* 1995, Milburn 1995, Harris and Gehrke 1997, Wahlquist 1997, Sinclair 1999, McNee 2000).

As early as the 1970's, it was recognised that 11 species of Australian freshwater fish were seriously threatened or considerably reduced in distribution as a result of dams and weirs blocking migration paths (Lake 1971).

All fish species within the Basin are known to undertake some degree of movement during their life, thus artificial barriers such as levees, culverts, weirs or flow control structures that obstruct fish movement are likely to make a significant contribution to this decline (McNee 2000). Indeed, the Draft Native Fish Management Strategy for the Murray Darling Basin 2002-2012 considers barriers to be a key threat to native fish populations in the Murray Darling Basin (MDBC 2002). In at least one other instance, these barriers have been implicated in the extinction or decline of fish species (Pierce 1992).

In systems like the Murray-Darling Basin where species have evolved to highly variable conditions, river regulation continues to have a sizeable impact. Research findings suggest that the diversity of fish communities decreases as catchments become more regulated (Gehrke *et al.* 1995). For example, changing the timing, duration, and frequency of flooding in the Murray-Darling Basin reduces the reproductive success of native fish by "desynchronizing environmental cycles and the reproductive cycles of native species" (Gehrke *et al.* 1995). The New South Wales Rivers survey found that in the Murray catchment introduced species, such as carp and redfin perch (*Perca fluviatilis*) dominated the catch. Stable (regulated) river conditions are thought to disadvantage native species and favour the spread of exotics (Harris and Gehrke 1997).

The stable river levels maintained by the weirs on the River Murray have affected adjoining wetlands. Wetlands that fill at what is now the regulated river level have become permanently inundated rather than fluctuating with the changing levels of the pre-regulated river. In the Lower Murray, the reduction in frequency and duration of floods has meant that wetlands situated at higher elevation on the floodplain do not become inundated as frequently as they would have under natural conditions. When flood conditions do occur, the duration of inundation is significantly reduced.

Within the constraints of river regulation, local wetland managers are actively managing wetlands to reinstate natural flooding regimes and prevent large carp from entering wetlands. To achieve this they use flow and fish control structures at the wetland inlets, with many different structure types being installed as part of approximately 20 established rehabilitation projects, and over 90 more proposed (Goodman *pers. com.* 2003).

Wetland inlet structures in the Lower Murray vary in size and dimensions, largely as a result of the absence of guidelines for construction, and an *ad hoc* approach to design and management. To date these structures have been designed and installed based on available knowledge, materials, and (often most importantly) funds, but with limited knowledge of their impacts on the passage and recruitment of native fish. Current management has raised community concerns about the exclusion of all large fish from wetlands, with anecdotal information suggesting wetlands are an important part of fish habitat.

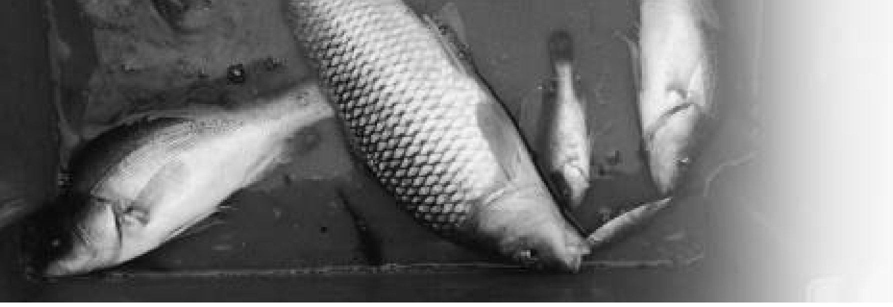
Wetland inlet structures can present a physical barrier to fish, preventing or limiting movement of different species and size classes through the structure due to physical swimming abilities or behavioural preferences (Harris 1985). Structures may also alter the local water quality through increasing water velocity, turbulence and noise, or changing water oxygenation and temperature so that the structure surrounds are unsuitable to some or all fish (WAEPA 1987, West 1992). Similarly, unsuitable design or location of a structure could result in fish being “instinctively reluctant” to enter the unnatural environment of a culvert

More detailed background information can be found in Appendix A Literature review.

This project aimed to quantify the effect of flow control structures and fish gates on fish movement, and determine methods to discourage the passage of carp, whilst promoting the movement of native species. By monitoring fish movement at different structures, we aim to make recommendations for optimal design of new structures and management of existing structures.

This project addresses several knowledge gaps raised by Humphries *et al.* (1999), who identified the need for further research on the following:

- “the use of floodplain habitats, and particularly the flood plain proper during inundation, by all life-stages of Murray-Darling Basin fishes”;
- “movement of free embryos, larvae, juveniles and adults of small and large Murray-Darling fish species”;
- “population dynamics of small and large species of Murray-Darling fishes”; and
- “the relative importance of in-channel versus floodplain habitats as nursery areas” (Humphries *et al.* 1999).



METHODS

Sampling regime

The following methods were adapted to suit local conditions from methodology recommended by NSW Fisheries.

Net design

In order to sample a range of fish species, fyke nets were considered the most effective method available. Fyke nets can be used to sample sites of various water depths (to as low as 20cm), directional movement within inlet channels and river or anabranch, non-directional movement in wetlands, and can be easily attached to modified fish screens at inlet structures in order to directly sample fish fauna at these locations.

To ensure the nets were capable of catching a representative sample of the fish community (ie a range of size classes) under a range of flow conditions, a mesh with a maximum bar length of five to six millimetre (10–12mm stretch mesh) was used.

The nets used in this study (Plate 1) comprised synthetic mesh (bar length of five millimetre), a flat-bottomed entrance hoop 600mm in diameter, and three internal funnel traps. A five metre long leader of the same mesh size was attached centrally and temporarily fixed (with cable ties) to either the left or right side of the entrance hoop when sampling for directional movement.

Fish captured were accessed at the opposite end to the entrance hoop by means of a drawstring opening (closed during the time that the net was set; termed the “collection end”). A polystyrene ball float was placed in the collection end to prevent drowning of air breathing animals (turtles, water rats and diving birds) that may become trapped in the net.

Standard sampling

General net set

As shown in Figure 1, a standard sample was carried out over two consecutive days (48 hours).

Nets were set on the first afternoon in the river (or anabranch) and inlet channel on the river side of the flow control structure. Where an inlet structure net was present, this was set to observe fish movement toward the river/anabranch at this time. Nets were then left overnight and checked and reset the following morning. In the afternoon of

Plate 1. Sampling Gurra Control Wetland with fyke net.

the second day, the nets were checked and moved to the wetland side of the flow control structure, where they were set in the inlet channel, the wetland itself, and at the inlet structure to observe fish movement toward the wetland. Nets were again left overnight, checked and reset in the morning of the third day, and left until the afternoon, when they were checked and removed. Variations of this net set pattern occurred at times throughout the survey (ie with nets set in the morning instead of the afternoon), however the length of net set remained consistent.

The above methods broke the data collected into two periods: a day period, and a dusk-night-dawn period (herewith referred to as the "night" sample). This enabled the determination of peak fish activity times and recommendations to be drawn about improving structure management (ie removal of fish gates during times of maximum native fish activity and installation at times when carp were most active).

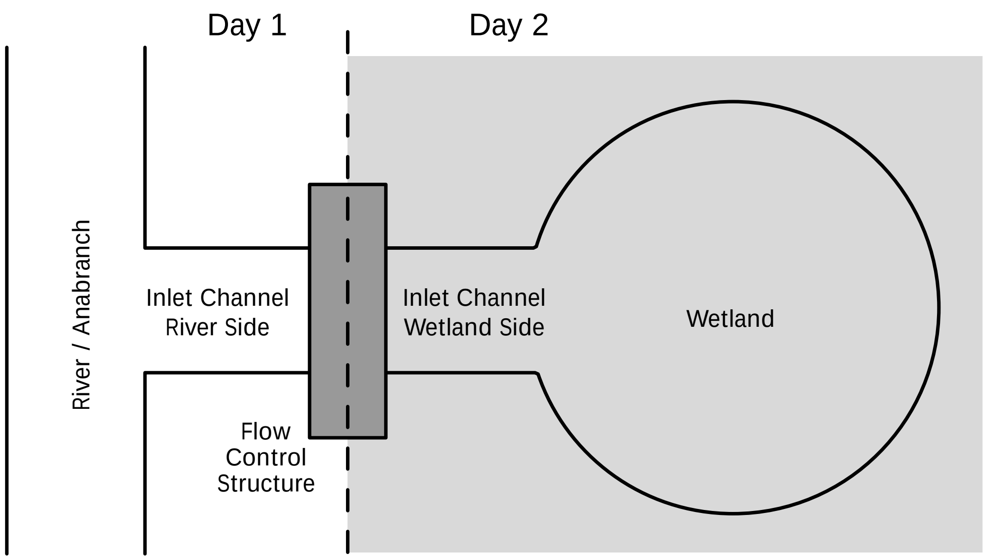


Figure 1. Standard sample showing staggered net set.

Net set was staggered either side of the structure to ensure that none of the nets would confound the catches of any of the other nets. For instance, if nets were set on both sides of the inlet structure at the same time, there is a potential to remove fish from the system prior to them moving through the structure in either direction, thus confounding the data collected.

Nets per wetland

In each wetland, nets were set as follows:

- in the river (or anabranch) adjacent to the wetland inlet (four nets);
- in the inlet channel on the river side of the structure (two nets);
- in the inlet channel on the wetland side of the structure (two nets);
- in the wetland (four nets); and where possible
- at the inlet structure itself (typically one net, set for upstream or downstream movement on consecutive days).

The position of nets during each sample period is shown in Figure 2.

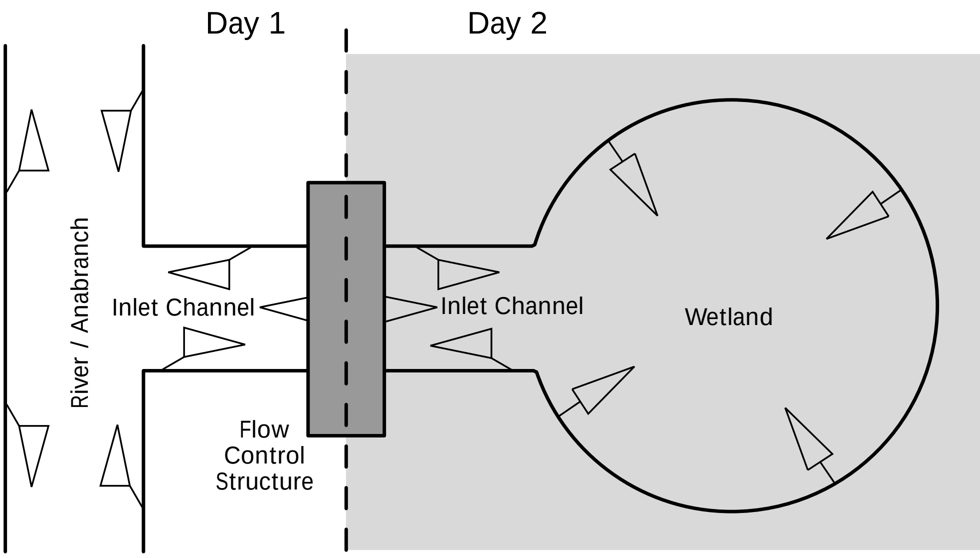


Figure 2. Typical positioning of nets.

Nets were set at these locations in order to capture

- fish available to move into the wetland (nets set in the river or anabranch);
- fish that are potentially willing to move into the wetland, or who have moved out of the wetland through the structure successfully (nets set in the inlet channel on the river/anabranch side);
- fish that have successfully moved through the structure from the river/anabranch side, or are trying to move out of the wetland (nets set in the inlet channel on the wetland side); and
- those fish who are inhabiting the wetland and not trying to move through the structure (nets set in the wetland).

Directional net set

River/anabranch and inlet channel nets

In order to determine the direction of fish movement at each site, nets in the river/anabranch and inlet channels were set to limit the fish catch, and sample fish only moving in one direction. This was achieved by temporarily fixing the net leader to either the left or right side of the entrance hoop with cable ties.

Where directional information was required, nets were set parallel to the bank with the entrance hoop facing up or downstream as desired. The body of the net was set within one to two metres from the bank, and the leader extended forward at an angle toward the bank. Stakes were used to secure the collection end and leader in place, and a weight was attached on the opposite side of the entrance hoop to the leader to prevent the net rolling over.

Where possible, nets were set in water not much deeper than the entrance hoop (usually around one metre), however the water depth may have been up to three metres at times.

Wetland nets
At sites within the wetland, nets were set perpendicular to the wetland edge. The leader was attached to the centre of the entrance hoop and extended toward the shore. The net was then stretched in the opposite direction, with the collection end toward the centre of the wetland.

Where water depth was not great enough to have the net completely submerged, nets were set some distance from shore, but always perpendicular to it. As with the river/anabranch and inlet channel nets, a foam float was inserted into the collection end to allow air breathing animals to survive, and a weight attached to the entrance hoop on the side of the prevailing wind to prevent the net from rolling over.

Inlet structure nets
In order to sample fish movement at each flow control structure, nets were attached to one cell of the flow control structure to catch fish as they moved through. This occurred at Lake Littra, Pilby Creek Lagoon, Lake Merreti (permanent and upstream temporary inlets) and Little Duck Lagoon, and generally required the development of an adapted fish gate.

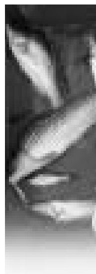
No inlet structure net was set for Werta Wert Lagoon inlet structure, as no fish gates were present, and no inlet structure net was set at Loveday Wetlands due to vandalism (removal) of the inlet structure net guides soon after their installation.

The adapted fish gates were made identical to those gates already present at the structure, but with a “D” shape section cut out of the base of the mesh (flat edge of the “D” on the base of the mesh gate). A leaderless fyke net was then attached to the mesh to catch all fish moving or attempting to move through the structure. The adapted fish gates were slid into position using guides already present, or those attached for the purpose of sampling.

Normal management of the wetland was able to continue during the sample period, as all the fish gates remained in place.

The only sites where an adjusted fish gate was not installed to the flow control structure was at Lake Merreti wetland. At the main inlet structure for this wetland (which is connected at pool level flows), at high flows, a large drum net was employed to catch fish moving through the structure with the water. This type of net was deemed necessary due to the high water velocities encountered at times of high flow, and the possibility of debris building up and breaking through an adjusted fyke net, and the almost certain damage to fish captured in the net.

The 10m long “drum” style net was made from synthetic mesh (approximately 25mm bar length). It possessed a series of 1.2m diameter aluminium tubing hoops for support, and a single funnel leading to the collection end which was tied with a draw



string. The net was attached to an aluminium guide that was slid over the end of the inlet structure's pipe, with the collection end tied to a tree, so that any fish captured were kept out of the high water velocities.

During low flow periods, this net was replaced with a small drum style net of the same mesh size. This net possessed a single funnel that was placed over the end of the inlet pipe, and led to a single collection area 1.2m diameter. Fish were collected from this net by means of an aluminium gate.

A small rigid framed box style net was also used for the capture of fish at the inlet structures on the temporary inlets to Lake Merreti. This net comprised a metal box shape frame, with synthetic mesh (approximately 25mm bar length). Fish entered the net through a centrally located entry point, leading directly into the body of the net. Fish were also collected by means of a gate present in the side of the net.

Water quality and flow readings

Water quality

Water quality was measured at the flow control structure, and at each net, with the exception of inlet channel nets, where only one measurement was taken due to the close proximity of the nets to each other.

Measurements were generally collected in the afternoon when nets were set, but when this was not possible, readings were taken in the afternoon sometime during the net set period.

Five water quality parameters were measured using a HORIBA U–10 automated water quality machine. Water quality parameters recorded using this machine were turbidity (Nephelometric Turbidity Units –"NTU"); dissolved oxygen (mg/L); pH; water temperature (°C) and conductivity (mS/cm or µS/cm).

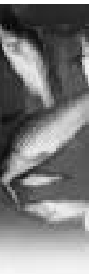
To account for the variation occurring with this machine when measuring turbidity and dissolved oxygen, four readings were taken for each of these parameters and averaged for each sample.

Where the HORIBA U-10 was not used, a handheld TPS conductivity-salinity-pH-temperature meter (model WP-81), and a handheld TPS dissolved oxygen-temperature meter (model WP 82) were used. As the names suggest, these machines measured conductivity (mS/cm or µS/cm); pH; temperature (°C); and dissolved oxygen (ppM).

All machines were regularly calibrated.

A visual measure of light penetration into the water column was also recorded using a secchi disc. This method measures the depth to which a black and white disc can be seen, as it is lowered into the water column. The point at which the disc reappears on raising it from its disappearance point is known as the secchi depth. Secchi depth was measured to ensure a measure of turbidity was always taken regardless of the water quality checker used.

All conductivity readings were converted to EC units prior to analysis. Similarly, all dissolved oxygen readings were converted to mg/L.



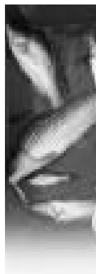
Flow
Water depth and flow were usually recorded for every net at the same time as water quality, but may have been taken at any time during the net set period. Flow readings were taken using a "Flow Mate 2000" flow meter.

Readings were taken at mid-depth of the water column at each net, with the exception of inlet channel nets, where flow was *often only recorded once due to the close proximity of nets*. The mainstream flow was also noted (as a subjective scale of still-strong flow).

At flow control structures, a flow profile was recorded. Flow measurements were taken at 10%, 50% and 90% of the culvert width, and at the surface, 20%, 50%, and 80% of the water depth. Water movement into or out of the structure was also noted.

Biological records
All fish captured were identified to species level where possible.

Where catches were over 15 specimens per species, 15 individuals were measured to the nearest millimetre (fork length for forked tailed fish; total length for others). All fish over the 15 measured individuals were counted. Where exceedingly large numbers of one species were present in a sample, an estimation of the total number of individuals was carried out.



Fish health (eg healthy, dead, ulcers, and parasites), sex, and sexual condition (eg running ripe, breeding) were also recorded, although not used during analyses. This data is stored on the project database held with the Australian Landscape Trust office, Calperum Station.

All fish, including carp, were released as soon as they had been processed. All fish were released in order to minimise the impact of the sampling process on the fish population. Destructive sampling of carp and other introduced species (by removing them from the water) may have resulted in a skewed representation of their abundance over time in comparison with the natives as a direct result of the sampling process. By returning all fish to the water after processing, the effects of the sampling methods on the fish population could be minimised.

Fish tagging program
In April 2001 a fish tagging program was initiated. Only robust fish such as carp, goldfish, callop and redfin perch were tagged to monitor their movements. Although very common, bony bream were not tagged, as they stressed easily through the capture process, and readily died without being tagged.

All robust fish greater than 170mm were tagged with a coloured, and uniquely numbered plastic dart tag when captured. The tags were divided into three colours: blue for fish between 170 and 300mm; yellow for fish between 300 and 500mm; and red for fish >500mm. All tags possessed a unique identification number, the words "Fish Research" and the contact details for the Australian Landscape Trust at Calperum Station.

Non target species
A number of non target species were captured using the above methods during the surveys including invertebrates, turtles, and ducklings. These animals were released as the catch was sorted.

Few records exist for the distribution of turtles throughout the state and the health of their population, therefore a decision was made to identify the turtle to species, record their upper carapace length and mid-width, and any damage to their shell or body. Data collected about these off-target species will briefly be presented here; it is stored in the project database held with the Australian Landscape Trust office, Calperum Station.

Sample frequency

During high flow periods, samples were taken at each wetland once within every 10,000ML/day rise in water level. Due to the rapid flow recession, sampling every 10,000ML/day drop was not possible. Only one sample was therefore taken during the flow recession, followed by one on return to pool level conditions.

The temporary wetlands within this project were monitored when flows were available to them. This only occurred from late November 2000 to early January 2001. Water levels within Chowilla Oxbow became too shallow to sample after January 4 2001, although water was artificially held back in Werta Wert Lagoons and Lake Littra until mid January 2001, allowing one additional sample to be taken from these wetlands.

All other wetlands were sampled throughout the project from November 2000 to December 2002. During the high river flow of 2000-01, sampling was undertaken at the frequency described above. During regular low flow periods (pool level flows), samples at pool level wetlands were undertaken seasonally.

In 2001, when no high river occurred over spring/summer, samples at wetlands connected at pool level were taken monthly from October to January to record fish activity during this period. Only one sample was taken in summer 2002 (December).

Site selection and wetland management during project

Wetland sites were chosen to reflect a range of flow control structure types present on rehabilitated wetlands that filled at a range of river flows. All wetlands were situated in the Riverland region of South Australia, from the New South Wales / South Australian border in the east, to the township of Cobdogla in the west (approximately 100km linear distance). Plate 2 indicates the location of all wetland sites upstream of Renmark, Plate 3 indicates those wetlands sampled downstream of Renmark, whilst Appendix B indicates the GPS positions of nets.

Temporary wetlands

Three temporary wetlands were sampled during this survey, all present on the Chowilla floodplain.

Lake Littra (high level temporary wetland)

Lake Littra wetland is located on the New South Wales/South Australian border, approximately 60km north east of Renmark (Plate 4a).

Lake Littra is a deflation basin with an area of 69ha. It is filled from Punkah Creek via a single, shallow, approximately 700m long, inlet/outlet at flows of between 47,200 and 62,000ML/day. When full, Lake Littra reaches a maximum depth of about one metre. Naturally, this wetland drains back to Punkah Creek on a flood recession.

Lake Littra has a flow control structure installed on the inlet channel near its junction with the wetland (Plate 4b). The flow control structure was constructed in 1995 and comprises two large box culverts with internal diameter of 126cm x 125cm, and an outside diameter of 138cm x 140cm. The structure is 3.64m in length. Revolving fish

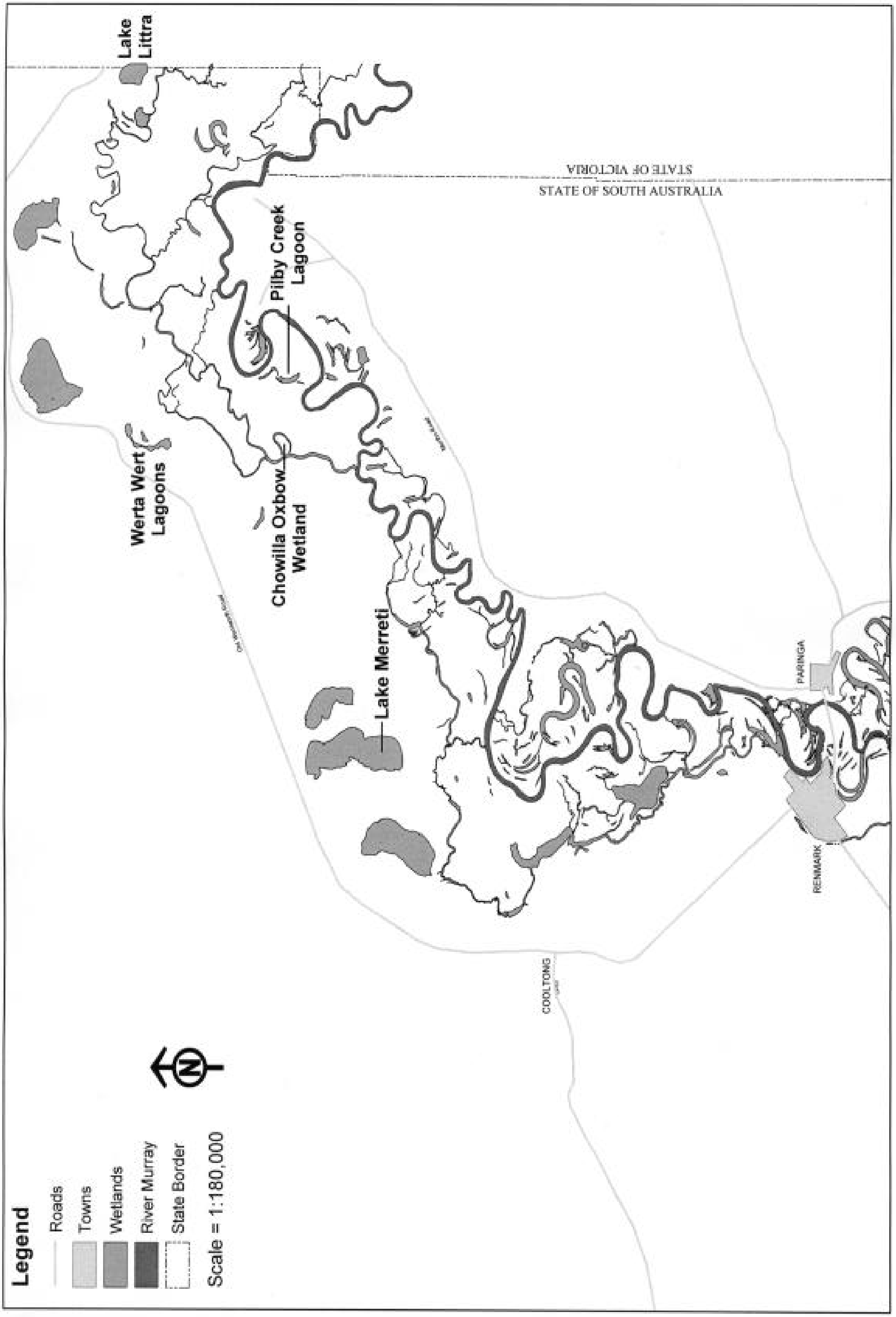


Plate 2. Location of sample sites upstream of Renmark.

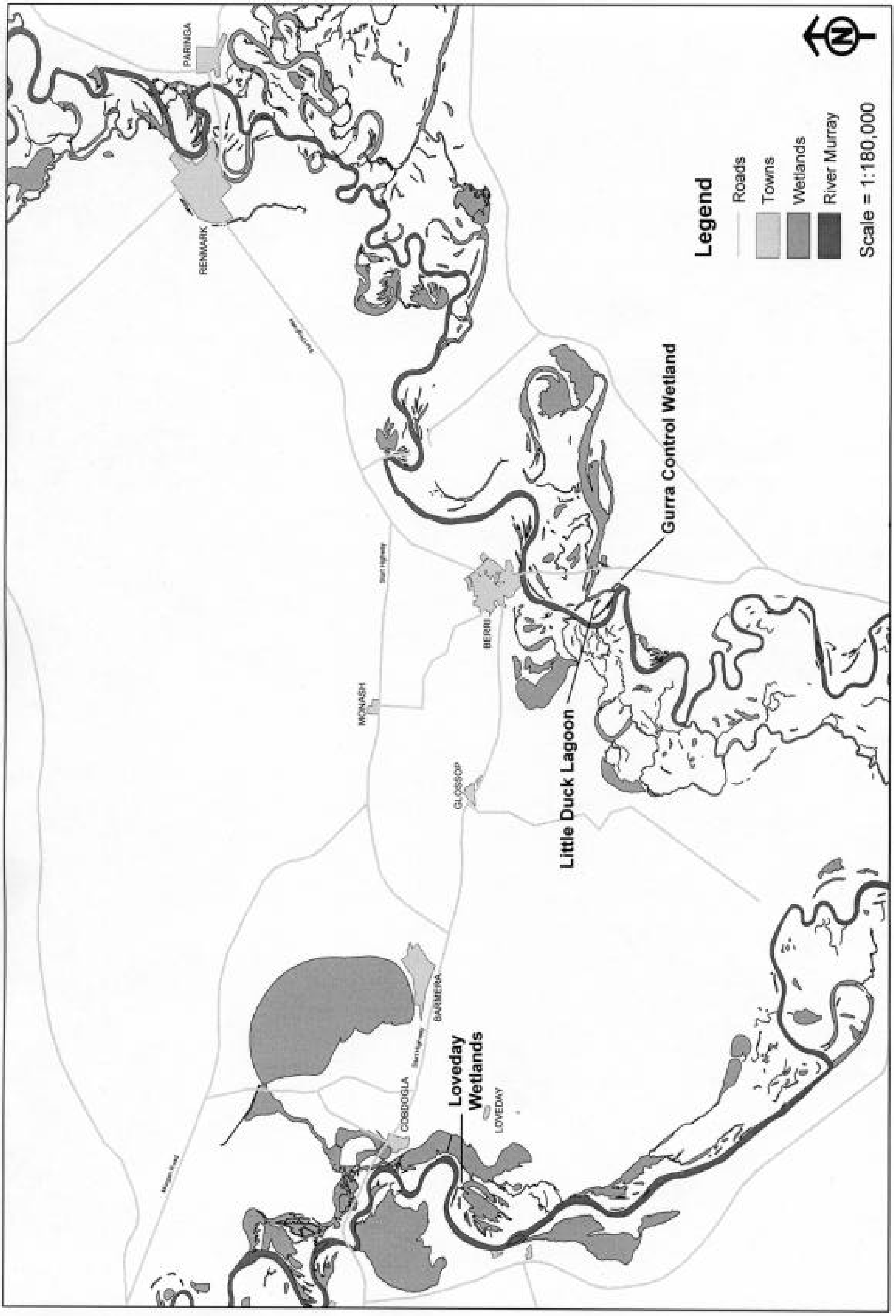


Plate 3. Location of sample sites downstream of Renmark.

gates were installed on the upstream side of the culvert in 1996. These gates comprise aluminium "security" mesh screens with openings 97mm wide x 33mm high, and 10mm wide metal rods welded vertically in the centre of these openings (effectively halving the opening size). Drop board guides are present on the downstream side of the culvert to allow water to be held back in the wetland during flood recession.

Red gums (*Eucalyptus camaldulensis*), black box (*Eucalyptus largiflorens*), river coobah (*Acacia stenophylla*), lignums (*Muehlenbeckia florulenta*) and spiny sedge (*Cyperus gymnocaulos*) dominate the vegetation that surrounds the lake. A small patch of lignum occurs centrally on the lakebed. No aquatic plant growth was observed during the sample period (spring/summer 2000/01).

Littra Inlet Channel

The shallow, temporary, 700m long inlet channel to Lake Littra winds its way across the clay floodplain through areas of lignum and adjacent areas of dry land tea-tree (*Melaleuca lanceolata)* and black box growing between the inlet and the lake. On the wetland side of the structure, the inlet channel is short (approximately 280m) and defined, and passes through dense lignum before entering the wetland.

The inlet channel sample sites were just upstream and just downstream of the structure (Plate 4c). No aquatic or riparian vegetation was present either in the channel itself or on the adjacent banks, although areas of lignum were present both upstream of the structure (prior to the sample sites) and downstream (after the sample sites). The inlet channel around the structure was composed of clay and rock rubble (left over from construction).

Punkah Creek

Punkah Creek is a permanent, narrow, relatively shallow secondary anabranch of the River Murray. It is located nearest the upland edge of the Chowilla floodplain, and is fed from a primary (un-named) anabranch of the River Murray, whose source is in NSW. Downstream of Lake Littra, Punkah Creek feeds into Slaney Creek, which in turn feeds into Chowilla Creek, before feeding back into the River Murray downstream of Weir and Lock Six. It therefore by-passes Weir and Lock Six and contributes to approximately half the flow into South Australia (the remaining half moving along the main river channel).

At the sample site adjacent to the Lake Littra inlet channel several snags were present. No aquatic vegetation was observed at the sample sites during the study, with vegetation on the creek bank being sparse. Patches of common reed (*Phragmites australis*) and spiny sedge were recorded along with areas of lignum. The overstorey was equally as sparse, with mature red gums scattered along the creek, and an area of dense younger red gums growing opposite the inlet to Lake Littra.

Lake Littra wetland management during project

This wetland filled during the high river flow in summer 2000-2001. Water was held back in the wetland from the peak in flow (21/12/00) until mid January 2001 using stop logs. Water was allowed to gradually drain from the wetland over several weeks. Only two samples were taken at Lake Littra when the flow control structure was closed (2/1/01 and 14/01/01), all others were taken when the flow control structure was open.

Fish screens were generally in place for all samples with the exception of 9/12/00 when a build up of debris had caused them to rotate slightly, allowing all fish access to the wetland for a period of time, although it is unknown how long the screens had been askew.

Werta Wert Lagoons (medium-high level temporary wetland)
Werta Wert Lagoons are located along the upland edge of the Chowilla floodplain, approximately 40km north east of Renmark.

Werta Wert Lagoons is a temporary lake system, consisting of three lagoons totalling 37ha (Plate 5a). The wetland is filled from Monoman Creek via a single inlet/outlet at flows of approximately 47,200ML/day. The inlet is approximately 1.8km long and passes through a lignum swamp before entering the wetland. Once filled, water remains in the lagoons for some time (weeks/months) after a flood recession due to an elevated sill level. Sampling took place in the first lagoon only (8.55ha), where water depths were approximately one metre in the centre of the lagoon.

Three pipes, feed the wetland through an inlet culvert installed beneath an access track, approximately 200m from the inlet's junction with Monoman Creek (Plate 5b). Two pipes are 90cm diameter, whilst the third is 70cm diameter. All pipes are approximately 8.6m long, and set slightly above the base level of the inlet structure (220, 110, and 120mm left - right respectively as facing the structure from Monoman Creek side; and 30, 50, and 100mm left – right respectively as facing the structure and looking to Monoman Creek). Drop board guides can be installed on the wetland side of the structure to allow water to be held back in the wetland during flood recession, however no fish gates are present at this structure.

The vegetation at Werta Wert Lagoons consists of mature red gums and black box lining the shores. No aquatic plant growth was observed during the survey (spring/summer 2000/01), however, when the water dries, the wetland beds become densely covered with ephemeral vegetation.

Werta Wert Lagoons Inlet Channel
The temporary inlet channel to Werta Wert Lagoons is approximately 1.8km long, with the inlet structure present approximately 250m from its junction with the Monoman Creek.

On the creek side of the structure, the temporary inlet channel is approximately 50-70cm deep when full, grassy with mature red gum and river coobah present on its banks. Directly adjacent the structure some rock rubble was present (Plate 5b).

On the wetland side of the structure, the inlet channel became shallower with mature red gum trees present adjacent the structure, and lignum both lining its path, and crossing it nearer the wetland.

Nets were set adjacent the inlet structure on both sides (Plate 5c).

Monoman Creek
Monoman Creek is a permanent secondary anabranch to the River Murray, both being fed, and feeding back into, Chowilla Creek. As such, it by passes Weir and Lock Six, and, with the other creeks present on the Chowilla floodplain, carries roughly half the flow into South Australia.

Monoman Creek can reach 20-30m wide in places, and varies in its depth. At the sampling location the creek was approximately half its maximum width (approximately 10-15m wide). Its depth at the sample location adjacent the inlet varied from deep with steep drop-offs to shallow with a gradual decline. Directly adjacent the wetland inlet, the water was quite shallow and the stream width narrow – red gums were present approximately five metres apart.

Mature red gums line and overhang the banks of Monoman Creek, with an occasional river coobah also present. The understorey includes spiny sedge, grasses and native licquorice (*Glycyrrhiza acanthocarpa*), with some sections of bank being bare. Occasional water primrose (*Ludwigia peploides* ssp. *monteridenis*) were also present, although no aquatic vegetation was observed at the sample sites.

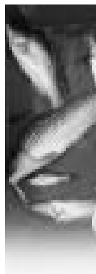
Werta Wert Lagoons wetland management during project

As with Lake Littra, this wetland filled only during the high river flow in summer 2000-2001, and water was also held back in the wetland from the peak in flow (21/12/00) until mid January 2001. Two samples were also taken at Werta Wert Lagoons when the flow control structure was closed (30/12/00 and 15/01/01).

Chowilla Oxbow Wetland (low level temporary control wetland)

Chowilla Oxbow is located approximately 35km north east of Renmark. This wetland has no flow control structure present on the wetland inlet, and was used in this study as a control wetland to determine fish use of a temporary wetland where fish passage was unhindered.

Chowilla Oxbow Wetland is a temporary oxbow lagoon, with an area of approximately ten hectares (Plate 6a). It is filled directly from Chowilla Creek via a short (approximately seven metres) low level “inlet/outlet” at flows of between 23,000 and 27,000ML/day. At higher flows, water is able to move in/out of the wetland from the other end of the oxbow (Plate 6a).



The vegetation surrounding Chowilla Oxbow Wetland consists of mature red gums, black box, and lignum. When dry, the wetland is covered in dense water couch (*Paspalum distichum*) (Plate 6b). This plant continued to persist when the wetland was full in spring/summer 2000/01, forming a thick covering across the wetland (Plate 6c). Chowilla Oxbow Wetland is grazed.

Chowilla Oxbow Wetland “Inlet”

Chowilla Oxbow Wetland possesses a very short, shallow (up to 90cm) inlet that connects it to Chowilla Creek. This inlet is initially narrow (two to three metres) when first filling, but becomes quite wide during higher flows (10-15m) – forming more of a continuation of the wetland rather than an inlet channel.

Dense young red gum trees are present across the “inlet” near its junction with Chowilla Creek, but little understorey vegetation is present.

Chowilla Creek

Chowilla Creek is one of the major permanent anabranch systems of the River Murray in South Australia (Plate 6a). Formed from an old river channel, the creek can be as wide as the main river channel. Similarly, it can be deep in places and possess steep banks. Adjacent Chowilla Oxbow Wetland, Chowilla Creek is approximately 30m wide with steep banks generally. Chowilla Creek by-passes Weir and Lock Six, with the permanent creeks present in the Chowilla floodplain carrying approximately half of the flow coming into South Australia.

Mature red gums, river coobah and black box line Chowilla Creek, with areas of lignum present on the floodplain. Emergent vegetation includes patches of common reed, marsh clubrush (*Bolboschoenus caldwellii)*, and spiny sedge. No aquatic vegetation was observed at any of the sample sites, although curly pondweed (*Potamogeton crispus*) and floating pondweed (*Potamogeton tricarinatus*) have been observed elsewhere.

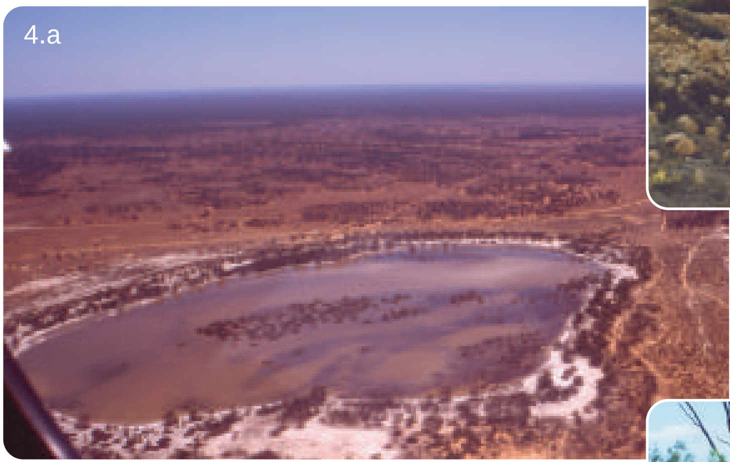


Plate 4. a) Lake Littra Wetland (aerial) December 2000, b) inlet structure (dry) creek side, and c) inlet structure (wet) creek side December 2000.

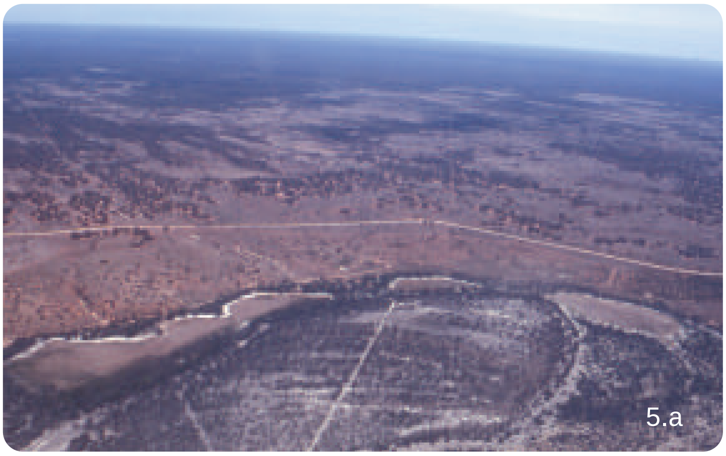


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Plate 5. a) Werta Wert Lagoons (aerial) December 2000, b) inlet structure (dry) creek side, and c) inlet structure (wet) creek side.

Plate 6. a) Chowilla Oxbow Wetland – centre (aerial), b) Chowilla Oxbow drying phase (from inlet) Jan 2001, and c) Chowilla Oxbow (wet) December 2000.

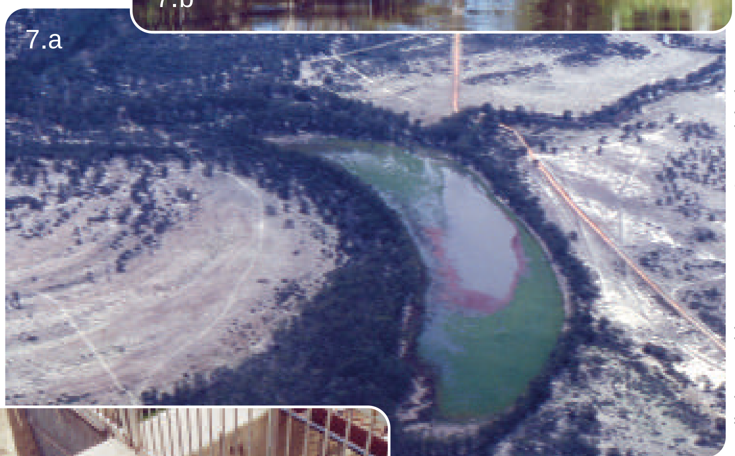

Plate 7. a) Pilby Creek Lagoon (aerial) December 2000, b) inlet structure (wet) from wetland December 2000, c) inlet structure (dry) from wetland, d) Management of structure – only one cell open (previous fish screen design), e) inlet structure new fish screen design, and f) Pilby Creek Lagoon outlet , river side, showing rubble at discharge point.

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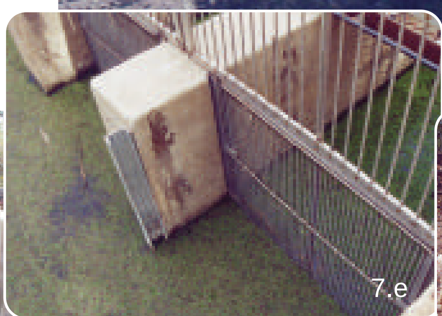
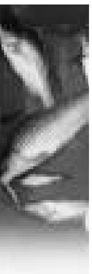




Chowilla Oxbow Wetland hydrology during project

The temporary control wetland, Chowilla Oxbow Wetland was also only sampled during summer 2000-2001. Water filled Chowilla Oxbow Wetland during early November 2000, and water remained in the wetland until soon after the flow peak in the latter half of December. By 3/1/01 (the final sample for the wetland), Chowilla Oxbow Wetland was disconnected from Chowilla Creek, with only 25-30cm of water remaining in places.

Permanently connected wetlands

Five permanently connected wetlands were sampled during this survey.

Pilby Creek Lagoon

Pilby Creek Lagoon is located approximately 30km north east of Renmark, adjacent Weir and Lock Six on the Chowilla floodplain (Plate 7a).

A relatively small wetland of 10.8 ha, Pilby Creek Lagoon was permanently inundated following the construction of Weir and Lock Six in the 1920's. In 1992, a flow control structure was installed on the wetland's inlet and outlet to change the hydrological regime of Pilby Creek Lagoon wetland to that of a temporary system. The wetland has been managed as such since this time.

Pilby Creek forms both the inlet and outlet channels to Pilby Creek Lagoon, with the wetland filling indirectly through overflow from the creek. The inlet channel's source is on the upper pool of Weir Six, while the outlet discharges into Chowilla Creek on the lower pool. This allows the wetland to be rapidly filled and drained as required. The wetland is approximately two metres deep when full.

During high river flows, another connection is made with the river at the opposite end of the lagoon to Pilby Creek. This connection is made via another wetland ("Lock Six Wetland") to the River Murray directly above Lock and Weir Six at flows of between 35-40,000ML/day.

The flow control structure on the inlet is an "open topped box culvert" design (Plate 7b, 7c). This structure is approximately 380m from the junction with the lagoon and comprises four cells, each 100cm wide x 114cm high x 400cm long. Each cell is has no overhead covering, allowing light to penetrate the water column for the full length of the structure. Half way along each culvert there is provision for drop boards to be placed into the structure to hold water out of the wetland (Plate 7d). These boards can be layered to the full height of the structure, however water is able to move around the structure before the full height is reached.

Fish screens are also present on this structure. Until July 2001, the 80cm high screens were made from a fine mesh with 10mm x 10mm openings (Plate 7d). Slots in the side of each culvert allowed these screens to be slid into place on the upstream side of the structure. In July 2001, these screens were replaced with rotating gates. These gates comprise metal rods, five millimetres in diameter, welded vertically onto the gates approximately ten millimetres apart (Plate 7e). The height of these gates is the same as the structure (114cm).

The vegetation at Pilby Creek Lagoon consists of mature and young red gums and some mature black box lining the shores. Dense lignum is present on the eastern side of the lagoon, away from the shore. A fringe of bulrush (*Typha* spp.) and common reed are generally present around the wetland, although pigs have damaged this zone at times.

When full, ribbon weed (*Vallisneria americana*) and watermilfoil (*Myiophyllum* spp.) have been recorded in the open water, although during this survey, dry phase vegetation - dominated by knot weeds (*Persicaria* spp.) -provided the submerged habitat (spring/summer 2000/01, continuing through 2002 following a short dry phase).

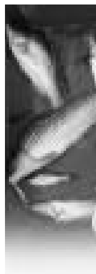
Pilby Creek Lagoon Inlet Channel

Pilby Creek Lagoon inlet channel is the section of Pilby Creek upstream of the wetland. It is approximately one kilometre long and between five and ten metres wide. Its depth varies, but is generally one to two metres with steep banks. On the upstream side of the structure the inlet is silty, however on the wetland side of the structure, the channel has a firmer base due to the implementation of drying cycles in Pilby Creek Lagoon.

Bank vegetation includes river coobah, black box, and many overhanging red gums. Emergent vegetation consists of common reed and bulrush with occasional water primrose. The only submerged vegetation observed on the river side of the structure during the survey was an occasional water primrose. Small snags were also present. On the wetland side of the structure submerged vegetation consisted of dry-phase herbs. Both above and below the inlet structure was occasionally covered with dense azolla (*Azolla spp.*).

Pilby Creek Lagoon Outlet Channel

The outlet channel of Pilby Creek Lagoon is a continuation of Pilby Creek, located downstream of the wetland. Pilby Creek continues downstream of the wetland for approximately 2.2km before it empties into Chowilla Creek, however the outlet structure is located only 150m past the wetland. At high river flows (approximately 35,000ML/day) water backs up into Pilby Creek outlet from Chowilla Creek.



The outlet structure on Pilby Creek Lagoon consists of a single pipe 600mm in diameter set into the Lock Six access road (Plate 7f). Water release from the lagoon is controlled by a sluice gate.

Several snags are present in the outlet channel, with overhanging red gums and black box trees growing on the bank. A small patch of common reed and small areas of bulrush grow along the channel at times (as with the wetland, these plants can be damaged by pigs). Submerged plants comprised dry phase herbaceous species – no aquatic vegetation grew at this location during the survey.

Murray River adjacent Pilby Creek Lagoon

The river near Pilby Creek Lagoon inlet is typical of much of the River Murray in South Australia. Approximately 100-150m wide at this location, the river possesses steep drop offs where it scours the bank, and shallow gradual declines in areas of deposition (inside river bends). Weir and Lock Six directly influence this section of the river.

Mature red gums line the banks with areas of dense young trees present. River coobah and black box are scattered throughout the survey site. All trees overhang the river bank in places and snags are present at several locations. Emergent vegetation consists of common reed and bulrush, with patches of marsh clubrush also occurring. Occasional individuals of water primrose and mud dock (*Rumex bidens*) are also present. Aquatic vegetation consists of patchy ribbon weed, curly pond weed and floating pondweed.

Pilby Creek Lagoon wetland management during project

The river sites at this wetland (including the inlet nets on the wetland side of the structure) were monitored throughout the study (November 2000-December 2002).

However, due to wetland management permitting two drying events within the project time frame, wetland sites were not sampled at all corresponding dates.

The first of the drying events began in late summer 2001 when stop logs were installed at the inlet flow control structure, and the outlet structure remained open. The drying event continued until early July 2001, after which the wetland was refilled. By the 17/10/01, however, the water depth in the wetland was only deep enough to set two nets. Water remained in the wetland until early January 2002, undergoing at least one short-term drawdown and refilling in early December, after which, a rapid drawdown was implemented so that only a large pool was left in the wetland on 18/2/02. The wetland then remained dry throughout the remainder of 2002, prohibiting samples to be taken from the wetland side of the structure.

Two other events occurred during the course of the project that have the potential to influence study outcomes. Firstly, during the high river flow of spring/summer 2000-2001, water entered the wetland through a secondary flow path that connects the wetland to the river just upstream of Weir Six via "Lock Six Wetland". This event would have allowed large fish to enter the wetland, rather than be excluded by fish screens. At the end of summer 2001, the wetland was completely dried, potentially removing all fish, however residual water may have remained in the deeper inlet and outlet channels for some time, providing refuge for some fish prior to refilling in July 2001.

Secondly, as stated in the site description, the original fish screens with 10mm x 10mm openings were replaced with vertical aluminium rods (each approximately ten millimetres apart) in July 2001 (Plates 7d, 7e). The change in fish screen type and size may have allowed different fish to enter the wetland during the second refilling event, thereby influencing the species composition within the wetland during this refilling phase.

Lake Merreti

Lake Merreti is located approximately 20km north east of Renmark on the Ral Ral Creek floodplain. The wetland, and the surrounding floodplain, form part of Calperum Station.

A large deflation basin, Lake Merreti has an area of 391ha (Plate 8a). It is connected to Ral Ral Creek by three inlet channels, one of which is permanent, the other two are temporary, feeding the wetland at higher river flows.

When filled at pool level, Lake Merreti has a maximum depth of between 80cm and one metre. During high river flows, when Lake Merreti is filled to capacity, both Clover Lake (to the east) and Woolpolool Swamp (to the west) receive its overflow. Flows to Clover Lake occur from Lake Merreti when levels in Ral Ral reach 18.2m AHD (river flows of between 55,000 and 60,000 ML/day). At normal pool level Ral Ral Creek is around 16.35m AHD).

All inlets to the wetland have structures present approximately 10-20m from their source. The main inlet has a flow and fish control structure, whilst the two temporary wetlands have fish control gates only.

The vegetation surrounding Lake Merreti consists of mature red gum and black box overstorey, and river coobah and lignum understorey. Red gum seedlings have grown in the edge zone in response the wetting and drying regime implemented since 1994. Isolated patches of cumbungi and phragmites, and extensive areas of the spiny sedge (*C. gymnocaulos*) are present on the lake edge. During a recent dry phase (2000), extensive and prolific growth of slender knot weed and creeping monkey-flower (*Mimulus repens*) were observed on the lake bed. In the following wet phase the knot weed persisted for some time before breaking down and being replaced by expansive areas of ribbon weed, and watermilfoil. Subsequent drawdown of the lake and the feeding action of waterbirds resulted in these species decreasing in distribution around the lake (becoming limited to deeper water).

Main Inlet

Lake Merreti's main inlet connects to Ral Ral Creek at pool level via a 1.7km long channel. The inlet channel is shallow at its junction with Ral Ral Creek (approximately 40cm), but forms a deep pool adjacent the structure (three metres at the deepest point). Past the flow control structure on the wetland side, the channel again forms a deep pool adjacent the structure (1-1.5m), prior to it becoming shallower (30cm near the wetland junction, but 50-60cm at the sample site).

The flow control structure on the main inlet to Lake Merreti was originally installed to store water in the lake for the purpose of offsetting the effects of high salinities on irrigators using a pumping station downstream of the lake on Ral Ral Creek. The culvert therefore has not been designed for wetland rehabilitation or fish movement, although this is its current purpose.

The structure is located approximately 15m from the junction with Ral Ral Creek. It comprises two 90cm pipes, one of which controls inflow and out flow to and from the wetland by means of a sluice gate, located two-thirds the way along the pipe (Plate 8b). The second pipe has flap valves on either end of the pipe, so that water can be stopped from entering or leaving the wetland. Should water be required to pass through the second pipe, both flap valves need to be manually raised. Both pipes are 17.8m long.

On the upstream side of the structure a cage (514 x 153cm) surrounds both pipes. Two solid walls are present either side of the cage, with the top covered in aluminium "security" type mesh (openings 97mm wide x 33mm high). The front of the cage comprises six rotating aluminium mesh screen gates (Plate 8c). Each of these gates is 145cm high and 78cm wide.

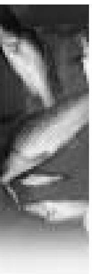
Mature red gums line and overhang the inlet channel along its length, with many snags present. Upstream of the structure, one side of the inlet channel is bordered by common reed from the creek to the structure, and partially crosses the channel in one place. On the other side of the channel, common reed is only present at the creek – inlet junction.

The only aquatic vegetation (ribbon weed) present in the inlet channel is located at the creek – inlet junction. Upstream of the structure azolla can form a thick blanket at times.

Temporary Inlets

Two other inlet channels feed the wetland during high river flows, and possess inlet structures, which were installed in 1997. These structures do not act as flow control structures, but have been installed on these inlets in order to stop the movement of adult carp into the wetland during small-medium level floods.

Both structures have four rotating aluminium "security" type mesh gates, headwalls constructed from red gum sleepers and rock rubble, but differ in their dimensions (Plate 8d, 8e).



Both inlets lack submerged or dry-phase vegetation in their channels, although are lined with red gum and black box trees. Several fallen branches would provide habitat for fish when the inlets contain water. When flowing azolla and debris, such as leaves and branches, can build up on the upstream side of the structures, requiring removal to maintain water movement.

<u>Upstream inlet</u>
The most upstream temporary inlet to Lake Merreti is approximately 2.5km long and connects to Big Hunchee Creek (which feeds directly into Ral Ral Creek). This channel begins to flow at approximately 27, 000 ML/day (water past fish control structure), and can be approximately two metres deep when full, although less at the inlet structure (Plate 8e). This inlet began to flow in mid October 2000 during a medium flow peak (maximum flow of 42,050ML/day). Water levels dropped during late October 2000 and November, before again increasing in December 2000 (peaking at 63,427ML/day). This inlet was only monitored during the first flow in October using a structure net and two fyke nets (60cm “D” front hoop, 3mm mesh, single 3m long leader). The results were not incorporated into the analysis for this project due to the different mesh size used, and the lack of personnel resources enabling sampling to continue throughout the high river.

The upstream inlet has an opening in the structure 300cm wide, bordered either side by a rock rubble and earthen headwall, and, on the left hand side as you face the creek, a 22m long earthen bank to prevent water moving around the structure during times of high flow.

Each of the rotating gates are 70cm wide x 132cm high, and one half of the structure has a permanent mesh cage present on the downstream side to monitor fish movement into the wetland (Plate 8d). This cage acts to move fish into a removable net when monitoring occurs, and possesses smaller mesh (25mm x 25mm) (Plate 8e).

<u>Middle inlet</u>
The middle temporary inlet channel is approximately 1.8km long and connects to Ral Ral Creek at the confluence of Ral Ral Creek, Big Hunchee Creek and Reny Creek, approximately mid way between the main inlet (downstream) and upstream temporary inlet. This inlet begins to flow to the wetland at river flows of approximately 40,400 ML/day (water past the structure), which occurred for a short period of time in mid October 2000, before dropping in late October and November, and again flowing in December 2000. This inlet was not monitored at all during the study due to resource constraints.

This inlet channel is deeper (2-2.5m) and narrower than the upstream inlet. Consequently the inlet structure is also narrower (275cm), but retains the majority of the inlet’s natural width.

Each of the four rotating gates 69cm wide x 120cm high. As with the upstream inlet, there is a permanent mesh cage present on the downstream side of the structure to monitor fish movement into the wetland.

Ral Ral Creek
Ral Ral Creek is a permanent anabranch of the River Murray running from Calperum Station to the township of Renmark. It is generally narrow (approximately 10m wide), although can be up to 400m (Ral Ral Widewaters). Ral Ral Creek is mostly quite deep, although in wider sections it may be shallow (approximately one metre). It is very “snaggy” in places, and is under the influence of Weir and Lock Five at Renmark.

Adjacent the main inlet
Ral Ral Creek is approximately 10m wide adjacent the main inlet to Lake Merreti. Here the creek is over three metres deep in places, with steep drop offs on the inside of bends. Gradual slopes also occur on the inside of bends, where sand is often deposited.

Several snags are present in the area, and aquatic vegetation comprises patches of ribbon weed and curly pond weed. Mature red gums overhang the creek, with common reed and some marsh clubrush forming the emergent species. Spiny sedge is also observed here.

Adjacent the upstream temporary inlet
The section of Ral Ral Creek adjacent the upstream temporary inlet is approximately 100m wide. Apart from the presence of spiny sedge and mature red gums, the creek bank is generally bare. Small areas of ribbon weed occur at this location, although the submerged vegetation is generally depauperate.

Adjacent the middle temporary inlet
This section of Ral Ral Creek is very narrow (10m wide) with steep banks and snags. Red gums overhang the creek, with common reed present at the waters edge. No submerged vegetation was recorded at this location.

Lake Merreti wetland management during project
The wetland, inlet and creek sites were all surveyed throughout the study period (November 2000 – December 2002), with the exception of one date (April 2002), when water was too shallow within the wetland to enable nets to be set (nets were set in the inlet channels and creek at this time however).

During the study the flow control structure was open and closed intermittently for various periods of time to allow for partial drying of the lake and maintenance of riparian vegetation fringe. The four partial drying events implemented during the study included a two month period during late 2000, a two month period in early 2001, a five month period during mid 2001, and a two week period in early 2002 (Table 1). All data and analyses have been adjusted for these management actions.

Until October 2001, only one of the two pipes present on the structure was used to deliver water to the wetland. However, at this time it was determined to open the second pipe to facilitate water movement into the wetland due to high evaporation rates and low flows occurring in Ral Ral Creek. Whilst the second pipe was open at non sample periods, at sampling times the second pipe was closed to allow for representative flow readings at the structure (ensuring that they were comparable to previous readings), and capture of fish at the structure (the attachment of a structure net on the second pipe was not possible).

During the course of the project, observations were made of fish congregating around on the wetland side of the closed main flow control structure. This occurred on the 29/11/00 when thousands of juvenile Australian smelt were seen milling around permanent inlet structure on wetland side, and large fish were noted jumping inside pipe. On the 8/3/01, thousands of bony bream (150-200mm) and some carp and goldfish were observed gulping air on wetland side of structure, whilst on the 24/3/01 thousands of carp and goldfish (150-200mm) were observed gulping air on wetland side of structure (no bony bream were observed at this time) (Nichols *pers. obs.* 2001).

It is thought that these fish were possibly attracted to a leak in structure (due to the sluice gate not closing properly), which would have supplied a trickle of “fresher” water to the inlet channel. In the inlet channel, it is possible that due to low flow conditions (with the structure closed), dissolved oxygen levels may have become very low, thereby causing fish to move toward the better quality water. It is possible that the use of a small freshwater inflow could be used as an “attractant flow” to encourage fish to a particular location, or out of a wetland prior to undertaking a drying event. This theory was investigated at Pilby Creek Lagoon wetland prior to that wetland being completely dried in 2001, although no statistical analysis was undertaken on the results, it appeared that an attractant flow did encourage fish activity, and could potentially be used as a management option. Further investigation is warranted (refer Objective 4 below).

Table 1. Lake Merreti management event dates, actions and observations

Management Dates	Management Action
8/9/00 - 28/9/00 (1 month)	Inlet opened to refill wetland
29/9/00 - 6/12/00 (2 months)	Inlet closed to maintain low lake levels but opened on 5 occasions for fish monitoring (3 days each) Only 2 samples affected for this study (15/11/00, 29/11/00) Temporary inlets began to flow around 8/10/00 (upstream inlet) - 12/10/00 (middle inlet)
7/12/00 - 2/2/01 (2 months)	Inlet opened to fill lake with rising river
3/02/01 - 27/3/01 (2 months)	Inlet closed to dry lake margins and support growth of red gum germinants, opened 8/3/01 for attractant flow
27/3/01 - 30/3/01 (3 days)	Inlet opened for fish monitoring
30/03/01 - 3/9/01 (5 months)	Inlet closed, lake levels lowered
5/4/01	Additional channel excavated near structure on wetland side and existing channel deepened at junction with the creek (river side of the structure) to facilitate flows
11/4/01	Inlet opened for overnight attractant flow (full for a short time, then 1/4 overnight)
3/9/01 - 28/2/02 (5 months)	Inlet opened fully, second pipe opened ? to facilitate additional flows
30/10/01	Flap valves on second pipe opened completely to maximise flow
28/2/02 - 12/3/02 (2 weeks)	Inlet closed to partially dry wetland
12/3/02 – present (9 months until end of study in December 2002)	Inlet opened, lake refilled

Shane Dooland

Shane Dooland

Plate 8. a) Lake Merreti, b) permanent inlet structure (wetland side), c) permanent inlet structure fish screen, d) temporary inlet structure, e) Ral Ral Creek.

Scott Nichols

Sarah Fairful

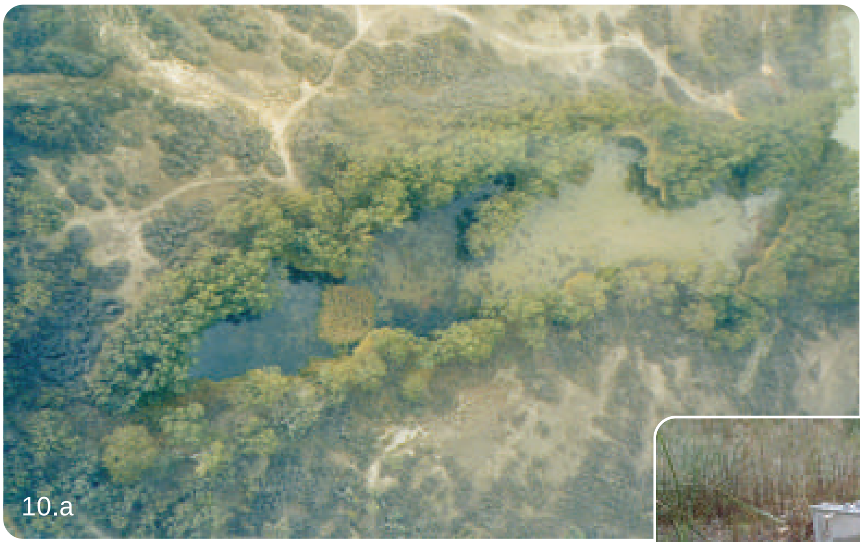
Scott Nichols

Julien Lepetit

Plate 9. a) Gurra Control Wetland from Gurra Creek, b) Gurra Control from back of lagoon.

Julien Lepetit

Plate 10. a) Little Duck Lagoon, b) inlet structure creek side, c) inlet structure wetland side



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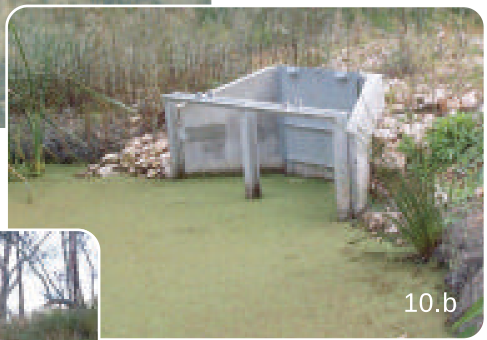


Sarah Fairful

Sarah Fairful

Methods

Mike Harper

Mike Harper

Plate 11. a) Loveday Wetlands, b) main inlet structure prior to adjacent reed growth, c) Murray River adjacent.

Shane Dooland

Gurra Control Wetland (permanent control wetland)

Gurra Control Wetland is located approximately one kilometre south of Little Duck Lagoon on the Gurra Gurra floodplain. In this study, Gurra Control Wetland was used as the permanent “control” wetland to monitor fish use of an unmanaged permanent wetland (Plates 9a, 9b).

This 1.8 hectare wetland is permanently connected to Gurra Gurra Creek near its junction with the River Murray (140m downstream). The wetland does not possess a distinct inlet channel, nor a flow control structure at its connection with Gurra Gurra Creek, although a small (narrow and short) channel connects the wetland to the River Murray at the opposite end to Gurra Gurra Creek.

Approximately 1-1.5m deep throughout, Gurra Control Wetland is generally fringed by a band of bulrush, with common reed and water couch present in places. Patches of ribbon weed are present in the wetland, with dense growth of curly pondweed occurring in late in 2001. Red gums, river coobah, occasional black box and lignum surround the wetland.

Gurra Gurra Creek

Gurra Gurra Creek is a lengthy permanent channel linking the River Murray to the expansive Gurra Gurra Lakes. The study area adjacent Little Duck Lagoon and Gurra Control Wetland is approximately 30m wide, and is at the bottom end of the creek near where it connects with the River Murray. All permanent water at this site is under the influence Weir and Lock Four, which is located just downstream.

Under river pool conditions water is drawn into the creek to replace water lost through evaporation in Gurra Gurra Lakes. During high flows however, the direction of water movement changes as temporary channels in the north of the complex feed into Gurra Gurra Lakes, before feeding Gurra Gurra Creek and emptying back into the River Murray below Little Duck Lagoon and Gurra Control Wetland. At these times rises in salinity can occur downstream of the lakes due to the greater influence of the salinised floodplain and lakes on the water quality of Gurra Gurra Creek.

Gurra Gurra Creek’s channel is formed from an old river channel meander, and is therefore deep in places. It is bordered by red gums, river coobah and black box that overhang the creek in places. A fringe of common reed occurs throughout the system, combining with bulrush at times. Many snags are present in the channel. Areas of ribbon weed and pondweed (curly and floating) can also be found.

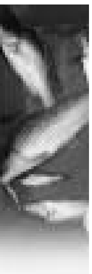
Gurra Control Wetland hydrology during project

This permanent control wetland was sampled throughout the study (November 2000-December 2002). Water levels remained constant throughout.

The only change that occurred during sampling for this project was in spring and summer 2001-2002, when curly pondweed (*Potomogeton crispus*) grew densely throughout the entire wetland (uniform rather than patchy in its distribution). Densities such as this are unusual due to the fragile nature of this water plant.

Little Duck Lagoon

Little Duck Lagoon is a small shallow wetland approximately 2.5 hectares in size located opposite the township of Berri on the Gurra Gurra floodplain.



Permanently inundated since construction of Lock and Weir Four in 1929, this wetland was chosen as a rehabilitation site in 1996, and a flow control structure installed on the 15m long inlet/outlet. Fed from Gurra Gurra Creek, and present on the salinised Gurra Gurra floodplain, this wetland is successfully resisting the effects of salinisation that has claimed the adjacent Causeway Lagoon and surrounding floodplain (Plate 10a). During high river flows a 500m long flow path connects the lagoon to the River Murray via a second lagoon at the opposite end to the inlet

The inlet structure consists of a single five metre long pipe (internal diameter 70cm) (Plate 10c). A sliding sluice gate on the upstream side of the culvert controls water movement into and out of the wetland (Plate 10b), whilst two aluminium "security" type mesh gates (openings 97mm wide x 33mm high) can be slid into place at the end of the headwalls on the upstream side to control fish access to the wetland. The structure itself and its associated access bank is overtopped (bypassed) at flows of 30-40,000ML/day.

Dense mature red gums surround the Little Duck Lagoon with an occasional river coobah understorey. A dense band of common reed surrounds nearly the whole lagoon, with large areas of bulrush present in the wetland itself and in the inlet channel on Gurra Gurra Creek side of the structure. During a recent drawdown, water couch grew extensively throughout the wetland. When the wetland was re-filled this vegetation decomposed producing anoxic conditions in the wetland at the beginning of this project, and continuing low dissolved oxygen conditions into 2002. As 2002 continued, dissolved oxygen levels increased, although no submerged vegetation established itself in the lagoon. Conversely, during the course of the study, bulrush grew extensively throughout the shallow wetland, spreading to form large, dense patches by the time of the final survey in December 2002.

Little Duck Lagoon Inlet

Little Duck Lagoon connects to Gurra Gurra Creek approximately 1.3km north of Gurra Gurra Creek's connection with the River Murray. A short and shallow channel cuts through a stand of bulrush on a bend of the creek to feed the wetland. The channel is silty, and narrow (two metres), although the stand of bulrush is quite large (approximately 10m wide x 10m long). Near Little Duck Lagoon's flow control structure, red gums overhang the channel, water couch and common reed grow on the bank, and an area of ribbon weed is present on the creek side of the structure. Azolla can cover the channel at times (both sides of the structure).

When this project began, the inlet channel led directly to Little Duck Lagoon, which in turn fed the neighbouring Causeway Lagoon wetland. In 2000, the direct connection between Little Duck Lagoon and Causeway Lagoon was blocked and an independent channel constructed for Causeway Lagoon. This allowed independent management of the water regime in both lagoons, but made analysis of the fish captured in the inlet channel more difficult (it is difficult to distinguish if fish are moving into the shared inlet to enter/exit Little Duck Lagoon or Causeway Lagoon).

The wetland side of the inlet channel is wider than on the creek side, although it is still shallow (approximately 15m wide, 50cm deep). The area has overhanging red gums, with common reed and water couch on the banks. No aquatic vegetation was present during the survey, although extensive water couch growth was present during the previous dry phase, causing anoxic conditions when the wetland was first refilled. Azolla was occasionally present, forming a thick covering at times.

Gurra Gurra Creek

As Little Duck Lagoon and Gurra Control Wetland are both connected to Gurra Gurra Creek, this creek site was combined for both wetland sites. Refer to the above site description.

Little Duck Lagoon wetland management during project

Little Duck Lagoon was sampled throughout the project period (November 2000 – December 2002). Prior to sampling commencing at this site in 2000, the wetland was filled through overbank flows (around the 9/10/00) and seepage from an adjacent channel, allowing large carp to enter the wetland despite the sluice gate being present.

By the 31/10/00 Little Duck Lagoon was full, although the water was anoxic, black, and possessed a foul odour. On this date the flow control structure (sluice gate) was removed and fish screens put in place until the 7/12/00, when they too were removed. On the 20/12/00, the structure was again overtopped, allowing water to enter via a secondary wetland “Old Loxton Road Lagoon” which joined to the end of the wetland opposite to the main inlet.

The structure remained open with no fish screens until the 12/3/01 when both the sluice gate and fish screens were replaced. The flow control structure then stayed closed until early November 2001, when the sluice gate was removed and fish screens engaged. The structure remained open for the remainder of the project (November 2001 - December 2002).

The first sample taken at the Little Duck Lagoon site was on the 9/11/00, however no nets were set in the wetland at this time due to the anoxic nature of the water. The water continued to have a dark colour and an odour into mid 2001, and although lessening towards the end of the project, a tannin colour remained along with an odour when the detritus (rotting water couch) was disturbed.

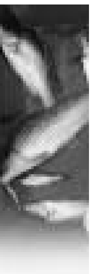
Despite the initial anoxic conditions, dark colour and foul odour, dissolved oxygen levels were found to be extremely high on several sampling occasions including 23/10/01, 26/11/01 and 18/12/01, when several sites recorded readings off the scale of the measuring instrument (>19.99mg/L).

Loveday Wetlands

The Loveday Wetlands complex is located on the eastern side of the River Murray, approximately four kilometres south of the township of Cobdogla. This low-lying complex is permanently connected to the river at pool level. Survey sites were centred in Big Mussel and Little Mussel Lagoons adjacent their junction with the main inlet (Plate 11a, centre left). When full these wetlands are approximately 1-1.5m deep.

The complex itself comprises several wetlands of high shoreline complexity, totalling approximately 500ha. The largest of these, Cobdogla and Loveday Swamps (343.5ha), have been employed as evaporation basins for irrigation drainage water since 1951 (Plate 11a, background) (Jensen *et al.* 1999), and are now highly salinised and remain permanent. The remaining permanent and temporary wetlands (Big Mussel, Little Mussel, Pipeline, and “Out the Back”) are not as salinised, and have been subject to a rehabilitation project since 1983, aiming to rehabilitate degraded vegetation and implement drying cycles on the permanently inundated wetlands.

Nets were set in Big Mussel and Little Mussel Lagoons - Little Mussel Lagoon has an approximate area of 21.6ha and Big Mussel Lagoon has an approximate area of 70.6ha, with the area of interest (ie the area where the nets were set) being 9.32ha.



The flow control structure for these wetlands is located 270m along the main inlet channel from the river and 190m to the junction with the wetland. The structure itself comprises six box culverts with an internal diameter of 122cm wide x 122cm high (outside diameter of 134cm x 134cm), and a length of 122cm (Plate 11b). A central 30cm wide strut extends past the box culverts both upstream and downstream of the structure by 120cm. The strut aims to provide stability to the structure during periods of high flow, minimising the possibility of the structure movement at these times.

Stop logs and/or metal plates that are slid into place on the upstream side of the structure control water movement to and from the wetland (Plate 11c). Two cells possess rotating aluminium "security" type mesh gates to control fish access into the wetland (Tucker, 2003). The openings in the mesh are 97mm wide x 33mm high with 10mm wide metal rods welded vertically in the centre of each hole, effectively halving the opening size. These gates can be slid into place using the guides present on the upstream side of the structure.

In many areas, the vegetation surrounding Little and Big Mussel Lagoons has been severely affected by salt. Around the lagoons salt scald and samphire (*Sarcocornia* spp.), and large areas of lignum are present. A narrow, less salinised, zone around the lagoons allows the growth of red gums and lignum, with dense growth of common reed present on the wetland edge, grading to thick bulrush in the water. Patchy areas of marsh clubrush, river clubrush (*Schoenoplectus validus*) occur around the wetland edges, and large patches of ribbon weed are present in deeper water. During drawdown, the native knot weed and the introduced bushy star wart (*Aster subulatus*) also grow in the wetland proper.

Loveday Wetlands Inlet

The main inlet to Loveday Wetlands is approximately 460m long and enters the wetland complex at the junction of Little Mussel Lagoon, and Big Mussel Lagoons. It is approximately five metres wide, and up to 1.2m deep. Throughout most of its length, overhanging red gums, lignum and common reed fringe the channel.

Prior to sampling, the inlet channel was partially blocked by extensive growth of bulrush. This bulrush was removed from the inlet channel either side of the structure in late 2000 using excavation equipment, providing a clear flowpath of at least 50m in either direction. In early 2002, these reeds had started to encroach on the channel once again, forming a dense area of growth directly adjacent the structure on either side, and invading the channel further upstream and downstream by the time of the last sample in December 2002.

Murray River adjacent Loveday Wetlands

This section of the River Murray is under the influence of Weir and Lock Three at Overland Corner. Loveday Wetlands are opposite Wachtels Lagoon, a large, permanent, and relatively shallow lagoon and surrounding floodplain that is heavily used by recreational fishers who camp and fish in the mainstream.

Adjacent Loveday Wetlands the River Murray is approximately 100-150m wide. It is fringed with common reed, with red gum, river coobah and black box growing on its banks. In places these trees overhang the river (particularly on the Loveday Wetlands side). Several snags are present, together with patches of ribbon weed, curly pondweed and floating pondweed.

Loveday Wetlands wetland management during project
As with the other permanently connected wetlands, Loveday Wetlands was sampled throughout the project.

The first sample for this wetland was taken on 7/11/00, when the flow control structure was fully open and the fish screens had been removed for some time (late September 2000) in response to a small flow peak in October 2000. The structure remained open for approximately one year, before being closed in October 2001. For the two samples taken just prior to the structure being closed, management of the structure was such that only two of the six cells were open to allow water movement into and out of the wetland.

The structure remained closed for the rest of the project period, with flow into the wetland only occurring through leakage between the stop logs, and the wetland undergoing a major drawdown event. One exception to this was the partial opening of the structure in January 2002, when two cells were opened for a short period of time (opened sometime between 20/12/01 and 17/1/02). By the next sample in May 2002, the structure was again closed, although some leakage was occurring.

Carp were noted trying to escape the wetland, jumping up against the structure on 29/11/01 and 20/12/01 when the flow control structure was closed and water on the wetland side of the structure was quite low –with poor water quality (low dissolved oxygen levels).

Statistical methodology and data storage

All data collected were stored in a Microsoft Access database developed by staff of the Australian Landscape Trust. Data were stored in a series of linked tables for fish and turtles, water quality, and structure details. All individual fish (and turtle) information were linked to the site location. The database for this project is currently stored with the Australian Landscape Trust. Example entry pages are presented in Appendix C.

All data from each net was standardised by net set period of each net (in hours) prior to analysis. Unless otherwise stated, all normality and statistical tests were undertaken using S-Plus 2000 (Insightful 2001).

Analyses undertaken investigating movement to and from the wetlands employed catch data taken from nets set within the inlet channel either side of the structure. It is assumed that each of the four nets set in the inlet channel sampled a different component of the moving fish community as described in Table 2. There is a small possibility that Net 2 and Net 3 will have captured fish that have moved up to the structure and turned around to face the opposite direction. Although minimal, the capture of these individuals should be considered during interpretation of the results.

Table 2. Assumed component of fish community sampled by each of the nets set in wetland inlets.

Net number	Direction and position	Migratory component sampled
1	Downstream facing net on the wetland side of the structure	Fish migrating upstream towards the structure
2	Downstream facing net on the river side of the structure	Fish which have successfully migrated upstream through the structure
3	Upstream facing net on the wetland side of the structure	Fish which have successfully migrated downstream through the structure
4	Upstream facing net on the river side of the structure	Fish migrating downstream towards the structure

With exceptions based on river level and the use of drop boards to retain water levels, it is assumed that fish moving into wetlands generally swam with the flow and fish moving out of wetlands generally swam against the flow.

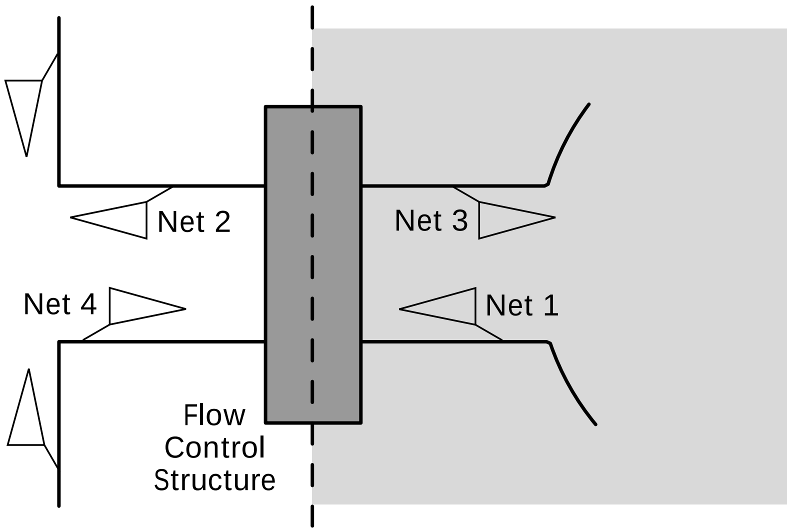


Figure 3. Net numbering as per description in Table 2.

The following tests were performed in relation to each of the project objectives:

Objective 1. Determine the influence of flow rate and flood height on movement of fish between the river and floodplain wetlands.

Movement of fish between the river and floodplain wetlands was assessed using data collected from nets set in the wetland inlets. Samples used for analysis were those that were collected moving into the wetland from the river, but not yet passing through the wetland inlet structure (Net 4), and those that were moving towards the river from the wetland, but not yet passing through the structure (Net 1). By using only these two samples, the results are not affected by the structure itself at each wetland. Data was assessed for normality prior to analysis.

The effect of water quality, season and river level on fish movement
The abundance of native species as a group, introduced species as a group and all species combined moving into and out of wetlands were used as response variables. Flow at the nearest lock (ML/day), flow in wetland inlet (m/s) (as measured mid-stream at $^{1}/_{2}$ depth x 0.9), depth (cm), turbidity (secchi depth (cm)), dissolved oxygen concentration (mg/L), temperature (^{o}C), pH and conductivity (µs/cm) were used as predictor variables. River level (rising, steady, falling) and season (summer, autumn, winter and spring) were also assessed. The native species group, introduced species group and combined species abundances were transformed to $\log_e(x+1)$ where x is the abundance per sample to achieve normality. Flow at the nearest lock (ML/day) and conductivity required $\log_e$ transformation. Flow at the sampling locations required a transformation of $\log_e((x+1) \times 10{,}000)$ to achieve normality.

Linear stepwise multiple regressions were performed to determine the relationship between water quality variables and fish movement into and out of wetlands. For the two categorical variables of river level and season, fish movement was compared by ANOVA.

The effect of time of day on fish movement
Diel (diurnal versus nocturnal / crepuscular) movement patterns were compared for each species using data from “night” (dusk-night-dawn) and day components of sampling for each net. Data from all wetland systems and habitats were pooled for analysis. Data was transformed using a double square-root transformation to achieve normality. Day and “night” samples were compared using a paired t-test analysis.

Objective 2. Identify the relative importance of channel versus over-bank flows for fish passage into and out of wetlands.

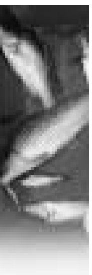
This objective could not be addressed as only a single over-bank flow (Little Duck Lagoon – December 2000) occurred.

Objective 3. Assess the importance of wetlands for fish recruitment.

Fish recruitment within wetlands was assessed by comparing fish that were sampled entering the wetland with those that were sampled moving out. Data was pooled from all wetlands.

Samples used for comparisons were from nets that captured fish moving into wetlands and had already passed through the wetland inlet structure (Net 3), and fish captured moving out of wetlands that had already passed through the wetland inlet structure (Net 2). These analyses are therefore representative of recruitment under current managed wetland conditions.

Fish abundance analyses
The proportion of fish moving out of wetlands over the abundance of fish moving into and out of wetlands was calculated for each species at each sample. A proportion of 0.5 indicates that an equivalent number of fish are moving in both directions. Proportions between 0.51 and one suggest that wetlands are a source of fish production as more fish are exiting the wetland than are entering it. Proportions between zero and 0.49 suggest that wetlands are not a source of fish production as more fish enter the wetland than leave it. For analysis, data was grouped by season.



Following an arcsine transformation for normality, 95% confidence intervals were calculated to allow statistical comparisons of whether the proportion of fish entering and exiting wetlands differed from 0.5 for each species during each season.

Size class data analyses
Length data for each species was analysed using Kolmogorov-Smirnov goodness–of–fit tests. Comparisons were only undertaken when lengths of more than 25 fish were measured both entering and exiting the wetland. Due to this sample size constraint, statistical comparisons could only be made for the native species: Australian smelt, bony bream, callop, western carp gudgeon, Midgely's carp gudgeon (*Hypseleotris* sp4), Lake's carp gudgeon, fly-specked hardyhead (*Craterocephalus stercusmuscarum*) and flathead gudgeon (*Philypnodon grandiceps*), and the introduced species; goldfish, carp, and gambusia.

Data was analysed in S-Plus 2000 if less than 100 fish were measured in either group. If greater than 100 fish were measured in both groups, data was converted to cumulative length frequencies and analysed as described in Sokal and Rohlf (1995). Data was not separated by sampling date. It is assumed that if wetlands are significant sites for fish recruitment, higher frequencies of small size classes would be present in the fish moving out of wetlands.

Objectives 4, 5 and 6. Impacts of structures, develop guidelines, and make recommendations for their management and construction.

The last three objectives within this project are related to the impacts of wetland flow control structures on fish movement, and finding ways to fix them. The three objectives were therefore analysed and discussed together. The original objectives are as follows:

- determine the impacts of wetland inlet structures on fish passage for native fish;
- develop guidelines to facilitate movement of native fish through inlet structures while excluding carp;
- make recommendations for the design of new structures.

Effect of structure on movement of fish community as a whole
For each sampling occasion, relative fish passage for each species was estimated as the proportion of individuals sampled at a structure that had successfully passed through. Fish passage out of the wetland (FP_{out}) was therefore (net numbers from Table 2 and Figure 3):

$$FP_{out} = \text{Net 2/(Net 1+ Net2)}$$

And fish passage into the wetland (FP_{in}) was:

$$FP_{in} = \text{Net 3/(Net 3+ Net 4).}$$

This proportion was used rather than the simpler proportion of approaching fish that passed through (ie FP_{out} = Net 2 / Net 1) as, due to sampling variance, in some instances more fish were sampled passing through than were sampled approaching the structure, which resulted in a poorly distributed data set. The relative fish passage index used (*RFP*) is distributed between 0 and 1 with:

Values 0	Totally obstructed fish passage
Values 0.01 - 0.49	Obstructed fish passage
Values > 0.5	Effectively unobstructed fish passage.

Three levels of *RFP* were calculated for both upstream and downstream fish passage. *FP* (both US and DS) was calculated for each species for each sample. The relative fish passage of each sample (RFP_{sample}) was calculated as the weighted average *FP* of all species within the sample. The relative fish passage of each structure ($RFP_{structure}$) was then calculated as the weighted average of RFP_{sample} at each structure when the structure was open to allow fish passage. Relative fish passage for individual species ($RFP_{species}$) was calculated as the weighted average *FP* for each species across samples at each structure. Weighted averages were used as more confidence can be placed in *FP* indices calculated from larger samples. Weighted averages and their standard error were calculated as suggested by Sokal and Rohlf (1996).

Prior to further analysis, *RFP* was compared with two alternative indices, a published index developed for assessing movement of terrestrial mammals through road underpasses (Clevenger *et al.* 2001), which is equivalent to a wetland inlet structure with no flow, and the number of fish successfully passing through structures. *RFP* was significantly correlated to both indices but had an underlying distribution more appropriate for the intended statistical analyses and interpretation.

95% confidence intervals were calculated for $RFP_{structure}$ and $RFP_{species}$ to allow statistical analysis of whether fish passage is significantly obstructed by any of the wetland inlet structures and which species are significantly affected. Any case where a RFP of < 0.5 is outside the range of the 95% confidence intervals is significantly different from effectively un-inhibited fish passage ($p < 0.05$).

Due to only a single observation in winter, significance tests could not be performed for Lake's carp gudgeon, crimson spotted rainbowfish, redfin perch, dwarf flathead gudgeon or gambusia during that season. Significance tests could be carried out for all other species at all other seasons.

As the direction of flow changed for some sampling occasions at Lake Littra, Little Duck Lagoon, and Loveday Wetlands, data from these sites were reanalysed based on movement with (FP_{DS}) and against (FP_{US}) the flow irrespective of whether fish were entering or exiting a wetland.

Fish community differences at different habitats

To determine if there is inherent differences in fish communities present in the different habitats sampled, or whether the differences are due to the presence of the wetland flow control structures, fish communities at the different habitats were compared.

Different habitats within each wetland system: wetland, inlet (wetland side), inlet (river side) and river, and between different habitats for all wetland systems combined (habitat is equivalent to the whole Lower Murray region) were investigated. Data was analysed using Analysis of Similarities (ANOSIM). When significant differences were found between fish communities, similarity percentages analysis (SIMPER) was performed to identify species most responsible for the differences.

$RFP_{structure}$ for both FP_{US} and FP_{DS} were correlated to the Bray-Curtis similarity between inlet sites on either side of inlet structures for each site to determine if fish passage efficiency at each wetland influences the dissimilarities in fish communities either side of the wetland inlet structure.

Effectiveness of fish screens – differences in carp abundance and biomass

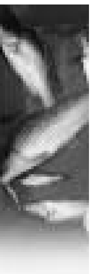
The effectiveness of fish screens on wetland inlet structures at excluding carp from floodplain wetlands was assessed by comparing carp abundances and biomass (grams)

in wetlands and the wetland side of wetland inlets with carp abundances and biomass on the riverine side of wetland inlets and within the river. As different numbers of nets were set in each habitat, data was standardised to catch per net in addition to being standardised by set period (in hours as undertaken for all other tests). Carp abundance was 4^{th} root transformed to achieve normality. Biomass was log transformed to achieve normality. Data was compared using ANOVA.

Length frequency comparisons were also made of carp in wetland and riverine habitats to identify whether wetland inlet structures effectively exclude large carp. Length frequency distributions were compared using Kolmogorov-Smirnov goodness-of-fit tests.

Structural characteristics affecting fish movement
The relationship between RFP_{sample} and the structural characteristics (below) of wetland inlet structures was assessed using weighted linear stepwise multiple regressions. For the categorical variables of cell type and open topped versus roofed cells, RFP_{sample} was compared by ANOVA.

Structural variables assessed included: depth of water within the structure (cm), flow velocity through the structure (m/s), the height of the invert above the inlet bed (cm), screen mesh size of fish screens (area in cm^2), the width of the apron (cm), the cross-sectional area of the culvert (cm^2), the percentage cross-sectional area of inlet (%) and openness of the structure (width x length/height: Reed and Ward 1985). All variables except depth and flow approached a normal distribution and were not transformed. Both depth and flow were log transformed to achieve normality.



Behavioural investigations of carp

Civil and environmental engineering students from the University of Adelaide were involved with this project in 2000 and 2001.

Investigations into carp behaviour and how the fish related to various types of deterrents and flow conditions in a laboratory environment (Dooland *et al.* 2000, Champion *et al.* 2001)

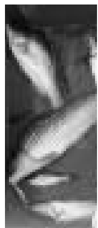
Carp deterrents investigated included responses to coarse substrate surrounding a culvert, light/dark environments, sound, light and sound combination, bubble curtain, and a half barrier (Dooland *et al.* 2000, Champion *et al.* 2001).

Analysis of the effect of water temperature, season and flow on fish movement through the Lock Six fishway was also undertaken using existing fish records over a ten year period from October 1987 to March 1997 (Dooland *et al.* 2000, Champion *et al.* 2001).

An electronic fish counter was developed and tested in the field to monitor fish movement through culverts (Dooland *et al.* 2000, Champion *et al.* 2001).

Methodology for these investigations can be found in the Honours thesis reports Dooland *et al.* (2000) and Champion *et al.* (2001).

RESULTS AND DISCUSSION



General

Sampling occurred from November 2000 – December 2002. During the study only one high flow event occurred, during summer 2001, when flows to South Australia reached 63,427ML/day. Once flows from this peak receded, only two minor peaks followed at the end of summer (16,222ML/day 10/02/01) and autumn of 2001 (24,460ML/day 06/04/01).

Flows then generally stayed below 10,000ML/day for the remainder of the study and never exceeded 8,000ML/day during 2002. Despite this generality, there were four peaks above 10,000ML/day between September and December 2001, which were extremely short (only two days each).

The management history of each wetland is outlined below. All temporary wetlands were only sampled during the high river flow in spring/summer 2000-01 when water reached these sites. All other wetlands were sampled throughout the project period.

Overall catch information

A total of 121,190 fish were captured during the two year survey period (all sites and wetlands combined). These fish comprised 16 species, 11 native and five introduced species. The native species included three carp gudgeon species that have not as yet been formally described, although they have been recognised by several authors (Larson and Hoese 1996, Allen *et al.* 2002). Carp/goldfish hybrids were separated from either carp or goldfish as a separate taxon. Table 3 indicates the total abundances of fish for all survey sites.

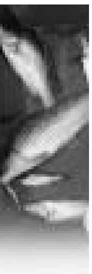


Table 3. Total fish abundances for all wetlands November 2000 – December 2002.

SPECIES	LIT*	WER*	CHO*	PIL	MER	LD**	GUR**	LOV	TOTAL
Australian smelt (*Retropinna semoni*)	110	46	33	16	2594	56	67	245	3167
Bony bream (*Nematalosa erebi*)	4529	2374	82	259	615	444	329	1042	9674
Callop (*Macquaria ambigua*)	31	31	39	65	50	23	36	34	309
Western carp gudgeon (*Hypseleotris klunzingeri*)	631	829	987	4590	5754	9316	3381	8949	34437
Midgely's carp gudgeon (*Hypseleotris* sp4)	69	364	1314	1667	1969	3181	1401	4526	14491
Lake's carp gudgeon (*Hypseleotris* sp5)	17	65	33	136	290	583	189	919	2232
Catfish (*Tandanus tandanus*)	0	0	1	1	0	2	0	1	5
Flathead gudgeon (*Philypnodon grandiceps*)	119	42	65	1341	591	438	723	1851	5170
Dwarf flathead gudgeon (*Philypnodon* sp1)	1	6	1	35	21	44	41	28	177
Fly-specked hardyhead (*Craterocephalus stercusmuscarum*)	64	6	17	16	62	846	466	2714	4191
Crimson spotted rainbowfish (*Melanotaenia fluviatilis*)	5	94	0	1	73	108	5	22	308
Common carp* (*Cyprinus carpio*)	7032	6500	1342	14092	1890	3142	155	1797	35950
Goldfish* (*Carassius auratus*)	190	59	27	35	319	98	10	68	806
Carp/goldfish hybrids*	5	2	0	0	6	12	2	1	28
Gambusia* (*Gambusia holbrooki*)	292	56	136	81	1580	2654	2	5391	10192
Redfin perch* (*Perca fluviatilis*)	1	3	2	2	8	6	19	12	53
TOTAL	13,096	10,477	4,079	22,337	15,822	20,953	6,826	27,600	121,190

LIT = Lake Littra; WER = Werta Wert Lagoons; CHO = Chowilla Oxbow; PIL = Pilby Creek Lagoon; Mer = Lake Merreti; LD = Little Duck Lagoon; GUR = Gurra Control; LOV = Loveday Wetlands.

Numbers represent actual abundances.

* Lake Littra, Werta Wert Lagoons, and Chowilla Oxbow were only sampled during high river November 2000 – January 2001.

** Little Duck Lagoon and Gurra Control shared the creek sample (adjacent wetlands), thus totals for Gurra Control do not include fish captured in Gurra Creek (these were included into Little Duck Lagoon's tally).

Figures 4, 5, and 6 indicate the proportional break up of the catch at all sites for the entire survey.

Overall, introduced species comprised 38.8% of the catch, the majority being carp (n = 35,950; 29.6%). For the native species (61.1%), the suite of gudgeon species (western carp gudgeon, n = 34,437; Midgely's carp gudgeon, n = 14,491; Lake's carp gudgeon, n = 2,232; and flathead gudgeon, n = 5,170) comprised most of the catch, totalling 46.7%, with western carp gudgeon dominating (28.4%) (Figure 4). This is comparable to a previous study of river systems in New South Wales, where western carp gudgeon were also found to be the most abundant species (Gehrke and Harris 2000).

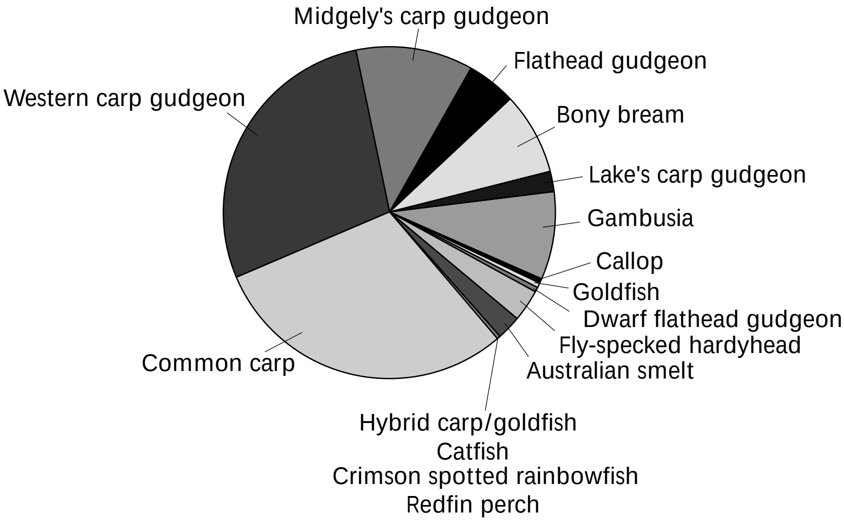


Figure 4. Contribution of all species to total catch.

The remaining catch included gambusia (n = 10,192; 8.4%), bony bream (n = 9,674; 7.9%), fly-specked hardyhead (n = 4,191; 3.4%), and Australian smelt (n = 3,167; 2.6%). Goldfish only comprised 0.66% of the total catch (n = 806), with callop (n = 309), crimson spotted rainbowfish (n = 308), dwarf flathead gudgeon (n = 177), redfin perch (n = 53), hybrid carp/goldfish (n = 28), and catfish (n = 5) all contributing less than 0.3% of the total catch at all sites over all dates.

When the catch is broken into large and small species (size at maturity), the large species within the catch remain dominated by carp (76.7%) – Figure 5. Bony bream comprise 20.66% of the catch of large fish species, with goldfish contributing 1.72% and callop only 0.65%. Catfish, redfin perch and carp/goldfish hybrids contributed less than 0.18% of the total catch of large species throughout the survey.

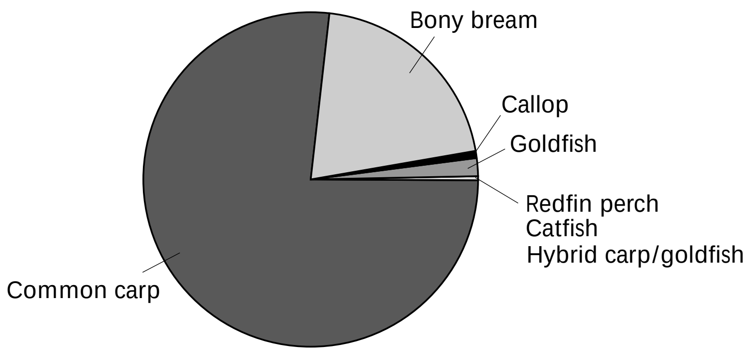
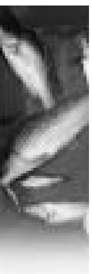


Figure 5. Contribution to catch of all large species (size at maturity).



Of the small fish species, the catch was dominated by western carp gudgeon (46.3%), and Midgely's carp gudgeon (19.4%). The introduced gambusia comprised 13.7% of the catch of small species, with flathead gudgeon, fly-specked hardyhead, Australian smelt and Lake's carp gudgeon contributing 6.9%, 5.6%, 4.2%, and 3.0% crimson spotted rainbowfish of the catch respectively. The two remaining small fish species (crimson spotted rainbowfish and dwarf flathead gudgeon) contributed less than 0.5% to the small species catch (Figure 6).

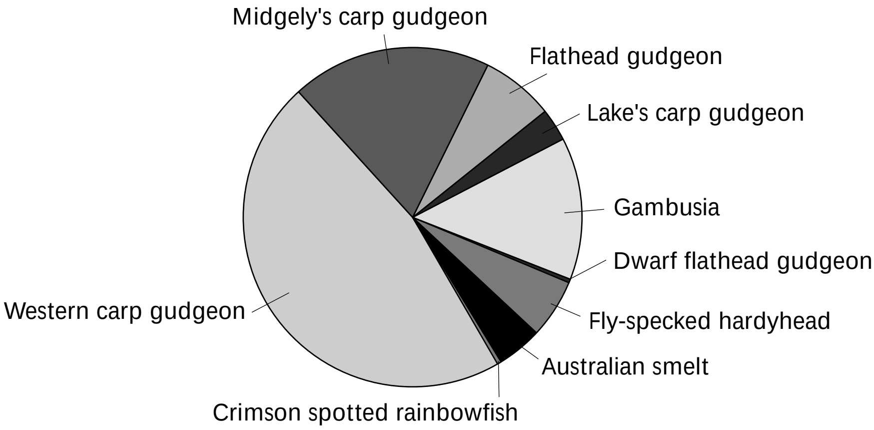


Figure 6. Contribution to catch of all small species (size at maturity).

The proportion of introduced species collected during the present study were lower than those found in the New South Wales "Fish and Rivers in Stress" survey, which found that within the "Murray, regulated lowland" 64.8% of the catch (n = 711) comprised introduced species (Harris and Gehrke 1997). All introduced species captured during the present study were also captured by Harris and Gehrke (1997), with the exception of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*). As with this study, the most abundant introduced species was found to be carp (n = 324), followed by redfin perch (n = 53) and goldfish (n = 37). In comparison to this study, only one specimen of gambusia was collected by Harris and Gehrke (1997) during their entire study within the "Murray, regulated lowland". This is most likely as a result of Harris and Gehrke's study sampling only riverine environments, whereas this study sampled both river and wetland habitats: gambusia are known to prefer warm, gently flowing or still waters, particularly near the edges of aquatic vegetation beds (McDowall 1996b, Allen *et al.* 2002).

Despite these overall similarities, within this study different wetlands were observed to have significantly different fish communities. These findings were analysed further to determine the reason for the differences, with the results discussed below under Objective 4.

Fish tag program

A total of 304 fish were tagged from April 2001 to December 2002. Most of the tagged fish were carp (n = 188), ranging in size from 165mm to >640mm. In addition 74 callop, 32 goldfish, and eight redfin perch were tagged during the course of normal sampling. Two adult silver perch (*Bidyanus bidyanus*) were also tagged, although these fish were captured in an illegally set drum net in Ral Ral Creek. Table 4 indicates the number and size range of fish tagged.

Table 4. Number of fish tagged April 2001 – December 2002.

	165mm – 350mm	350mm – 500mm	>500mm	*TOTAL*
Carp	129	30	29	188
Goldfish	30	2	0	32
Redfin perch	8	0	0	8
Callop	59	15	0	74
Silver Perch	2	0	0	2
TOTAL	228	47	29	304

Although the number of fish tagged was quite low, there were eight fish recaptured during the study. Of these, most were callop (five), with the three other fish being two redfin perch, and a single carp (Table 5).

Table 5. Movements of recaptured tagged fish.

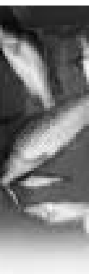
Species	Tag	Tag site	Recapture site	Date of tagging	Date of recapture	Time away	Distance between sites
Callop	17	Pilby inlet (river side)	Pilby inlet (river side)	21-04-01	27-07-01	3 months	~10m
Callop	191	Ral Ral Ck (adjacent perm inlet)	Ral Ral Ck (adjacent perm inlet)	25-04-01	11-10-02	5 months	~100m
Callop	507	Gurra Creek	Mainstream adjacent Gurra Creek	26-04-01	11-05-01	2 weeks	~1.4km
Callop	508	Loveday inlet (river side)	Moorook Game Reserve	01-05-01	21-10-01	6 months	~1km
Callop	550	Gurra Control (wetland)	Mouth of Gurra Creek	30-04-02	30-07-02	3 months	~300m
Redfin perch	134	Loveday (river)	Loveday (river)	30-11-01	21-12-01	1 month	~0m
Redfin perch	155	Loveday (river)	Loveday (river)	21-12-01	18-01-02	1 month	~0m
Carp	96	Ral Ral Ck (adjacent Merreti middle inlet)	Chowilla mainstream adjacent 608km mark	15-11-01	08-08-02	9 months	~9-11km
Carp	531	Pilby (river)	Chowilla mainstream adjacent 393 mile mark	10-12-01	04-05-03	2 years, 3 months	~2km

The longest time period between tagging and recapture was 27 months for a carp. In this time, the fish had grown approximately seven centimetres in length. The second longest time period between tagging and recapture was nine months (also a carp). Callop were recaptured six, five and three months, and two weeks after initially being tagged, and two redfin perch were both recaptured one month after being tagged.

Nearly all the fish were recaptured either at, or close to their initial release site, moving from one side of the river to the other (callop at Loveday), from Gurra Creek to the adjacent mainstream (callop), recaptured in exactly the same position as they were released (callop at Pilby Lagoon inlet channel (river side), redfin perch at Loveday mainstream channel), or making a small upstream movement (approximately 2km for carp 531). The exception to this was the carp (tag 91), which moved between 9-11km upstream (depending on the route taken) between being tagged and recaptured. This fish could have moved upstream wholly via the anabranch system of Ral Ral Creek, Big Hunchee Creek to its recapture location (nine kilometres), or via the mainstream river channel for part of the distance (via Ral Ral Creek, Big Hunchee Creek, Little Hunchee Creek, mainstream river channel).

Few conclusions can be drawn from this information due to the low recapture rate. However, it is interesting to note that the only species that moved some distance from its release site was a carp. It is possible that both callop and redfin perch have a high site fidelity during times of low flow. High site fidelity for callop has recently been reported for both callop and carp (Stuart and Jones 2002, O'Connor *et al.* 2003), and previous tagging studies have shown that callop can move large distances during high river flows (Reynolds 1983).

Although no further tagging will be undertaken as part of this project, it is hoped that other tags will be returned over time, providing some useful information about fish movements, especially during high flow periods.



Turtle captures & distribution

Three species of freshwater turtle are found in the Murray-Darling basin: the long-neck turtle (*Chelodina longicollis*), short-neck turtle (*Emydura maquarii*), and the broad-shell turtle (*Chelodina expansa*). All three species were captured as "by-catch" during this study.

The most common species captured was the long-neck turtle (n = 759), which was captured at all sites, either in the wetland, inlet channel, or river/feeder creek (anabranch). The next most common species was the short-neck turtle (n = 20) that were caught at Lake Merreti (one animal at the inlet structure), Gurra Control Wetland (n = 4), Little Duck Lagoon (n = 2), and Loveday Wetlands and its inlet channel (n = 10).

Only seven broad-shell turtles were captured for the entire survey, mostly in the first year. Broad-shell turtles were captured at Chowilla Oxbow Wetland (n = 1), Lake Littra Punkah Creek (n = 2), Werta Wert Lagoons Monoman Creek (n = 1), Gurra Control Wetland (n = 1), Little Duck Lagoon (n = 1), and in the mainstream river at Loveday Wetlands (one individual that was recaptured during both the day sample and the dusk-night-dawn sample of the same date).

The low numbers of broad-shelled and short-neck turtles captured during this study is of concern. Broad-shell turtles can be found in permanent streams and wetlands although they prefer the riverine environment, whilst short-neck turtles are essentially a riverine species (Cogger 2000). As a result of river regulation, the riverine environment has changed from a flood-drought system, to one with little variation in the hydrograph in the small – medium flood range. It is possible that these species are becoming limited in their distribution to small isolated or semi-isolated populations throughout their range in South Australia in a similar manner to other riverine species that are essentially riverine species. Species such as the River Murray crayfish (*Euastacus armatus*) and the river mussel (*Alathyria jacksoni*) have either become extinct in South Australia or restricted in their range as a direct result of river regulation, and the creation of conditions more suited to wetland species such as yabbies (*Cherax destructor*), wetland mussels (*Velesunio ambiguus*) (Walker 1990), and the long-neck turtle. It is also likely that predation has had an effect on these species (discussed below).

Long-neck turtles were collected at all sites throughout the study except the mainstream channel adjacent Pilby Creek Lagoon, Monoman Creek, and the inlet channel on the wetland side of the structure at Lake Littra. Figure 7 indicates long-neck turtle abundance at all wetlands.

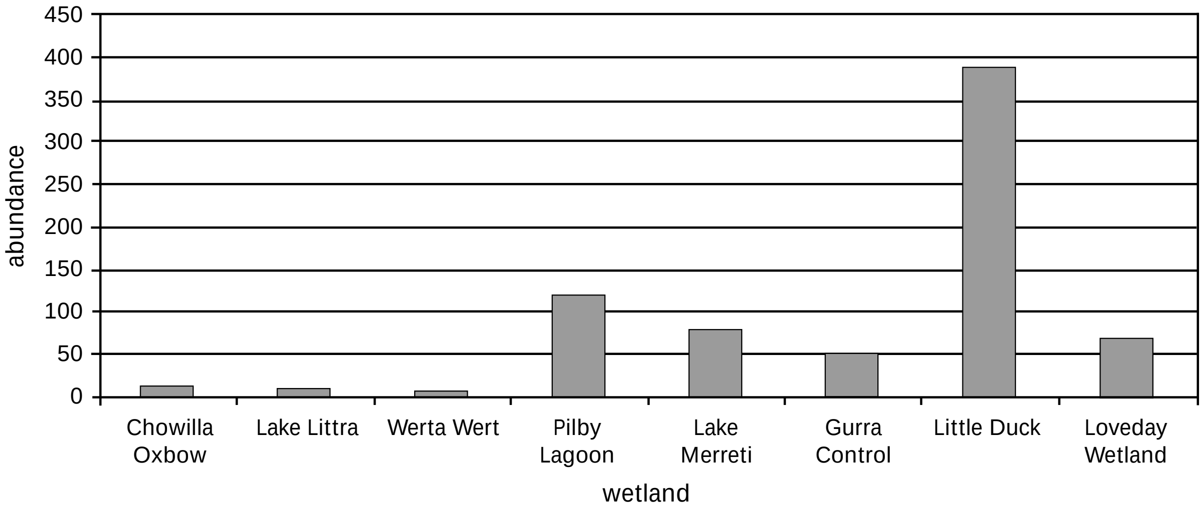
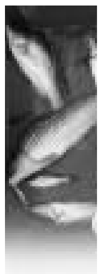


Figure 7. Long-neck turtle abundance at all wetlands.

The wetland with the most long-neck turtles captured was Little Duck Lagoon (n = 390), with all other wetlands connected at pool ranging in captures from 54 (Gurra Control) to 120 (Pilby Creek Lagoon). All temporary wetlands in this study showed minimal captures (nine, 10 and 12 for Werta Wert, Lake Littra and Chowilla Oxbow respectively). This may be a result of the time spent sampling at these wetlands, the short duration of inundation, that long-neck turtles are not common in temporary wetlands, or that they have been favoured by river regulation and prefer wetlands that are wet more often (connected at pool level).

Long-neck turtles prefer the wetland environment or slow moving rivers (Cogger 2000). It is therefore no surprise that for most wetlands (except Lake Littra), a greater number of animals were captured in the wetlands themselves compared to the river/feeder creek (Figure 8). In all wetlands (except Pilby Creek Lagoon) that are connected to the river at pool level, there was a gradual decline in numbers from the wetland to the inlet channel either side of the flow control structure to the river/feeder creek. For Pilby Creek Lagoon, Werta Wert Lagoons and Lake Littra, more turtles were captured in the inlet channel on the creek side of the structure compared to the wetland side of the inlet channel or the river/feeder creek. No long-neck turtles were collected in the inlet channel to Chowilla Oxbow, although eight were captured in the wetland and four in Chowilla Creek.



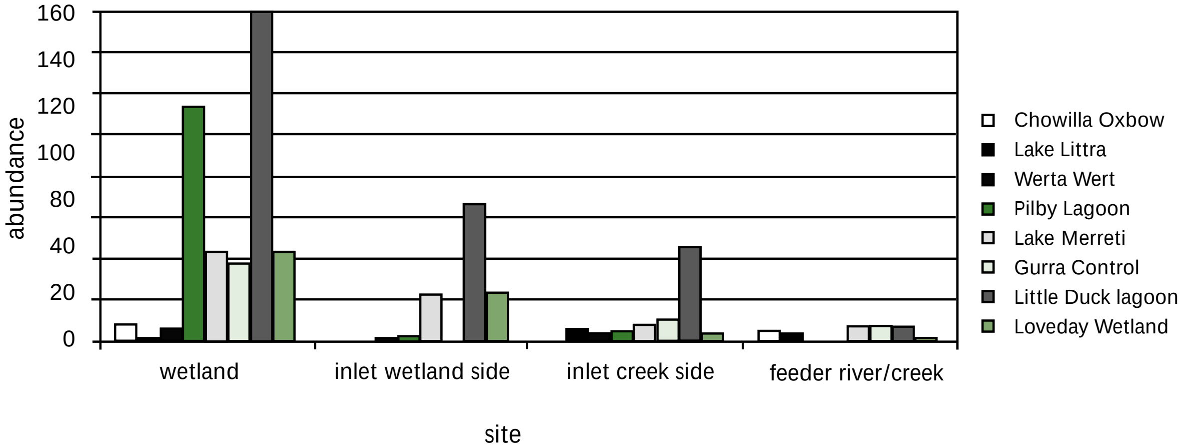


Figure 8. Long-neck turtle abundance by site at each wetland.

Predation (signs of damage to shell or body)
Turtles are particularly vulnerable to predation or attack when laying eggs or undertaking overland movements to new wetlands and waterways. Short and long-neck turtles lay their eggs adjacent to their wetland, however broad-shell turtles lay them further away (Cogger 2000). It would therefore be expected that broad-shell turtles would be exposed to a greater risk of predation due to the distances they move before finding an appropriate nest site. However, long-neck turtles have been observed making overland movements (Nichols, *pers. obs.* 2002), therefore this species is also exposed to a greater risk of predation from terrestrial predators.

Figure 9 indicates the proportion of long-neck turtles captured at each wetland that showed signs of damage to their shell or body. Damage recorded included small pieces removed from the edge of the carapace, holes in the shell, large sections of shell removed, damage, loss of eyes, limbs and claws. No broad-shell or short-neck turtles captured showed signs of damage, although predation from foxes, cats, pigs and dogs has been implicated for the sharp decline in the abundance of short-neck turtles (Hoser 1989), and is likely to also have an effect on broad-shell turtles.

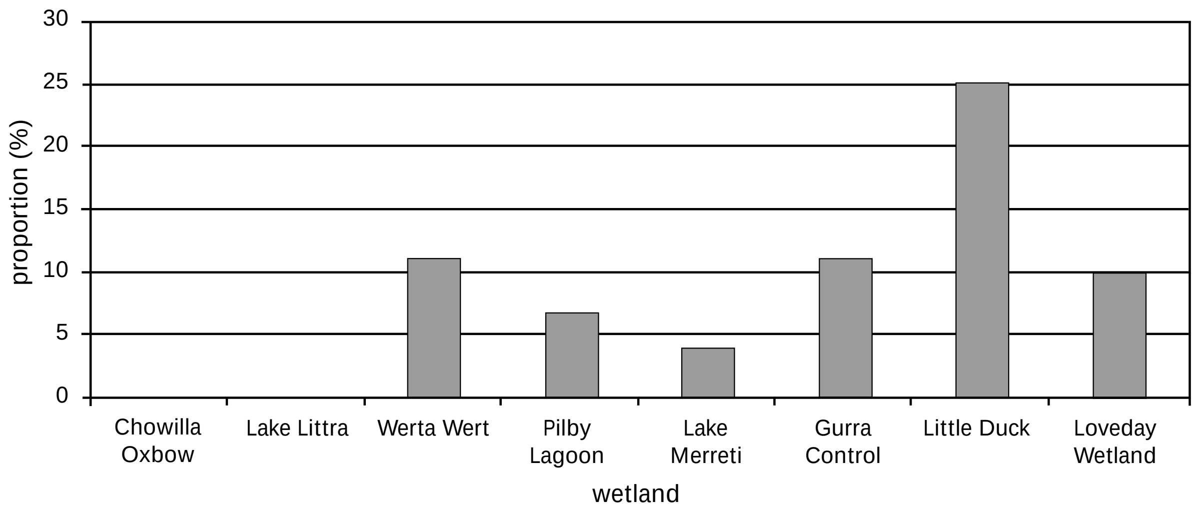


Figure 9. Proportion of long-neck turtles at each wetland with damage to either their shell or body.

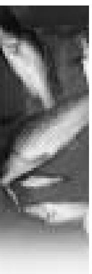


Figure 9 demonstrates that at two of the three temporary wetlands (Chowilla Oxbow and Lake Littra), no long-neck turtles captured were recorded with damage to their shell or body. Both these wetlands had very low capture rates (12 and 10 individuals respectively), however the third temporary wetland, Werta Wert Lagoons (which only had nine individuals captured), showed 11.1% of individuals with predation damage.

Of the permanently connected wetlands, Little Duck Lagoon showed the greatest signs of predation (24.87%), with Gurra Control Wetland and Loveday Wetlands being around 10%, Pilby Creek Lagoon at 6.6%, and Lake Merreti at 3.75%. The large proportion of animals attacked at Little Duck Lagoon is a concern, as this wetland seems to be a stronghold for this species.

It is interesting to note the low amount of predation effects observed on long-neck turtles at Lake Merreti. Only three out of 80 captures (<4%) showed signs of predation effects at Lake Merreti. This wetland is the only one within the study that has a regular (monthly) fox baiting program undertaken on the surrounding floodplain. It is thought that, although there were some predation effects, these has been minimised as a result of the fox baiting program.

When divided into sites within the wetlands (Figure 10), turtles with damage to their bodies or shells were more prevalent in the wetland at Werta Wert Lagoon, Pilby Creek Lagoon and Little Duck Lagoon. At Lake Merreti and Loveday Wetlands, more animals were affected in the inlet channels than elsewhere, and at Gurra Control, more animals from Gurra Gurra Creek showed scars than in the wetland or "inlet channel".

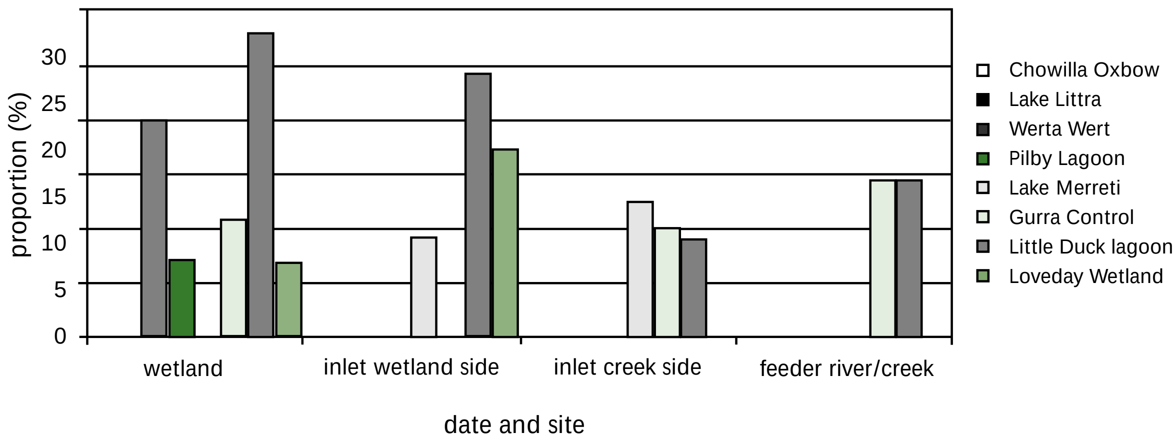
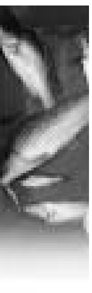


Figure 10. Proportion of long-neck turtles with damage to either their shell or body at each site within each wetland.

No analysis of size measurements was undertaken for turtles.



Addressing project objectives:

Objective 1. Determine the influence of flow rate and flood height on movement of fish between the river and floodplain wetlands.

Permanent wetlands may have permanent localised fish communities that do not undergo immigration or emigration (Humphries *et al.* 1999). Examples of species commonly found in permanent wetlands include gudgeons, crimson spotted rainbowfish, Australian smelt (Humphries *et al.* 1999), and gambusia (Wedderburn 2001). Western carp gudgeons have been recorded having a strong association with snags and aquatic plants, and are most often found in wetland environments (Wedderburn 2001). Similarly, some fish are riverine specialists, preferring to remain within mainstream habitats (eg Murray cod, *Maccullochella peelii*: Harris and Rowland 1996). Australian smelt have been associated with flowing waters and high turbidity (Wedderburn 2001). In addition to species that are either riverine or wetland specialists, there are a number of species that move between rivers and wetlands to some extent, termed lateral migration. For example, although bony bream are known to prefer backwaters and wetlands over mainstream habitats, they move between the two habitats, and have been recorded spawning in backwaters during floods, although it has been noted that only juveniles use the floodplain proper (Humphries *et al.* 1999). In the Czech Republic, roach and redfin perch were found to move laterally between backwaters and the mainstream (Hohausova 2000).

Movement into wetlands

When examining the fish community as a whole, the water quality variables predominantly responsible for triggering fish movement from the river into floodplain wetlands were temperature and conductivity ($F_{2,58}$ = 20.1, p <0.0001) (Table 6). These two variables accounted for 40.94% of the variation in fish movement into wetlands, with fish moving into wetlands when water temperature and conductivity were increasing.

For native fish water temperature and conductivity, as well as flow within the wetland inlet contributed to trigger movement into wetlands. Temperature and conductivity were significantly related to fish movement and, although flow within the inlet channel was not significant individually, it contributed to improving the explanatory power of the model ($F_{3,57}$ = 13.21, p <0.0001) (Table 6). These three variables accounted for 41.01% of the variation in movement of native fish into wetlands. When the relationship between fish movement, water quality, and environmental parameters is explored, it can be seen that native fish moved into floodplain wetlands when water temperature and conductivity increased, and flow within wetland inlets declined.

Although significant ($F_{4,56}$ = 6.60, p = 0.0002), the relationship between water quality and flow variables and the movement of introduced fish into floodplain wetlands was not as strong as for native fish. For introduced fish species, a combination of conductivity, temperature, turbidity and flow within the inlet channel accounted for 32.05% of the variation of movement of fish into wetlands. Conductivity, temperature and turbidity were significantly related to fish movement, with flow within the inlet channel adding to the explanatory power of the model (Table 6). The direction of this relationship appears such that introduced fish moved into floodplain wetlands when conductivity, temperature and flow within wetland inlets increased and turbidity declined.

River flow at the closest lock, river level, depth in the inlet channel, dissolved oxygen, pH and season were not found to affect fish movement into wetlands during this study.

Increasing conductivity and temperature were both found to be very important triggers for fish movement into floodplain wetlands. Flow within the inlet channel was also important for initiating movement of both introduced and native fish, although natives were stimulated to move by decreasing flow while introduced fish were stimulated by increasing flow.

Table 6. Results of stepwise multiple linear regressions of movement of fish between floodplain wetlands and the river for native, introduced, and all fish species.

Movement into wetlands				Movement out of wetlands			
Variable	Regression coefficient	± SE	P	Variable	Regression coefficient	± SE	P
Natives				*Natives*			
Temperature	0.064	0.014	<0.0001	Flow at closest lock	-0.151	0.096	0.122
Conductivity	0.717	0.137	<0.0001	Turbidity (Secchi)	-0.013	0.007	0.051
Flow in wetland inlet	-3.353	1.72	0.056				
Introduced fish				*Introduced fish*			
Conductivity	0.396	0.106	0.0004	No significant relationships			
Temperature	0.035	0.012	0.006				
Turbidity (Secchi)	0.013	0.006	0.045				
Flow in wetland inlet	2.424	1.289	0.065				
Total				*Total*			
Conductivity	0.817	0.147	<0.0001	No significant relationships			
Temperature	0.060	0.015	0.0002				

Movement out of wetlands

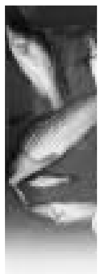
Unlike the movement of fish into floodplain wetlands, no water quality or environmental variables were found to be significantly associated with the movement of the entire fish community out of wetlands ($F_{1,59} = 2.91$, $p = 0.093$) (Table 6).

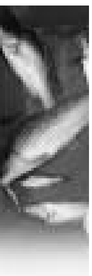
When introduced species were omitted, however, flow at the nearest lock and turbidity of the water were found to be significantly associated with movement of native fish out of wetlands ($F_{2,58} = 3.50$, $p = 0.037$) (Table 6). Despite this association the relationship was weak, with these two variables accounting for only 10.77% of the variation in fish movement out of wetlands. In addition, neither variable was significantly related on their own but the combination of both provided a significant model.

No environmental or water quality variables were found that were significantly associated with the movement of introduced species out of wetlands ($F_{1,59} = 3.10$, $p = 0.083$).

Synopsis

It should initially be clarified that the data analysed here were pooled to form groups of fish, rather than being analysed on an individual species basis due to the sample sizes for individual species being small in the area of interest (inlet channel either side of the flow control structure). Similarly, no distinction has been made for life stage information, which potentially may have influenced the results.





The specific relationship between water quality, environmental variables and fish movement is difficult to determine. From the relatively low explanatory power of the variables measured, it would appear that other variables not recorded are also factoring in the inducement of fish to move either into or out of wetlands, or that the groups of fish chosen are inappropriate (individual species may be acting differently, dampening any overall relationship between fish movement and water quality or environmental variables). Despite this, several hypotheses can be proposed to explain the relationships observed.

Increases in flow in the mainstream channel have been recorded as being associated with fish migration upstream for breeding purposes (Reynolds 1983). Flow in wetland inlet channels would therefore also be thought to influence movement as this is also naturally associated with mainstream flow increases. During the initial stages of wetland filling, water velocities within the inlet channel would increase, possibly giving an indication to fish that new foraging or breeding areas were opening up. This appears to have occurred during this study for the introduced species, combining with other water quality variables to stimulate movement into wetlands.

As part of this project, a small pilot study investigated fish movement when an attractant flow was initiated at Pilby Creek Lagoon prior to a drying cycle being implemented on the wetland (Nichols 2001). Although no statistical tests were possible, fish activity in both the inlet and outlet was noted to increase with application of an attractant flow from the inlet and opening of the outlet structure – indicating that changes to flow is may be an important factor in stimulating fish movement (Nichols 2001).

Fish moving into wetlands with decreasing flow in their inlets is a little more difficult to explain. It is possible that native fish have adapted to move into wetlands when flow in their inlets decreases as an indication that a wetland is full and therefore the maximum area has been opened up for foraging, breeding, or rearing. This, in combination with other variables may indicate that the wetland is “safe” or “ready”.

Flow, in combination with increasing salinity and water temperatures appears to stimulate both native and introduced fish to move into wetlands. Increasing water temperatures in the mainstream are a function of season, with higher water temperatures occurring in summer, and lower temperatures in winter. The natural hydrological cycle prior to river regulation was high river flows occurring in spring-early summer, coinciding with rising water temperatures. In wetlands increasing water temperatures are also a function of seasonality, but also of water depth (shallow water heating more than deeper water), and may indicate that a newly opened area has been created.

Analysis of fish captures from Lock and Weir Six fishway by Dooland *et al.* (2000) indicated that movement of callop and silver perch upstream through the fishway were strongly associated with water temperature and time of year with slightly more movement occurring with rising water levels. Activity was noted to begin at around 16°C, with most activity occurring in January and February when water temperatures were around 23-24°C, and continuing until temperatures were falling below 19°C (Dooland *et al.* 2000). In contrast, movement of carp through the fishway occurred earlier (starting in August or September), peaking in October or November, with less movement occurring in summer (December to February) (Dooland *et al.* 2000). In addition, carp did not appear to be stimulated by a specific water temperatures, although did not move through the fishway when temperatures were below 14-15°C. when their movement peaked when there was very little pool level differences (Dooland *et al.* 2000).

Similarly, increasing conductivity could also indicate suitable habitat for fish within floodplain wetlands. Where saline ground-water levels were low, water on the floodplain is likely to be absorbed by the soil quicker and therefore floodplain wetlands would empty/dry more rapidly. Conversely, if the saline ground-water table was high, floodplain waters would remain for longer periods of time. As a result, the level of the ground-water table could act as an important predictor of the suitability of floodplain wetlands for fish habitat. Under this hypothesis, if the level of the ground-water table is reflected by conductivity level within the river, riverine conductivities may have evolved as an indicator to riverine fish populations that floodplain wetlands are likely to persist for sufficient periods of time to act as suitable fish habitat.

It is surprising that changes in dissolved oxygen levels were not significantly correlated with fish movement, as this is taken to be one of the main water quality parameters that influence fish distribution in the river and on the floodplain (Welcomme 1985). Gehrke (1991) found a positive correlation between callop larval density and dissolved oxygen concentrations in an artificially inundated floodplain habitat and pond environment (Gehrke 1991). In his experiment Gehrke found that higher densities of larvae were found in the pond environment compared to the newly inundated floodplain habitat where low dissolved oxygen concentrations occurred (Gehrke 1991). This was despite the presence of higher densities of food items on the floodplain compared to the pond habitat. Low dissolved oxygen concentrations were attributed to the breakdown of plant matter on the floodplain, and could not be separated from the effects of tannins also released from rotting vegetation (Gehrke 1991). Gehrke (1991) therefore hypothesised that water quality parameters such as dissolved oxygen and tannin concentrations exerted a greater influence on the distribution of callop larvae than did food density in an artificially inundated floodplain environment (Gehrke 1991). The same may be true for other species, and probably of more mature life stages of callop. For older age classes, however, the ability to avoid poor conditions is greater than for the larvae due to their swimming ability, with poor water quality areas potentially still available for feeding, but within a shorter time frame.

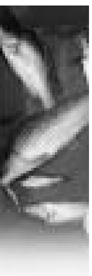
The poorer relationship between introduced fish and the parameters measured possibly should be expected due to the short time frame in which these animals have been present in this system. Associations with environmental and water quality parameters are built up over evolutionary time-scales, and would not be expected to be evident in species that are relatively new to an environment.

The lack of water quality and environmental variables associated with fish moving out of floodplain wetlands indicate that other factors are stimulating movement out of wetlands for native and introduced fish, and for the fish community as a whole. The absence of these cues (whatever they are) could lead to fish strandings.

Diel patterns of fish movement in the Lower Murray

Significant differences in the capture rate during day and “night” samples occurred for 12 of the 16 species sampled for this project (Table 7). For three of these species (catfish, goldfish/carp hybrids, and redfin perch), the sample sizes were low (n = 5, 28, 53 respectively), however the other species that did not show a significant correlation with either activity time, bony bream, were found in high abundances (n = 9,674).

Only three species were significantly more active during the “night” sample: goldfish, carp, and callop. All other species were found to be more active during the day than “night” samples, indicating the diurnal nature of their activity.



The significance levels were generally lower for the 'inlet only' analyses due to the smaller sample sizes. No contradictory results were found between the two analyses although some species that showed significant differences when the whole data set was analysed, were not significant with the reduced data set.

Table 7. Results of Wilcoxon's signed-ranks tests comparing fish catches during day and "night" samples.

Species	*p* value (all habitats)	*p* value (inlet channels only)	Active period
Native species			
Fly-specked hardyhead	<0.02	>0.1	Diurnal
Western carp gudgeon	<0.001	<0.001	Diurnal
Midgely's carp gudgeon	<0.001	<0.01	Diurnal
Lake's carp gudgeon	<0.001	<0.001	Diurnal
Callop	<0.001	<0.001	Nocturnal / Crepuscular
Crimson spotted rainbowfish	<0.01	>0.5	Diurnal
Bony bream	>0.5	>0.5	
Flathead gudgeon	<0.001	<0.001	Diurnal
Dwarf flathead gudgeon	<0.01	>0.5	Diurnal
Australian smelt	<0.001	>0.1	Diurnal
Catfish	>0.5		
Introduced species			
Goldfish	<0.001	<0.001	Nocturnal / Crepuscular
Carp	<0.001	<0.001	Nocturnal / Crepuscular
Goldfish/carp hybrids	>0.2	>0.5	
Gambusia	<0.001	<0.001	Diurnal
Redfin perch	>0.1	>0.2	

Synopsis

Although bony bream were not found to be more active during either the day or "night" samples during this study, sampling in the Cooper Creek system has indicated that this species is crepuscular in its activity, ie the time of greatest activity occurs at dusk and dawn, rather than day or night (Pritchard *pers. comm.* 2002). Conversely, a preliminary survey of fish movements in Chowilla wetlands found that bony bream moved exclusively during the day (Pierce 1992). More directed sampling of this species, during day, night, dusk, and dawn periods will determine the period of greatest activity for this species.

As with bony bream, it has previously been noted that callop are also crepuscular in their activity (Mallen-Cooper 1992, Mallen-Cooper 1994), although one study has indicated that they are diurnal (Pierce 1992). Crepuscular activity, rather than purely nocturnal activity would explain the significant correlation with the "night" samples of this project, as "night" samples included dusk, night and dawn periods. The same, therefore, could also be true of carp and goldfish which also showed greater activity during the "night" samples of this study. However, Pierce (1992) found that carp and goldfish moved out of Chowilla (temporary) wetlands exclusively at night, indicating that they are genuinely nocturnal in their activity (Pierce 1992).

The non-significant relationship of those species not related to either the day or "night" samples may be due to the pooling of data from all life stages collected during this project. Different life stages may have different activity periods within a 24hour period, leading to a non-significant relationship between fish activity and day, "night" samples.

It may also be due to the low sample sizes for some species (catfish, carp/goldfish hybrids, and redfin perch).

The findings of this study that the gudgeon species and fly-specked hardyheads are diurnal in their activity concur with a previous study of fish movement in the Chowilla wetlands (Pierce 1992).

Determination that some species, particularly the introduced species, are nocturnal or crepuscular in their activity provides opportunity for flow control structure management at rehabilitated wetlands. Closure of the fish screens at night, and opening them during the day, may provide native fish access to the wetlands during the day, and limit the number of carp and goldfish accessing the wetlands at night. The finding that callop are also nocturnal or crepuscular in their movements may not be an inherent dilemma for structure management, as only 35.3% of all callop (n = 311) were captured within the wetland environment (managed or unmanaged). Of those fish on the wetland side of the structure, only 34.5% were greater than 200mm (n = 38) compared to 56.7% of callop on the river side of the structure (n = 114), indicating that adult fish are not using the wetlands in high numbers.

The potential use of wetlands as breeding areas is discussed further in Objective 3.

Objective 2. Identify the relative importance of channel versus over-bank flows for fish passage into and out of wetlands.

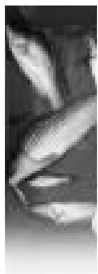
This objective could not be addressed as only one over-bank flow occurred in December 2000 at Little Duck Lagoon, when the structure embankment was overtopped. Despite the lack of overbank flows, the temporary inlets to Lake Merreti began to hold water during October – December 2000, and provided an opportunity to undertake sampling at the upstream inlet site in October.

Lake Merreti upstream inlets

Sampling was focussed on the inlet structure net due to timing and resourcing issues, although nets were set in the inlet channel on the creek side of the structure and in the adjacent Ral Ral Creek (two nets only). No nets were set on the wetland side of the structure, and the structure net was only set for movement into the inlet channel. No formal statistical analysis was possible due to the low number of samples taken, and individuals captured.

Overall, three samples were taken with the structure net, inlet channel, and Ral Ral Creek. A total of 361 fish were captured from nine species in the upstream temporary inlet and inlet structure net, and six species from Ral Ral Creek. Only three species were captured using the inlet structure net (25mm bar length): carp (n = 37), goldfish (n = 30), and bony bream (n = 1).

The most common species captured overall were carp (n = 184), goldfish (n = 70), and western carp gudgeons (n = 70), with the majority of these being captured within the inlet channel. Midgely's carp gudgeon (n = 20) were the next most common species, again predominantly captured in the inlet channel itself. All other species captured consisted of less than ten individuals (flathead gudgeon, n = 6; Australian smelt, n = 3; bony bream, n = 3; hybrid carp/goldfish, n = 2; callop, n = 1; gambusia, n=1; redfin perch, n = 1). Callop and flathead gudgeon were only found in the creek sample. Australian smelt, Midgely's carp gudgeon, gambusia, and redfin perch were only captured in the inlet channel nets (the redfin perch was a juvenile ~35mm long).



Sampling in October 2000 coincided with the main carp breeding event that occurs at around this time annually (Hume *et al.* 1983, Smith 1999). Environmental cues such as rising air and water temperatures, increased flows, water height, and photoperiod appear to trigger reproductive activity at this time (Smith 1999). Carp were observed in the shallow water of sections of inundated floodplain at the time of sampling (Nichols *pers. obs.* 2000).

The initial sample predominantly captured carp and goldfish greater than 200mm in caudal length, although some smaller individuals of goldfish were also captured within the inlet channel at this time (Figure 11 and 12). During the following two sample events, the size classes dropped so that the catch was predominantly composed of carp within the 10-20mm and 20-50mm size class. Carp approximately 40mm in length are generally around 50 days old (Smith 1999). With this age estimate, fish in the 0-30mm size class appearing during these samples were probably spawned within the month prior to sampling.

Goldfish catches on the later dates remained dominated by 100-200mm fish, with lesser contributions from fish between 50-100mm and 200-300mm. This indicates that spawning for this species is likely to be earlier or later than for the carp.

Synopsis

Previous studies have indicated that fish became more abundant after flooding, when creek and floodplain habitats contained water (Gehrke *et al.* 1995). Diversity has also been noted to increase at these times (Theiling *et al.* 1999, Medeiros and Maltchik 2001), with the absence of flooding (through lack of natural flows) leading to a more stable, and less diverse fish fauna (Medeiros and Maltchik 2001).

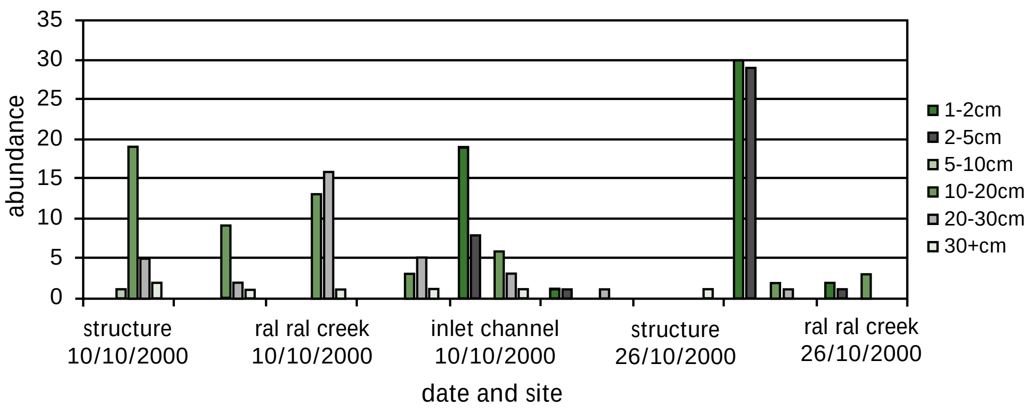
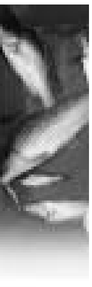


Figure 11. Carp abundance by site and date at Merreti upstream temporary inlet.



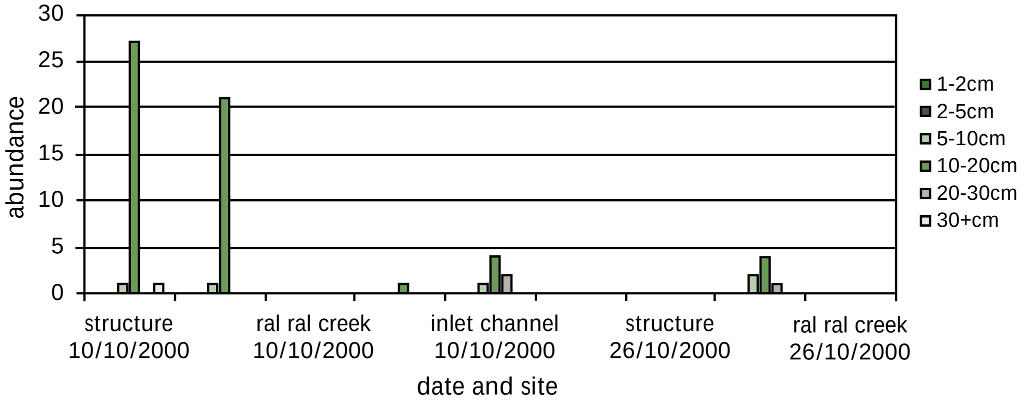


Figure 12. Goldfish abundance by site and date at Merreti upstream temporary inlet.

In Australia, the "flood pulse concept" has been applied to describe the link between flooding, fish reproductive activity and recruitment (Junk *et al.* 1989). However, little field evidence has been provided to indicate that all fish native to the Murray-Darling basin fit this model, leading to the development of alternative theories on reproductive traits employed (Humphries *et al.* 1999). Indeed, previous studies have shown that it is predominantly juvenile carp that have been found in large numbers in floodplain lake (temporary wetland) habitat (Gehrke *et al.* 1995).

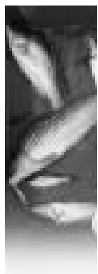
During this survey, carp were found to be the dominant fish at all three temporary wetlands monitored. This was also the case during a previous fish survey at Lake Littra, where a total of only four species were captured using three capture methods: carp, gambusia, Australian smelt, and callop (one adult individual only) (Dominelli 1996).

Although it is known that other species do use the floodplain during high floods, it is thought to be only for short periods of time (Koehn and Nicol 1998). As Humphries *et al.* (1999) remark, more directed research is required to investigate the use of temporary wetlands and the floodplain proper by fish during high river and overbank flows.

Objective 3. Assess the importance of wetlands for fish recruitment.

Despite the popular belief that the floodplain and its wetlands are important areas for fish recruitment (eg Cadwallader 1978), and knowledge that some species prefer permanent wetland habitats (Humphries *et al.* 1999), for most species little evidence has been found to support the use of wetland as spawning and recruitment sites (Geddes and Puckridge 1989).

The "flood pulse concept", originally proposed by Junk *et al.* (1989), has been used to describe the integral part flooding flows play in the biology of native fish species. More recently, the notion that all native fish species rely on flooding flows to complete their life cycle has been challenged (Humphries *et al.* 1999). This has led to the proposal of alternative reproductive strategies such as the "low flow hypothesis", which suggests that some fish species reproduce and recruit within the main river channel, and are not reliant on flooding flows to complete their life cycles (Humphries *et al.* 1999). In addition, some authors have suggested that floodplain wetlands are not used as spawning sites for many species, but act as grow-out (nursery) areas for juveniles (Geddes and Puckridge 1989).

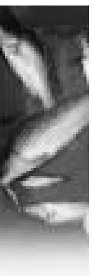


Abundance data
Analysis of abundance data from the current study has shown that none of the wetlands surveyed were a significant source of recruitment for any species during any season. In fact, several species were found to have significantly more individuals entering wetlands than leaving them, suggesting that the wetlands were acting as a population sink for these fish (Figure 13).

Of the introduced species, significantly more carp entered wetlands than left in summer, and significantly more gambusia entered wetlands than left in autumn and spring. Significantly more redfin perch entered wetlands than left them in autumn. The use of wetlands by redfin perch was minimal, however, (low numbers were collected throughout; generally only single individuals from the wetland or inlet on the wetland side of the structure, except Gurra Control wetland where a total of 16 juvenile and one adult fish were captured from the wetland during the entire project).

Of the native species, significantly more western carp gudgeon entered wetlands than left them in summer, autumn and winter; significantly more Lake's carp gudgeon entered wetlands than left in spring; significantly more crimson spotted rainbowfish entered wetlands than left in autumn and spring; and significantly more Australian smelt entered wetlands than left in winter.

Size class data
The results based on abundance data are supported by analyses of length data (Figure 14). The assumption with this analysis is that if a wetland was acting as a site of significant recruitment, it would be expected that a greater number of smaller individuals would be sampled moving out of a wetland than moving into it. Size class data was only analysed for species with greater than or equal to 25 individuals entering and leaving the wetland, therefore analyses were not undertaken for crimson spotted rainbowfish, dwarf flathead gudgeon, catfish, or redfin perch.



For the fish that were analysed, four species (Australian smelt, bony bream, callop and goldfish), showed a significantly higher frequency of small size classes moving into wetlands, with larger size classes moving out. For these species at least the wetlands sampled may be acting as a grow-out (nursery) area, where juvenile individuals (and possibly larvae) move into the wetlands, grow, and move back to the mainstream.

For two of the introduced species (carp and gambusia), the significant differences in size frequency distributions were due to differences in the number or fish present within the intermediate size classes. Significant differences in size frequency distributions in the direction expected if wetlands were a significant site of recruitment (greater number of smaller individuals leaving than entering the wetlands) were only found for Midgely's carp gudgeon and Lake's carp gudgeon. No significant differences in size frequency distributions were found for western carp gudgeon, fly-specked hardyhead or flathead gudgeon.

The non-significant result for western carp gudgeon, fly-specked hardyhead and flathead gudgeon may be a result of a sampling effect produced by the fyke nets used. These nets were inefficient at capturing fish less than 15-20 mm (having a mesh bar length of five millimetres) and therefore were not capable of capturing the small size classes of any of the small fish species. Small individuals of Midgely's and Lake's carp gudgeons were greater than 20mm length, and the size classes for both species overlapped those for western carp gudgeon, fly-specked hardyhead and flathead gudgeon. For these species therefore, the wetlands sampled may still be acting as a grow-out (nursery) area, with small fish (including larvae) moving in and juveniles moving out, but that the size frequency for fish leaving is less than for other species.

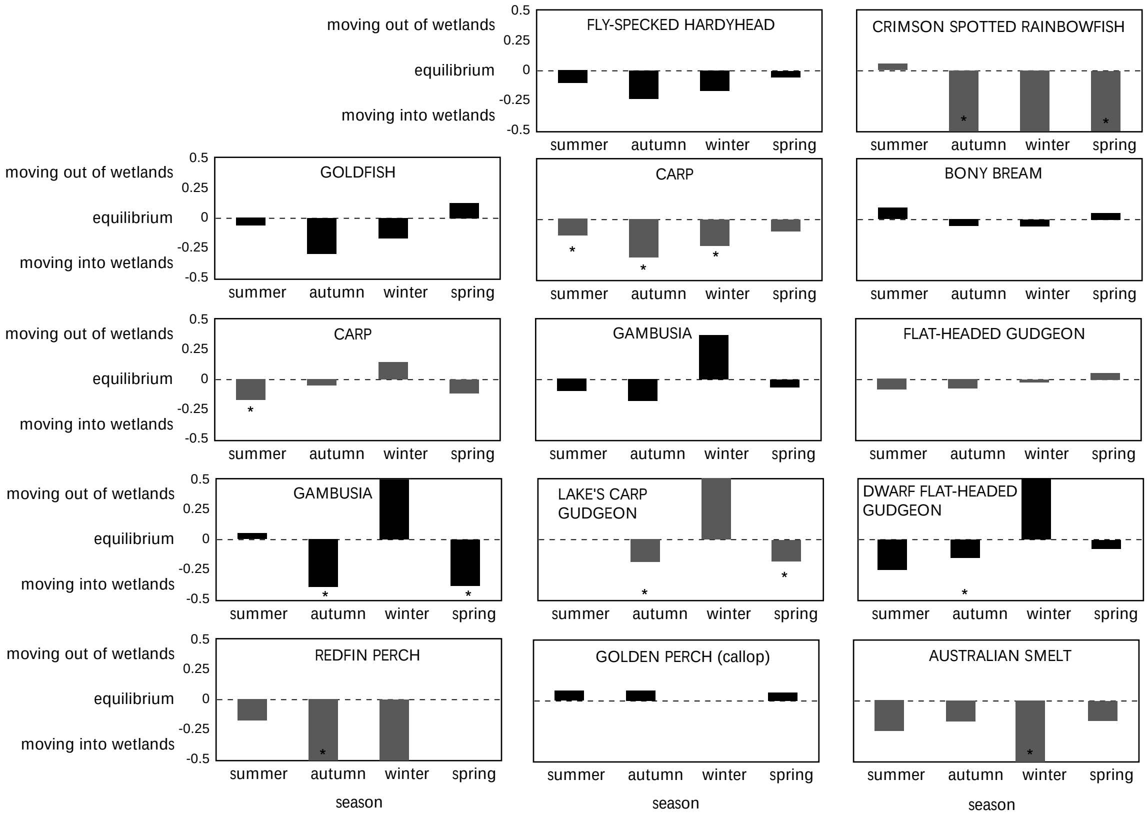


Figure 13. Proportion of fish moving out of and into wetlands.

Zero represents an equilibrium between the number of fish moving between wetlands and the river (ie. no significant recruitment). Positive values indicate that a majority of fish were moving out of wetlands towards the river. Negative values indicate that a majority of fish were moving into wetlands. Values that differed significantly from equilibrium ($p < 0.05$) (ie. The population is either a source of recruitment or a sink) are indicated with an *.

Synopsis

Data from all wetlands within this study were pooled to undertake the analyses using abundance data, and size frequency data. Data used for all analyses were from nets capturing fish that had moved through the structure in either direction (Nets 2 and 3). The results are therefore reflective of current wetland management conditions, where flow control structures are present on six of the eight wetlands surveyed. Results should therefore be qualified with the potential impact the flow control structure is having on juvenile fish movement to and from the wetland (refer Objectives 4-6).

In addition, due to the type of gear employed during the project, sampling of larval fish was not possible. Complete comment on the use of these wetlands as spawning sites therefore cannot be made. Further research on larval fish movement to and from wetlands with and without flow control structures would be advantageous for future management of these wetlands and their larval fish fauna.

Geddes and Puckridge (1989) agreed with other authors who believe the floodplain habitat to be important as a fish nursery. Further, they suggested that the floodplain and its wetlands may provide a major role as a nursery for juvenile fish rather than larvae as has previously been assumed (Geddes and Puckridge 1989). The loss of these habitats, through installation of intentional or unintentional barriers, may therefore present a major loss of habitat that is crucial to the life cycle of many fish species. Determination of the effects of flow control structures on fish movement is therefore critical in the long term conservation of the fish fauna within the Murray River.

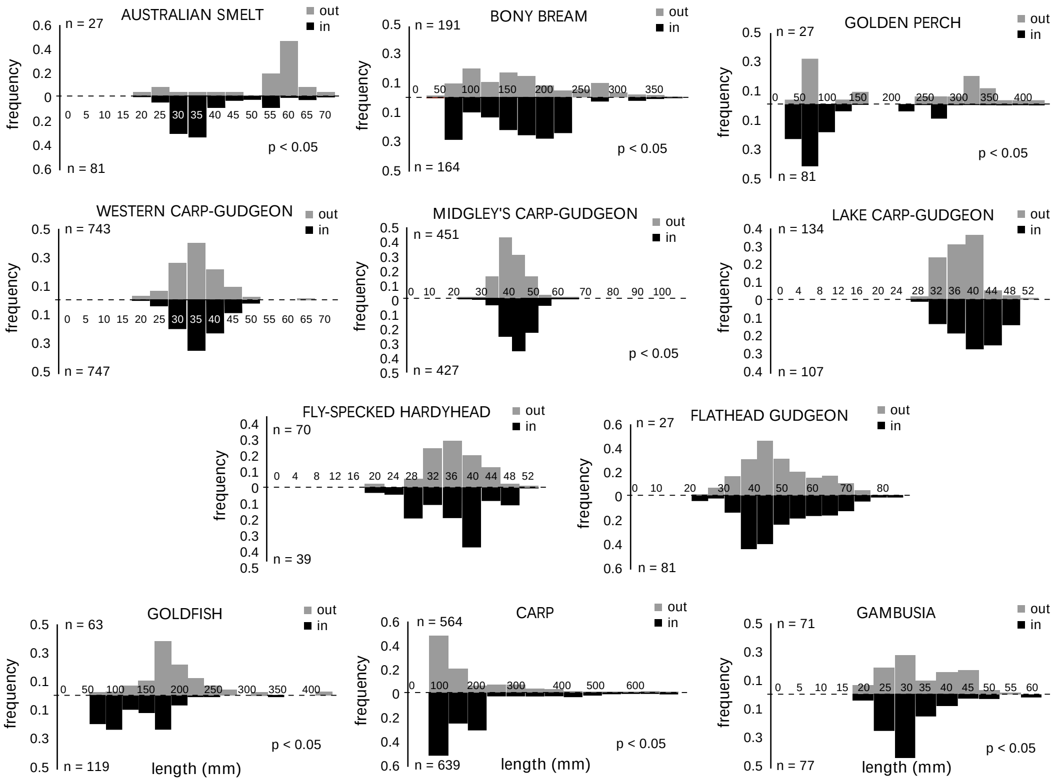


Figure 14. Length frequency distributions of fish entering (black) and leaving (clear) wetlands.

Abundance data collected during this project has indicated that for some species, the wetlands surveyed were acting as population sinks, with significantly more fish entering wetlands than leaving them during certain seasons.

Analysis of size frequency data within this project has indicated that wetlands may be acting as grow-out (nursery) areas for Australian smelt, bony bream, callop and goldfish, with a greater number of larger individuals of these species collected moving out of the wetlands than were collected moving in. For bony bream, callop and goldfish, the use of wetlands as grow-out areas is possibly true, with size class data and abundance data indicating movement out (although fish movement out of wetlands for any species at any season was not found to be significant).

Significant results relating to the movement of fish into the wetlands, but non-significant results for fish moving out, indicate that the wetlands may also be acting as population sinks for many species. It is possible that these results are a reflection of the presence of flow control structures on the wetlands within this survey. The presence of a structure may present a barrier to fish movement out of wetlands physically or behaviourally, thereby limiting movement of fish back into the mainstream. Structural characteristics, their influence on water quality and flow conditions, as well as positioning of structures all play a part in the ability of fish to traverse them. Equally important to structure design and positioning is structure management. The number of cells opened during the filling phase will influence water velocities through the structure, as will the build up of debris across the culvert. Timing of opening and closing may influence the species that are able to move through, and closure of the structure will completely inhibit movement of fish through the structure in either direction.

With the exception of Pilby Creek Lagoon, all of the wetlands within this study are dried through evaporation by closing the inlet structure on the wetland inlet. When this occurs there is no chance of escape for any aquatic organism, unless they move overland (eg yabbies, turtles). Management of structures in this way therefore causes wetlands to act as population sinks for all fish species unless they are able to escape prior to the inlet structure being closed. It is likely, therefore, that significant differences in movement of fish into wetlands compared to movement out is a direct reflection of structure management, and drying of wetlands by evaporation. For species that appear to have a preference for wetland habitat (such as the suite of gudgeon species and Australian smelt), this management action could become (or is currently) a threatening process to the survival of these species. Structure management is further discussed in the following section (Objectives 4-6).

Objectives 4, 5 and 6. Impacts of structures, develop guidelines, and make recommendations for their management and construction.

The last three objectives within this project are related to the impacts of wetland flow control structures on fish movement, and finding ways to improve them. The three objectives will therefore be discussed together here, with the original objectives being as follows:

- determine the impacts of wetland inlet structures on fish passage for native fish;
- develop guidelines to facilitate movement of native fish through inlet structures while excluding carp;
- make recommendations for the design of new structures.

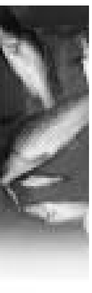
Fish communities present

Analysis of fish community data was undertaken to determine the differences or similarities between fish communities at different habitats within different wetlands, and between managed and unmanaged wetlands.

The analyses suggest that the sampling undertaken for this project was sufficiently powerful to detect significant differences between fish communities. When all wetland systems were pooled, ANOSIM analysis revealed significant differences occurring between fish communities within the different habitats of the managed wetland systems (Table 8).

Table 8. ANOSIM results from analysis of fish communities among different habitats sampled (all wetland systems pooled).

Habitats compared *Significantly different communities are shaded.	Significance
River - Inlet (wetland side)	0.001
River - Inlet (river side)	0.001
River – Wetland (managed)	0.001
River – Inlet (un-managed)	0.801
River – Wetland (un-managed)	0.459
Inlet (wetland side) – inlet (river side)	0.001
Inlet (wetland side) – Wetland (managed)	0.011
Inlet (wetland side) – Inlet (un-managed)	0.820
Inlet (river side) – Wetland (managed)	0.001
Inlet (river side) – Inlet (un-managed)	0.998
Wetland (managed) – Wetland (un-managed)	0.325
Inlet (un-managed) – Wetland (un-managed)	0.611



Fish communities occurring in managed habitats were found to be significantly different from the riverine fish community (Table 8). In contrast, un-managed wetlands and inlets have fish communities consistent with the riverine fish community (Table 8). This relationship is consistent when all wetlands were analysed separately with the exception of Lake Littra where the river and lake where only just non-significantly different (p =0.054) -Table 9.

In managed wetlands, fish communities occurring on the river and wetland side of wetland control structures were found to be different (Table 8). This suggests that wetland inlet structures created an artificial discontinuity in fish communities moving between wetlands and the river. Although the combined results were significant, when wetlands where analysed separately, inlet fish communities on either side of the control structures were not significantly different at Little Duck, Loveday or Werta Wert (Table 9). These differences may have resulted from the improved power of the combined analysis, or through the demonstrated differences in fish passage efficiency of each structure. However, non- significant correlations of $RFP_{structure}$ with Bray-Curtis similarities of fish communities on either side of each structure (FP_{US}; r = -0.21, $p > 0.05$, FP_{DS}; r = 0.22, $p > 0.05$) do not support the later argument.

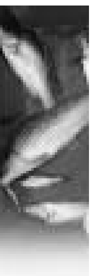
Fish communities occurring within managed wetland inlets and the wetlands themselves were also found to be significantly different but were not significantly different in un-managed wetlands (Table 8). When each wetland was analysed individually, however, significant differences were only found at Loveday Wetlands, Lake Merreti and Pilby Creek Lagoon (Table 9).

No significant differences between managed and un-managed inlets could be detected in the pooled analysis (Table 8). This is likely to be a result of small numbers of replicates in un-managed inlets, as it would be expected that a significant difference would be found between communities on the wetland side of managed inlets and those in the un-managed inlets.

Table 9. ANOSIM results from analysis of fish communities among different habitats sampled.

Habitats compared *Significantly different communities are shaded.	Significance
Lake Littra	
Punkah Creek - Inlet (creek side)	0.008
Punkah Creek - Inlet (wetland side)	0.048
Punkah Creek – Lake Littra	0.054
Inlet (creek side) – Inlet (wetland side)	0.029
Inlet (creek side) – Lake Littra	0.029
Inlet (wetland side) – Lake Littra	0.8
Werta Wert Lagoons	
Monoman Creek – Inlet (creek side)	0.071
Monoman Creek – Inlet (wetland side)	0.016
Monoman Creek – Werta Wert Lagoons	0.018
Inlet (creek side) – Inlet (wetland side)	1
Inlet (creek side) – Werta Wert Lagoons	0.5
Inlet (wetland side) – Werta Wert Lagoons	0.971

Habitats compared *Significantly different communities are shaded.	Significance
Pilby Creek Lagoon	
Murray River - Inlet (creek side)	0.024
Murray River - Inlet (wetland side)	0.008
Murray River – Outlet	0.005
Murray River – Pilby Creek Lagoon	0.001
Inlet (creek side) – Inlet (wetland side)	0.012
Inlet (creek side) – Outlet	0.006
Inlet (creek side) – Pilby Creek Lagoon	0.001
Inlet (wetland side) – Outlet	0.946
Inlet (wetland side) – Pilby Creek Lagoon	0.01
Outlet - Pilby Creek Lagoon	0.058
Lake Merreti	
Ral Ral Creek - Ral Ral Creek US	0.329
Ral Ral Creek – Inlet (creek side)	0.215
Ral Ral Creek - US Inlet (creek side)	0.071
Ral Ral Creek – Inlet (wetland side)	0.001
Ral Ral Creek – Lake Merreti	0.001
Ral Ral Creek US – Inlet (creek side)	0.731
Ral Ral Creek US – US Inlet (creek side)	0.143
Ral Ral Creek US – Inlet (wetland side)	0.003
Ral Ral Creek US – Lake Merreti	0.001
Inlet (creek side) - US Inlet (creek side)	0.587
Inlet (creek side) – Inlet (wetland side)	0.002
Inlet (creek side) – Lake Merreti	0.001
US Inlet (creek side) – Inlet (wetland side)	0.138
US Inlet (creek side) – Lake Merreti	0.077
Inlet (wetland side) – Lake Merreti	0.015
Little Duck Lagoon	
Gurra Gurra Creek - Inlet (creek side)	0.001
Gurra Gurra Creek - Inlet (wetland side)	0.001
Gurra Gurra Creek - Little Duck Lagoon	0.001
Inlet (creek side) - Inlet (wetland side)	0.141
Inlet (creek side) – Little Duck Lagoon	0.006
Inlet (wetland side) – Little Duck Lagoon	0.083
Loveday Wetlands	
Murray River - Inlet (creek side)	0.022
Murray River - Inlet (wetland side)	0.001
Murray River – Loveday Wetlands	0.001
Inlet (creek side) – Inlet (wetland side)	0.105
Inlet (creek side) – Loveday Wetlands	0.001
Inlet (wetland side) – Loveday Wetlands	0.012
Chowilla Oxbow	
Chowilla Creek – Inlet	0.589
Chowilla Creek – Chowilla Oxbow Wetland	0.125
Inlet – Chowilla Oxbow Wetland	0.3
Gurra Control Wetland	
Gurra Gurra Creek – Inlet	0.901
Gurra Gurra Creek – Gurra Control Wetland	0.649
Inlet – Gurra Control Wetland	0.929



No significant differences were detected between fish communities in managed and un-managed wetlands as groups (Table 8). When wetland fish communities were compared individually, however, many wetlands contained significantly different fish communities. The non-significant result between the managed and un-managed wetlands in the combined analysis is therefore most likely due to the differences within the managed wetlands group being just as great as the differences between managed and un-managed wetlands (ie that all wetlands are different).

Only two control (un-managed) wetlands were used during this study – one permanent and one temporary. Given the inherent variation amongst managed wetlands, to determine if the differences between managed wetlands and un-managed wetlands are due to the presence of the flow control structures, a greater number of un-managed wetlands would be required within the analysis. At present it can be said that Gurra Control Wetland is significantly different to all managed wetlands but cannot be said that it is because of the wetland inlet structures. In contrast Chowilla Oxbow Wetland was not found to be significantly different to the other wetlands except for Gurra Control Wetland and Little Duck Lagoon. However, this non-significant result is likely to be a Type II error, resulting from the low number of replicate samples at Chowilla Oxbow.

In order to determine the structure induced and natural differences in wetland fish communities, a greater sampling effort would be required employing more wetlands and in particular more un-managed wetlands. Despite this, a comparison of the ability of the structures monitored within the study can be made.

Effect of structure on fish passage under current management

Fish passage through the structures monitored within this study was determined through the calculation of a relative fish passage index (*RFP*). *RFP* values are spread between zero and one (zero being totally obstructed fish passage) and values greater than 0.5 being equivalent to unobstructed fish passage).

Movement of fish into wetlands was found to be significantly inhibited at Little Duck Lagoon and Loveday Wetlands, although this was only slightly obstructed for Loveday ($p < 0.05$) (Figure 15). Movement of fish into Pilby Creek Lagoon was also obstructed, although this relationship was not found to be significant. Lake Merreti, Werta Wert Lagoons, and Lake Littra structures were all found to allow fish passage into wetlands, with fish passage indices of 0.5 or above.

Wetlands that have unobstructed fish passage in the downstream direction indicate either of two things: a) fish are moving with the flow of their own accord and the structure is not proving to be a behavioural barrier to fish movement in this direction, or b) fish are being swept in during periods of high flow (eg wetland filling), giving the impression that the structure is not an obstruction.

For upstream fish passage (movement out of wetlands), Lake Merreti and Pilby Creek Lagoon structures are significant obstructions to fish movement ($p < 0.05$) (Figure 15). Lake Littra, Werta Wert Lagoons, Loveday Wetlands, and Little Duck Lagoon were all found to have unobstructed fish passage out of the wetlands ($p < 0.05$). Of these structures, Lake Littra was the closest to unobstructed fish passage out of the wetland, followed by Werta Wert Lagoons, with Loveday Wetlands and Little Duck Lagoon only slightly significant.

Of those structures that obstruct fish passage, it is of no surprise that the Lake Merreti structure is one of them. This structure is a long (17.8m), 90cm diameter pipe structure, set into a large embankment. Within this structure, a long distance of relatively uniform high velocities would be created at times of high river flow or wetland filling, requiring fish to battle against strong laminar flow in order to “escape”.

Flows recorded on the wetland side of the structure (mid depth and width) reached over 2.00m/sec (highest recorded velocity was 2.56m/sec on the 10/10/00) when two flow peaks of 42,050ML/day and 63,427ML/day reached South Australia in October and December 2000.

These velocities are the highest of all structures measured (Table 10), and exceed the 1.8m/sec maximum burst speed that has been recorded for adult callop and silver perch negotiating a mainstream vertical slot fishway (Mallen-Cooper 1994). In addition, these velocities are much greater than the prolonged swimming speeds of 0.3m/sec recorded for fish greater than 100mm at Torrumbarry fishway (Mallen-Cooper 2001). Velocities of this magnitude would therefore prove to be a significant barrier to most species. The only other structure where similar flow velocities were recorded was Pilby Creek Lagoon with velocities of 2.028m/sec on the 8/01/02 (Table 10).

With the exception of the high velocities experienced in late 2000, early 2001, and a short period in November-December 2001 when flows reached 0.86m/sec, water velocities through Lake Merreti inlet structure remained below 0.323m/sec for the remainder of the project when river flows were restricted to pool level (3/12/02).

Table 10 indicates the maximum and minimum velocities recorded for each structure.

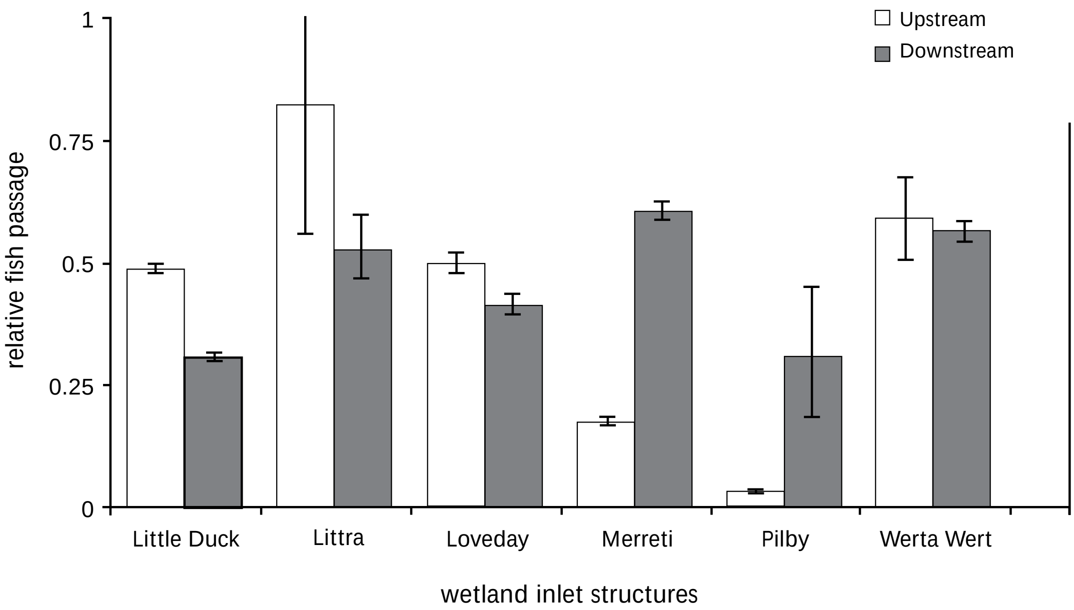


Figure 15. Relative fish passage at each wetland inlet structure assessed when structures were open only.

Table 10. Maximum and minimum water velocities (into wetland) recorded for each structure

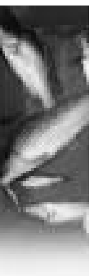
*only 2 recordings taken, # average of inlet nets

	Max Velocity (m/sec)	Date	Min Velocity (m/sec)	Date
Lake Littra	0.753	19/12/00	0.005	01/01/01
Werta Wert Lagoons*	0.968	18/12/00	0.053	06/12/00
Chowilla Oxbow Wetland#	0.01	06/12/00	0.00	20/11/00
Pilby Creek Lagoon	2.028	08/01/02	0.005	21/04/01
Lake Merreti	2.56	10/10/00	0.003	11/04/01
Little Duck Lagoon	0.145	13/10/02	0.008	06/01/01
Gurra Control Wetland#	0.0675	08/12/02	0.00	03/02/01
Loveday Wetlands	0.775	16/01/02	0.002	25/07/02

All other permanently connected wetland structures had flow velocities similar to Lake Merreti during pool level flows when water levels in the river and wetlands had equalised (Pilby Creek Lagoon below 0.118m/sec; Little Duck Lagoon below 0.105m/sec; Loveday Wetlands below 0.085m/sec).

In addition to the Lake Merreti structure, Pilby Creek Lagoon structure also obstructed fish passage out of the wetland. This finding is surprising as this structure (open-topped box culvert) is currently one of the preferred structure design options. Clarification of this finding may lie in the structure setting and management.

Pilby Creek Lagoon has an inlet that connects to the upper pool of Weir Six, and an outlet that connects to the lower pool of Weir Six (upper pool of Weir Five). This means that when the wetland is full and the inlet and outlet structures are open, water travelling through the wetland can by-pass Weir Six. However, in order to hold water out of the wetland, as during a drying phase, the inlet structure must be at least as high as the upper pool level of Weir Six. This has meant that the structure is perched above the bed level of the inlet channel downstream of the structure (on the wetland side) and where the structure is situated (Plates 7b, 7c). Therefore, when water in the wetland is not at pool level (such as when the structure is partially open, or when there is a greater outflow than inflow), fish must first negotiate a step or cascade effect before passing through the structure itself.



To avoid the perched nature of the structure, the base of this structure should have been set at the base level of the inlet channel rather than at a higher level. This would have allowed water on the wetlands side inlet channel to reach the structure and allow fish access to it, but would still provide a barrier to fish movement out of the wetland until water levels were near equilibrium. To improve fish passage through this culvert, a recommendation by Mallen-Cooper (2001) could be applied. Mallen-Cooper suggests that to allow fish passage to occur at perched culverts a “grade control structure” should be installed to raise the water level on the wetland side. This is a form of small fishway, where a series of pools are created, joined by small riffle areas until the water is raised to the level of the structure (Mallen-Cooper 2001). Unfortunately this remedy would be expensive, and require major earthworks to install.

In addition to the perched nature of the culvert, until July 2001 (during the initial stages of sampling at Pilby Creek Lagoon) the fish screens on this inlet structure had very small openings (10mm x 10mm) (Plate 7d). These were replaced in July 2001 by screens with a vertical grill design, with the metal rods also placed approximately 10mm apart

(Plate 7e). The size of these fish screens is small, and may have also contributed to the obstructed fish passage out of Pilby Creek Lagoon, although the fish passage index for fish movement into Pilby Creek Lagoon contradicts this. Further discussion on the effectiveness of fish screens (especially in relation to carp control) follows in the section "*effectiveness of fish screens – differences in carp abundance and biomass*".

Effect of structure on movement of individual fish species (under current management)

Average $RFP_{species}$ for movement into and out of wetlands are given in Table 11 and Table 12. $RFP_{species}$ are weighted averages for each species based on the number of individuals collected. Weighted averages were used as more confidence can be placed in fish passage indices calculated from larger samples. Both tables of $RFP_{species}$ should be viewed as an illustration that, although the fish community may or may not be affected by certain water quality, environmental, or structural characteristics, individual species are affected differently at the different structures.

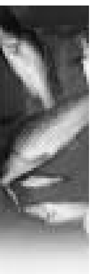
Table 11. $RFP_{species}$ indices ± standard errors for each species moving into wetlands.

Cases of significantly inhibited fish passage are highlighted in grey. Instances where no standard error is given represent values calculated from a single replicate sample (no statistical test possible).

Species	Loveday	Werta Wert	Merreti	Pilby	Littra	Little Duck
Bony bream	0.50 ± 0.03	0.08	0.22 ± 0.06	0	1	0.86 ± 0.03
Callop	0.99 ± 0.08	1	0.07 ± 0.01		0.68 ± 0.34	0.03 ± 0.00
Common carp	0.69 ± 0.11	0.01 ± 0.00	0.45 ± 0.06	0.00 ± 0.00	0.95 ± 0.24	0.99 ± 0.07
Goldfish	0		0.00 ± 0.41		0	1.0 ± 0.04
Carp/goldfish hybrids	0.28 ± 0.03	0.34 ± 0.17	0.85 ± 0.04	0.30 ± 0.03	1	0.30 ± 0.02
Gambusia	0	1	0.99 ± 0.16	0	0.77	0.98 ± 0.09
Redfin perch	0	1	0.00 ± 0.25		0	0.35
Australian smelt	0.29 ± 0.02	0.10 ± 0.02	0.35 ± 0.02	0.26 ± 0.02	0.98 ± 0.13	0.27 ± 0.01
Lake's carp gudgeon	0	1	0.00 ± 0.00			0.87 ± 0.04
Midgely's carp gudgeon	0	0.34	0.16 ± 0.09		1	0.93 ± 0.04
Western carp gudgeon	0.57 ± 0.04	0.30 ± 0.11	0.54 ± 0.02	0.59 ± 0.11	0.73 ± 0.33	0.63 ± 0.01
Flathead gudgeon	0.77 ± 0.34	0.13 ± 0.06	0.30 ± 0.01	0.75	0	0.27 ± 0.01
Dwarf flathead gudgeon	0.41 ± 0.04	0.38 ± 0.01	0.32 ± 0.01	0.00 ± 0.00	0.03 ± 0.00	0.31 ± 0.02
Fly-specked hardyhead	0.69 ± 0.11	0.20 ± 0.10	0.23 ± 0.04	0.53 ± 0.27		0.98 ± 0.09
Crimson spotted rainbowfish		0.04	0.16 ± 0.01		0.00 ± 0.00	0.77 ± 0.03
Catfish						

Loveday Wetlands appears to have least effect on fish movement into the wetlands (under current management), with only one species, Australian smelt, being significantly inhibited (Table 11). Lake Merreti was found to be the worst structure for movement of fish into the wetland, effecting ten species. Lake Littra and Pilby Creek Lagoon both significantly inhibited three species from moving into the wetlands, with the other two structures, Little Duck Lagoon and Werta Wert Lagoons, significantly inhibiting five species.

For movement out of wetlands, $RFP_{species}$ indicate that Werta Wert Lagoons structure is the least inhibitive to fish, with only two species – carp and gambusia – being significantly inhibited. Again, Lake Merreti structure inhibited movement of the most species (ten). Lake Littra inhibited the movement of four species, with all other structures inhibiting the movement of six species out of the wetlands.



Carp movement into wetlands was only significantly inhibited at Werta Wert Lagoons and Pilby Creek Lagoon. Carp movement out of wetlands was only significantly inhibited at Werta Wert Lagoons and Lake Littra. Interestingly Werta Wert Lagoons is the only managed wetlands without carp screens.

Table 12. $RFP_{species}$ indices ± standard errors for each species moving out of wetlands.

Cases of significantly inhibited fish passage are highlighted in grey. Instances where no standard error is given represent values calculated from a single replicate sample (no statistical test possible).

Species	Loveday	Werta Wert	Merreti	Pilby	Littra	Little Duck
Bony bream	0.55 ± 0.05	0.31 ± 0.16	0.11 ± 0.02	1	0	0.91 ± 0.04
Callop	0.82 ± 0.41	1	0.00 ± 0.00	0	0	0.29 ± 0.03
Common carp	0.49 ± 0.06	0.21 ± 0.04	0.69 ± 0.23	1.0 ± 0.02	0.03 ± 0.01	0.96 ± 0.05
Goldfish	0.50 ± 0.25		0.00 ± 0.07	0	0.99 ± 0.23	1.00 ± 0.07
Carp/goldfish hybrids	0.86 ± 0.08	0.62 ± 0.31	0.20 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.43 ± 0.03
Gambusia	0.98 ± 0.49	0.20 ± 0.10	0.01 ± 0.00		0	0.61 ± 0.07
Redfin perch	1	0	0			0.63 ± 0.04
Australian smelt	0.33 ± 0.02	0.38 ± 0.06	0.50 ± 0.03	0.02 ± 0.00	0.00 ± 0.00	0.21 ± 0.01
Lake's carp gudgeon			0			0.78 ± 0.04
Midgely's carp gudgeon	1.0 ± 0.18	0.91	0.00 ± 0.04		0	0.76 ± 0.02
Western carp gudgeon	0.41 ± 0.03	0.43 ± 0.11	0.08 ± 0.00	0.31 ± 0.08	0.14 ± 0.05	0.44 ± 0.01
Flathead gudgeon	0.63 ± 0.21	0.61	0.14 ± 0.01	0	0.51 ± 0.06	0.29 ± 0.01
Dwarf flathead gudgeon	0.51 ± 0.05	0.44 ± 0.12	0.23 ± 0.01	0.37 ± 0.19	0.88 ± 0.11	0.06 ± 0.00
Fly-specked hardyhead	1.0 ± 0.29	0.34	0.78 ± 0.05	1.0 ± 0.04	1	0.73 ± 0.04
Crimson spotted rainbowfish		0.12	0.00 ± 0.00		1.00 ± 0.28	0.80 ± 0.04
Catfish						0

Effect of structure on fish passage taking into account flow direction

For several wetlands (Lake Littra, Little Duck Lagoon, and Loveday Wetlands), slight changes in flow direction through the structure occurred during the survey. When data from these wetlands was re-analysed based on the direction of flow, $RFP_{structure}$ values suggest that downstream fish passage (movement with the flow) was only significantly inhibited at the Loveday Wetlands structure, with Pilby Creek Lagoon structure also obstructing fish passage, although the relationship was not significant. All other structures remained un-inhibited, with relative fish passage actually improving slightly for the Lake Littra structure (Figure 16 cf Figure 15).

However, when upstream fish passage (movement against the flow) was re-analysed Lake Merreti and Pilby Creek Lagoon continued to inhibit upstream fish passage, with upstream fish passage also becoming significantly inhibited at Lake Littra (which was non-significant when analysed on direction of fish movement only). Little Duck Lagoon and Werta Wert Lagoons structures remained un-inhibited throughout the survey, with the slight obstruction recorded at Loveday Wetlands now not evident when direction of flow is taken into consideration (Figure 16).

Lake Littra structure being found to inhibit upstream fish passage is a surprise. As with Loveday Wetlands, this structure is a relatively short box culvert with a cross-sectional area approximating that of the inlet channel. Unlike Loveday Wetlands, however, Lake Littra structure is high, allowing light to easily penetrate into the culvert cells.

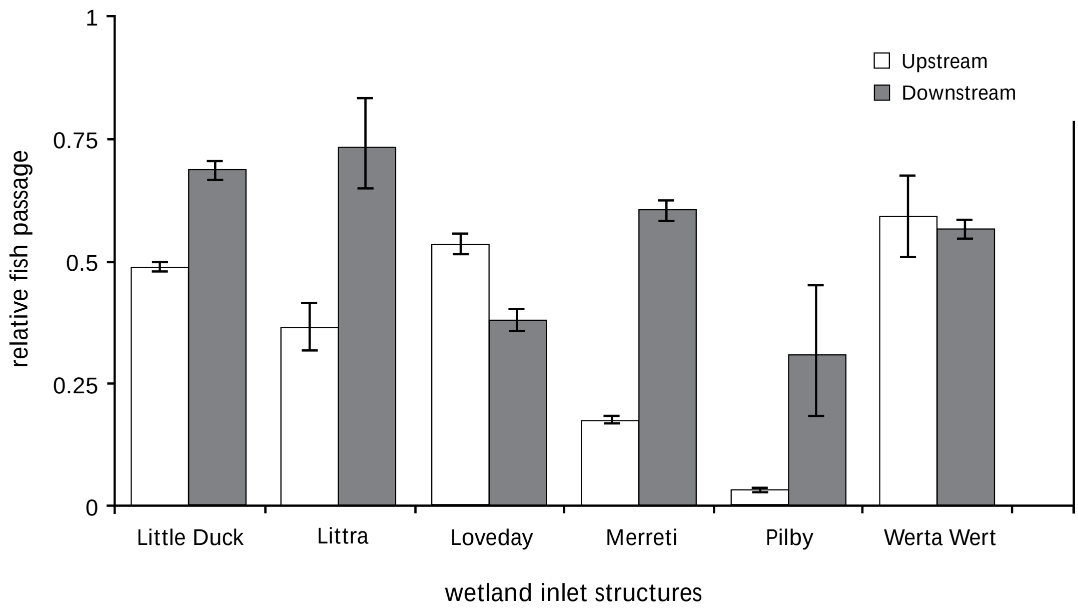
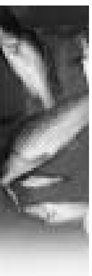


Figure 16. Relative fish passage at each wetland inlet structure assessed based on fish moving with (downstream) or against the flow (upstream).

It is therefore unknown why this structure would inhibit upstream fish passage, but again, this may be a result of structure management. On some occasions debris was noted to have built up on the river side of the structure, creating a headloss between the upstream and downstream sides. In addition to the barrier the debris would have created, the headloss may have made it difficult for fish to traverse the culvert. Maintenance of the culvert can therefore be seen to be an important part of management.

Lake Littra structure also has fish screens present on the culvert. These screens comprise the "security type" mesh with vertical metal rods welded mid way across each opening so that the area of each hole in the mesh is halved (from 97mm wide x 33mm high to approximately 50mm x 33mm). The lesser opening size of the screen may limit the size of fish able to move through the structure, therefore contributing to the poor $RFP_{structure}$ for upstream passage. Further discussion on the effects of structure characteristics occurs in the section *"structural characteristics affecting fish movement"*.

It was surprising to find Loveday Wetlands structure also inhibitive to fish passage into the wetland. This structure, comprising six box culvert cells, is short in length, roughly equates to the width of the surrounding inlet channel, and is open enough to allow light penetration into the culvert. However, despite its structural characteristics being appropriate, management of the structure may be causing its poor performance for fish passage. During times of high river flow, the fish screens and stop logs that allow its operation are removed (this normally occurs at flows of approximately 15,000ML/day: Weir *pers. com.* 2003). However, management of the structure is such that not all cells are open at any one time (Nichols *pers. obs.* 2001b). This limits the cross sectional area available for water movement into and out of the wetland, thus increasing water velocities, and potentially limiting fish movement back to the river.



Synopsis

Analysis of the relative fish passage values for each structure indicates that it is not only structural characteristics that affect fish movement, but also structure management.

Wetland management objectives have a major part to play in the ease of access for fish into and out of wetlands. Essentially the inlet structure present on a wetland is used for management of water to allow wetting and drying of the wetland. This, in turn, allows the growth of vegetation in both the wet and dry phases, which provides food, shelter and nutrients in the aquatic ecosystem. However, using the flow control structure to provide water at a certain rate of filling to allow plant growth to occur, may not necessarily be conducive to allowing fish passage into and out of a wetland. In addition, to plants it does not matter how the water is supplied (whether two are fully opened or six cells are partially opened at the same time), but to fish the number of cells open will be very important – influencing water velocities within each cell of the structure. Therefore if fish passage is important, it is necessary to manage the flow control structure to allow wetland filling at the correct rate and maintain fish passage by utilizing the structure to its full capacity.

Inherent within this study is the inability to separate the effect of structural characteristics on fish passage from the effect of the fish screens at each structure. Despite this, it was possible to determine the effectiveness of fish screens at controlling carp abundance and biomass within managed wetlands overall by comparing the carp populations within screened wetlands with those wetlands without fish screens present within the study. This is further discussed in the section "*effectiveness of fish screens – differences in carp abundance and biomass*".

It is interesting that at Little Duck Lagoon structure (a single small and short pipe) downstream fish passage (movement into the wetland) is significantly less than upstream fish passage (movement out of the wetland) during normal operation. The structure is near level, set on the base of the inlet channel (not perched), and does not receive high velocity flow except during the initial stages of refilling, therefore it should not prove to be a great barrier to fish movement. Indeed this was the case when fish passage was re-analysed based on the direction of flow, with the $RFP_{structure}$ improving so that the downstream fish passage was no longer obstructed.

For movement out of the wetland, Little Duck Lagoon structure was not found to obstruct fish passage under current management, although remained on the borderline 0.5 $RFP_{structure}$ value during this analysis. When direction of flow was taken into account upstream fish passage increased slightly.

If improvement of Little Duck Lagoon structure is required, this structure could be improved for fish passage by increasing the percentage cross-sectional area of the structure which at present is very low (important structural characteristics are discussed in the section *"structural characteristics affecting fish movement"*). This would allow lower water velocities to occur within the culvert, enabling fish to pass through the culvert with greater ease when travelling against the flow. Installation of a box culvert(s) at this wetland would improve fish passage into and out of this wetland, however consideration should be made before this occurs as to whether this small, shallow wetland is important fish habitat.

Only Lake Littra structure and the structure at Werta Wert Lagoons were not found to be obstructions to fish passage in the upstream direction under current management. The structures on these temporary wetlands were only sampled over a short timeframe (spring / summer 2000) and a greater sampling effort is required to improve undoubtedly improving the reliability of the findings. Unfortunately further sampling at these structures or the temporary control wetland, Chowilla Oxbow, was not possible due to the lack of high river flows experienced during the study.

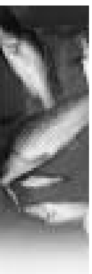
Lake Littra structure (a large box culvert) roughly approximates the cross-sectional area of the inlet channel, and is short and high enough to allow light to penetrate to the middle of the culvert. Therefore according to recommendations from other reports (eg Mallen-Cooper 2001), movement of fish through the structure in either direction should not be inhibited. This appears the case for upstream movement (out of wetlands) under current management. However, when the direction of flow was taken into account at Lake Littra, the relative fish passage for that structure dropped to become significantly inhibited. Downstream movement of fish remained uninhibited for both analyses, although was found to be nearing the 0.5 $RFP_{structure}$ value (borderline value between obstructed and unobstructed fish passage) when flow direction was not accounted for.

It is possible that the build up of debris observed at this structure may have contributed to obstruction of fish movement into (and out of) the wetland. In addition, as with Loveday Wetlands, this wetland has fish screens whose mesh size is approximately half that of the regular "security" mesh type as a result of vertical metal rods welded midway across the existing holes. This smaller mesh size may have led to a greater obstruction of fish both into and out of the wetland, by limiting the size of fish that can pass, and increasing the tendency for the screens to become clogged with debris.

At Loveday Wetlands structure under current management, downstream movement (into the wetlands) was found to be significantly obstructed. During the same analysis the upstream passage of fish was found to be unobstructed ($p < 0.05$), although remained around the borderline 0.5 $RFP_{structure}$ value indicating the structure was not acting optimally for fish passage.

When taking into account the direction of flow, the Loveday Wetlands structure remained as an obstruction to fish passage in the downstream direction, although for the same analysis it was not found to be significantly obstructing fish passage in the upstream direction.

Loveday Wetlands structure comprises six box culvert cells that extend the entire width of the inlet channel. The structure is short, allowing light to penetrate the entire length of the culvert, and is set at the bed level of the surrounding channel. Thus, according to recommended guidelines (Mallen-Cooper 2001, Fairfull and Witheridge 2003), this structure should not form an obstruction to fish movement. Management of the structure is therefore the most likely reason that the structure has been found to inhibit fish movement. Management of the structure to allow water movement into the wetland during normal pool level flows usually only employs one or two of the available six culverts (Nichols *pers. obs.* 2001b), as these cells are the only ones in the structure to have fish screens in place (Tucker 2003). Management of the structure in this way, whilst allowing adequate water movement into the wetland, effectively decreases the size of the culvert to one or two culverts wide (one sixth or one third of the actual structure width). This has the effect of increasing water velocities within the operational cells and obstructing fish movement out of the wetland. Similarly, management of the structure in this manner may inhibit movement of fish into the wetland by either producing some sort of behavioural barrier (avoidance of being swept into the culvert), or physical barrier (use of the fish screens). It is therefore recommended that management of this structure utilize all cells within the structure rather than employing only one or two.



Management of the Loveday Wetlands structure during high river flows has been to open all cells and remove the fish screens at relatively low flows (forecast river flows of >15,000ML/day) due to structure access issues (structure over-topped at 30,000ML/day) and to minimize the effects of the screens on native fish species (Weir *pers. com.* 2003). The effectiveness of fish screens at controlling carp abundance and biomass is discussed further in the section "*effectiveness of fish screens – differences in carp abundance and biomass*". Future management of fish screens should take into account the findings discussed in that section.

In addition to structure management, structure maintenance is important. At Loveday Wetlands structure this comment mostly refers to the removal of reed growth in the inlet channel (*Typha* sp. (the most aggressive species) and *Phragmites australis*). It is not known what effect extensive reed growth has on fish movement, but it is likely to limit the size of fish that can access these areas if reed growth extends across the entire inlet channel. Reeds had been removed from the inlet channel prior to the first samples being taken at Loveday Wetlands, but have once again grown extensively near the structure. Reed growth should therefore continue to be managed in the inlet channel of this wetland.

$RFP_{structure}$ values for Lake Merreti structure (two long pipes) show that the passage of fish in a downstream direction (into the wetland) was not obstructed for either analyses, whilst the passage of fish in an upstream direction (out of the wetland) was found to be significantly obstructed at all times. Obstruction of upstream fish passage was expected at this structure due to the poor design of this structure for fish passage (originally designed for water management rather than fish movement). Unobstructed movement of fish into the wetland may be a result of fish being sucked into the culvert during high flows, although for most of the project water velocities were low (minimum flow of 0.003m/sec – Table 10).

To move out of the wetland fish must swim for a long distance against laminar flow created in the pipes as a result of the almost constant head difference present across the structure (pipes are below water level on Ral Ral Creek side of the structure, but are generally at the water surface at pool level flows on the wetland side of the structure). According to Mallen-Cooper (2001), a headloss of only eight centimetres is enough to be considered impassable to native fish. During the high river in spring/summer 2000, the maximum velocity recorded in the main inlet pipe was 2.56m/sec (Table 10), which is well above the recommended water velocities for adult native fish to pass (0.75m/sec for fish greater than 25cm: Mallen-Cooper 2001).

In addition, the structure is likely to be acting as a behavioural barrier to some species (eg bony bream) due to the dark conditions within the pipes (Mallen-Cooper 2001). This contradicts the relatively unobstructed $RFP_{structure}$ values in the downstream direction for the community as a whole, but corresponds with the high number of species that are significantly inhibited at this structure in either direction when relative fish passage was analysed species by species (Tables 11 and 12).

Lake Merreti main inlet structure could have its physical limitations on fish passage out of the wetland lessened by increasing the cross-sectional area of the structure relative to the inlet channel width, and by decreasing the length of the structure. This would increase the area through which water can pass, thereby decreasing the water velocities encountered within the structure, decrease the distance that fish would be required to swim to move out, and increase the amount of light that could enter the culvert. Installation of additional cells is therefore required for this structure, with box culverts being preferable (Mallen-Cooper 2001) to minimise laminar flow within the culvert. It would be possible to lower the embankment surrounding the Lake Merreti structure, which would allow the length of the structure to be lessened, without losing much of the ability to flood the mature red gum zone as part of the wetland management protocol for this wetland. A shorter structure is preferable for fish movement (Mallen-Cooper 2001).

Pilby Creek Lagoon structure (open-top box culvert) proved to be almost totally inhibitive to fish movement out of the wetland during both analyses ($RFP_{structure}$ values less than 0.05 for all analyses). $RFP_{structure}$ into the wetland was obstructed under current management (non-significant relationship), however when flow direction was taken into account $RFP_{structure}$ values were nearly equivalent to free passage.

Upstream movement of fish out of the wetland is most likely inhibited as a result of a combination of the effects of structure position and structure management. Pilby Creek Lagoon structure is perched from the downstream (wetland) side in order to hold water out of the wetland at Lock and Weir Six upper pool level. This means that at low water levels, fish must first navigate a steep incline before they actually reach the structure itself. In addition, the fine mesh screens ($1cm^2$) used during the initial stages of the project would obstruct fish movement both into and out of the wetland. As with the Loveday Wetlands structure, management of the Pilby Creek Lagoon structure was such that not all culvert cells were employed when providing water to the wetland. Therefore, as with the Loveday structure, management of the Pilby Creek Lagoon structure in this manner effectively reduces the cross-sectional area of the structure, and increases the water velocities through the culverts actually used to supply the wetland.

In order to reduce the impacts of current management on the fish passage through the structure, as with Loveday Wetlands, it is recommended that all cells within the culvert be employed to deliver water to the wetland. The current fish screens installed (vertical bars) are a vast improvement on the previous design, which would have been a major obstruction to all fish movement, including the suite of small fish species that can usually access wetlands through other fish screen designs (eg “security” type mesh).

However, the current screens would still be limiting to those fish that were not laterally compressed, and as with all fish screens, would not allow large adult or sub-adult fish to enter the wetland. Further discussion of fish screen effectiveness occurs in the following section.

To overcome the effects of the perched structure and allow fish passage out of the wetland through the inlet structure, Mallen-Cooper (2001) recommends the installation of a “grade control structure” which is a form of small fishway, where a series of pools are created, joined by riffle areas until the water is raised from the bed level to the level of the structure (Mallen-Cooper 2001). Unfortunately this remedy is expensive, and would require major earthworks to install.

In addition, movement of fish out through Pilby Creek Lagoon outlet structure is not optimal. When the wetland is drained into the downstream section of Pilby Creek, discharge occurs onto rock rubble, which was distributed there following construction of Lock Six access road. At pool level flows, when there is no water present in the creek downstream of the structure prior to draining, fish will undoubtedly become damaged or killed as a result of being flushed from the wetland. As with the upstream passage of fish out the inlet structure, fish would benefit from a series of pools being installed to minimise damage as they are expelled from the wetland, and allow safe return to the river. Works such as this would also minimise effects of erosion as a result of water discharge from the structure. However, as with the upstream “grade control structure” earthworks required would be expensive.

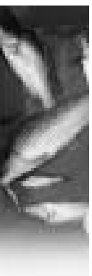
Werta Wert Lagoons structure (medium length, temporary pipes) was the only structure to not inhibit fish movement in either direction during either analyses; however $RFP_{structure}$ values for both upstream and downstream fish passage remained only slightly above the borderline 0.5 $RFP_{structure}$ value indicating the structure was not acting optimally for fish passage.

As with the Lake Merreti structure, fish would be required to swim against laminar flow over a moderate distance in order to move out of the wetland. At Werta Wert Lagoons structure however, the water velocities experienced would likely be less than those at Lake Merreti due to the lesser head difference experienced at times of flow. As with Lake Littra wetland, Werta Wert Lagoons was only sampled during the high river of spring/summer 2000. In addition, structural readings (eg flow) at the time of sampling were only taken on two occasions; therefore it is not valid to conclude that this structure is satisfactory for fish passage without more samples being taken.

Effectiveness of fish screens – differences in carp abundance and biomass

Differences in carp populations in wetlands versus river environments were examined in order to determine the effectiveness of fish screens in controlling these introduced fish.

Fish screens are installed on many wetland flow control structures in an attempt to control carp populations within the wetlands and allow enhanced rehabilitation of these sites. Carp are known to prefer the warm, shallow, well vegetated floodplain or wetland environments to spawn (Smith 1999). Reynolds (1983) noted a general movement of carp (approximately 325mm: 0+ to 1+ year class) out of wetlands and into the mainstream, indicating that these areas may act as nursery areas for juvenile carp. Stuart and Jones (2002) captured young of the year carp at all floodplain sites sampled in the Barmah-Millewa forest during the flood of spring/summer 2000. They hypothesised that recruitment appears reliant on access of adults to floodplain spawning areas and on nursery habitats in off-stream and anabranch habitats being available to young of the year fish (Stuart and Jones 2002).



In addition to their spawning habits, the feeding action of carp has been implicated in the increase in turbidity, and the uprooting of water plants (Fletcher *et al.* 1985). Removal or prohibition of carp from entering wetlands is therefore seen as an advantage in allowing the development of wetland vegetation which provides nutrients, cover and food to many wetland species, and limiting the recruitment success of this species.

Carp abundance analysis

Analysis of the wetlands within this study reveal a significant habitat by wetland system interaction for carp abundance, suggesting that the relationship between carp abundances within wetlands and the river or anabranch systems differs at different wetland systems (Table 13).

Comparisons at individual wetland systems suggest that carp are generally more abundant in wetlands than in riverine habitats within all wetland systems except Gurra Control Wetland. However, as shown in Figure 18, the relationship was not found to be significant at Gurra Control Wetland, Little Duck Lagoon, Loveday Wetlands, Lake Merreti or Werta Wert Lagoons. In addition, carp abundances in wetlands with fish exclusion screens were not found to be significantly lower than those in Gurra Control Wetland, Chowilla Oxbow Wetland or Werta Wert Lagoons that do not have fish exclusion screens (Figure 17). It can therefore be concluded that fish screens are not effectively reducing carp abundances in the wetlands surveyed.

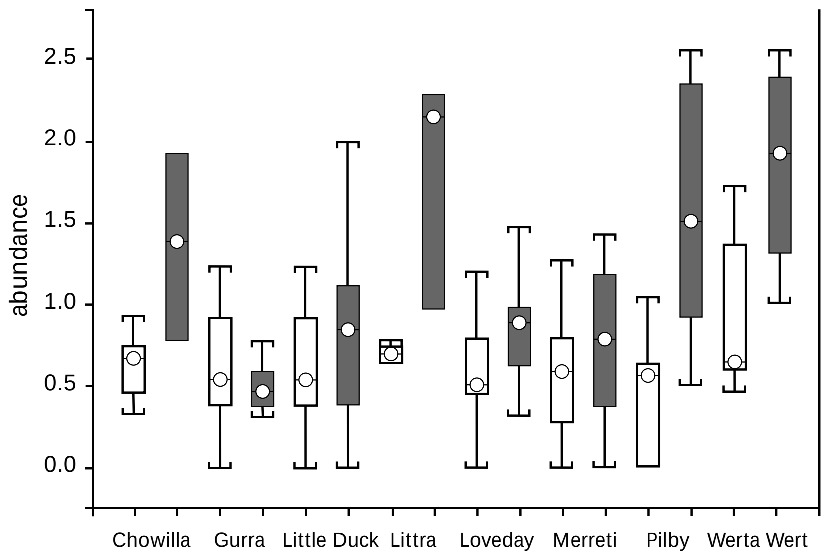


Figure 17. Carp abundance (4th root transformed) at each wetland system in wetland (black) and river/creek (clear) habitats.

Circles represent the median, the boxes indicate the upper and lower quartiles and the whiskers represent the upper and lower limits of the data.

Table 13. F-ratios and significance levels for analysis of variance of carp abundance in wetland and riverine habitats with or without fish exclusion screens.

df – degrees of freedom; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; *ns*, not significant.

	Habit	Wetlands	Habitat * Wetland interaction
All wetland systems combined			
Combined data	$43.636_{(df:\ 1,149)}$***	$5.721_{(df:\ 7,149)}$***	$4.289_{(df:\ 7,149)}$**
Each wetland system analysed separately			
Wetlands with fish screens			
Little Duck Lagoon	$1.306_{(df:\ 1,28)}$ ns		
Lake Littra	$13.280_{(df:\ 1,6)}$*		
Loveday Wetlands	$3.080_{(df:\ 1,27)}$ ns		
Lake Merreti	$2.383_{(df:\ 1,36)}$ ns		
Pilby Lagoon	$24.539_{(df:\ 1,23)}$***		
Wetlands without fish screens			
Werta Wert Wetland	$3.972_{(df:\ 1,7)}$ ns		
Gurra Wetland	$1.600_{(df:\ 1,27)}$ ns		
Chowilla Oxbow	$6.960_{(df:\ 1,6)}$*		

Size class analysis

Significant differences in size distributions between carp sampled from wetland and riverine habitats were found at all wetland systems except Gurra Control Wetland (Figure 18). All significant results were based on greater frequencies of small carp (50 - 200mm) in wetlands. No significant differences were detected for carp greater than 250 - 300mm except for Loveday Wetlands where significant differences were detected for almost all size classes and a greater frequency of large carp occurred in the wetland (Plate 12).

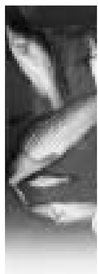


Table 14. F-ratios and significance levels for analysis of variance of carp biomass (grams) in wetland and riverine habitats with or without fish exclusion screens.

df – degrees of freedom; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; *ns*, not significant.

	Habit	Wetlands	Habitat * Wetland interaction
All wetland systems combined			
Combined data	$0.599_{(df: 1,243)}^{ns}$	$5.752_{(df: 7,243)}^{***}$	$5.793_{(df: 7,243)}^{***}$
Each wetland system analysed separately			
Wetlands with fish screens			
Little Duck Lagoon	$20.279_{(df: 1,44)}^{***}$		
Lake Littra	$0.215_{(df: 1,49)}^{ns}$		
Loveday Wetlands	$8.715_{(df: 1,37)}^{**}$		
Lake Merreti	$1.538_{(df: 1,45)}^{ns}$		
Pilby Lagoon	$0.001_{(df: 1,17)}^{ns}$		
Wetlands without fish screens			
Werta Wert Wetland	$0.148_{(df: 1,17)}^{ns}$		
Gurra Wetland	$13.144_{(df: 1,19)}^{**}$		
Chowilla Oxbow	$1.053_{(df: 1,25)}^{ns}$		

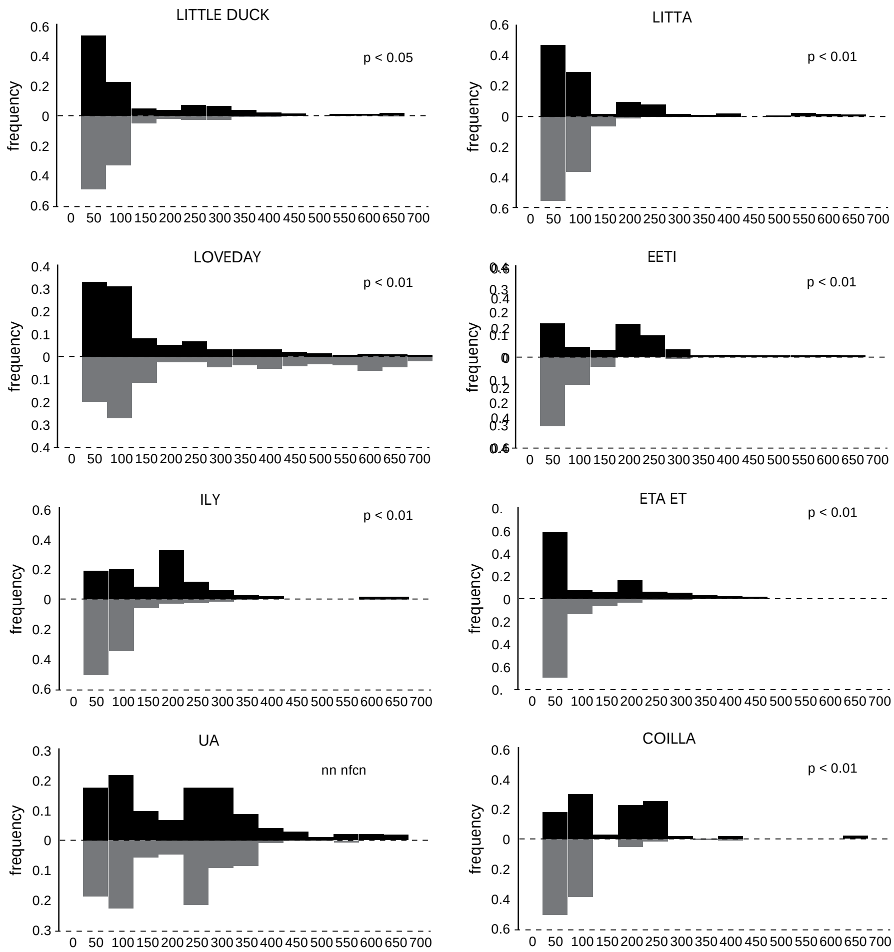


Figure 18. Length frequency distributions for carp sampled in riverine (black) and wetland habitats (clear).

Probability values are based on Kolmogorov-Smironov goodness-of-fit tests comparing size distributions in each habitat.

Scott Nichols

Plate 12. Carp captured at Loveday Wetlands (December 2002).

Carp biomass analysis

As with the abundance data, a significant habitat by wetland system interaction was identified for carp biomass, indicating that the relationship between carp biomass within wetlands and the river differs at different wetland systems (Table 14).

Comparisons at individual wetland systems suggest that carp biomass is significantly greater in Gurra Gurra Creek than in either the unregulated Gurra Control Wetland or the regulated Little Duck Lagoon (Table 14). Lakes Littra and Merreti also had lower carp biomass than adjacent creek habitats although these differences were not significant (Figure 19). In contrast carp biomass was greater in Loveday Wetlands, Chowilla Oxbow Wetland, Pilby Creek Lagoon and the Werta Wert Lagoons (Figure 19), although this difference was only significant at Loveday (Table 14). Personal observations showed that, although both Pilby Creek Lagoon and Loveday Wetlands had significantly higher biomass of carp in the wetlands, the size classes were quite different between the wetlands (Figure 18), with Pilby Creek Lagoon continually having a large number of small carp (≤100mm) captured and Loveday Wetlands having a large number of large carp (≥500mm) (Plate 12, Nichols *pers. obs.* 2001c).

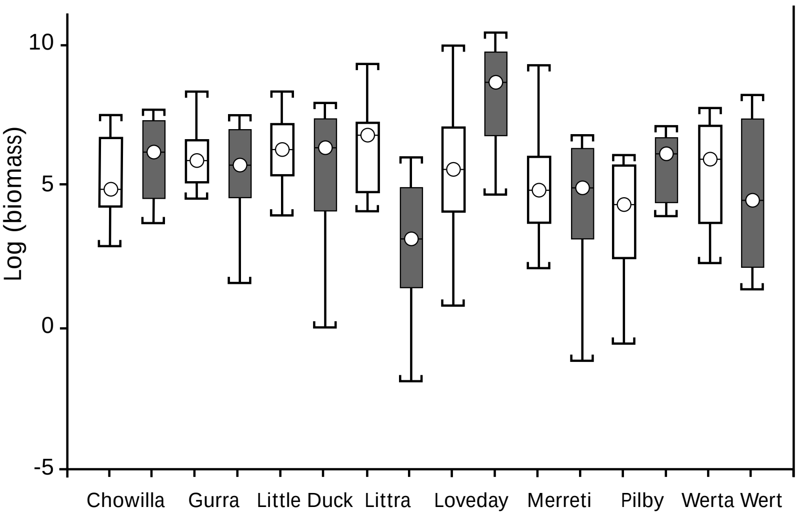


Figure 19. Carp biomass (log(grams per net)) at each wetland system in wetland (black) and river (clear) habitats

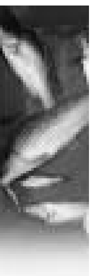
Circles represent the median, the boxes indicate the upper and lower quartiles and the whiskers represent the upper and lower limits of the data.

Synopsis

These results suggest that fish screens fitted to wetland inlet structures do not significantly reduce carp abundances within wetlands. The results for biomass are mixed. Despite the existence of fish screens, large carp (>250 – 300 mm) occur in equivalent frequencies in riverine and wetland habitats. This indicates that either large carp are able to enter wetlands despite the existence of fish screens, or that juvenile carp spawned elsewhere, enter wetlands and grow very rapidly within wetland habitats. Carp are known to reach 200mm in their first year of life and 400mm by their third year (Brown 1996). At this size, carp would be benthic feeders, thus would be continuing to cause disturbance to the wetland environment despite the presence of fish screens. In addition, carp are known to jump over 20cm above the water surface, potentially being able to avoid by-pass fish screens on wetland inlets (Stuart and Jones 2002). Serious thought must therefore be made in regards to the potentially detrimental effects fish screens may have on native fish passage and the screens poor success at controlling carp abundance and biomass in wetlands.

Structural characteristics affecting fish movement

A combination of flow, apron width and proportional cross-sectional area of the inlet contributed to fish passage efficiency for fish migrating against the current ($F_{3,27}$ = 34.54, p < 0.0001) (Table 15). This combination of variables accounted for 79.33% of the variation in upstream fish passage efficiency. Fish passage is most efficient at higher flows, when the apron width is low and when the cross-sectional area of the culvert is a large proportion of the cross-sectional area of the inlet channel. The greater proportion of cross-sectional area of the inlet channel that the structure occupies will decrease water velocities encountered in the structure and aid fish passage through it. It is unclear what factor the apron width plays in improving fish passage, although a lesser width would decrease the distance of foreign material (cement) that fish must pass over in order to escape, and therefore possibly lessen the behavioural avoidance of a structure. Improved upstream passage with increasing flow is interesting, as it would seem in opposition to successful upstream fish passage.



Flow was the only variable that contributed to fish passage efficiency for fish moving in the direction of flow ($F_{1,29}$ = 11.15, p = 0.002) (Table 15), although this only accounted for 27.78% of the variation in downstream fish passage efficiency. Fish passage was most efficient as flow declined, possibly indicating that fish successfully avoided being sucked into the culvert at higher flows. Due to the low explanatory power of the model, it is obvious that other structural factors not measured, water quality, or environmental variables are more influential for fish movement into wetlands.

Table 15. Results of multivariate linear regressions of fish passage based on structural characteristics of wetland inlet structures.

Upstream fish passage				Downstream fish passage			
Variable	Regression coefficient	± SE	P	Variable	Regression coefficient	± SE	P
Flow	0.0941	0.0226	0.0003	Flow	-0.1184	0.0355	0.0023
Apron width	-0.0053	0.0008	<0.0001				
% inlet area	0.0044	0.0012	0.0014				

Dooland *et al.* (2000) found that when using an artificial pipe culvert in the laboratory flume that carp would swim with the flow or drift with it when flows were less than or greater than 0.4m/sec. At 0.4m/sec velocity carp (n=8, mean total length 372mm) would spend a greater proportion of time on the upstream side of the culvert, rather than drifting or actively swimming downstream through it. At velocities lower than this, carp were observed drifting through the culvert with the flow whilst facing upstream. When velocities were higher than 0.4m/sec carp would be swept through the culvert, employing burst speed several times in order to again move upstream through the culvert. At water velocities of 0.4m/sec, carp would actively swim upstream away from the culvert once they felt themselves being pulled into it (Dooland *et al.* 2000).

It is therefore possible that this finding could be used as a management option when filling wetlands. If filling velocities could be kept at approximately 0.4m/sec, carp may avoid moving into the wetlands. Further investigations are needed to determine if native fish act in a similar or different fashion when faced with these filling velocities. In addition, field investigations should occur to determine if the behavioural reactions observed in the laboratory environment also occur within a natural inlet channel.

Carp deterrents

Aspects of carp behaviour in relation to structural characteristics, flow, and carp deterrents were investigated by Dooland *et al.* (2000) and continued by Champion *et al.* (2001). All behavioural investigations were carried out in the laboratory using mock culverts in a flume environment. Abstracts of each of their investigations are found in Appendix D. A brief discussion of their findings is below.

Light

Carp were found to be reluctant to leave darkened areas of the flume under no flow and flow conditions, with single carp strongly preferring the dark region and multiple carp retaining a strong affinity with the dark areas (Dooland *et al.* 2000). Multiple fish were noted congregating on the dark/light boundary for an observation period before one fish would dart into the light area, followed by the others, when they would return to the darkened area (Dooland *et al.* 2000) . When multiple fish were tested against strong illumination (halogen light) within a non-lit laboratory, carp were found to hesitate for longer but still dart through the lit culvert (Champion *et al.* 2001). Illumination was not found to be a complete barrier, but acted as a deterrent to carp movement within the laboratory environment (Dooland *et al.* 2000, Champion *et al.* 2001).

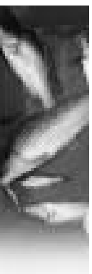
It has been noted by previous studies that a lit passage is required for some species of native fish to move through tunnels (Mallen-Cooper 1996). Larvae of callop and silver perch have also been shown to be attracted to a light source (Gehrke 1990). It is therefore possible that a lit culvert may provide for native fish passage, but discourage carp movement into and out of wetlands, with its effectiveness possibly being improved when in combination with other deterrents. However, its field relevance should be investigated further to determine its effectiveness in a turbid water environment.

Acoustic deterrent

Fish are known to have different sound reception abilities (Knudsen *et al.* 1994), possibly leading to ability for a species specific deterrent to be developed for carp.

A semi submerged speaker was placed over the centre of a culvert in a laboratory flume by Champion *et al.* (2001) in order to test the effects of sound as an acoustic deterrent to a group of carp and a single fish. Adult fish were constantly subjected to frequencies in the range 5 to 1000 Hz when they attempted to traverse the culvert.

Carp responses were found to differ with the different frequencies tested for groups of carp with a leader fish, and single carp (410mm total length) (Champion *et al.* 2001).



At 10 and 20Hz, it was observed that these fish took a longer time to pass through the culvert than at other frequencies where behaviour varied from casually moving through the culvert or darting through it. The greatest effect was observed at 20Hz where fish would either dart through or turn back, splitting the group of fish (Champion *et al.* 2001). The largest carp (410mm total length) was also found to be the most affected by sound.

When the single carp was tested at frequencies between 15 and 50 Hz, the fish would negatively react to the sound, either darting through or turning away from the device and reapproaching it (Champion *et al.* 2001). The greatest effect for this fish was at 20 and 25Hz frequencies.

The group of fish without a leader behaved differently to the group with a leader and the single fish, with no difference recorded in the time taken for fish to traverse the culvert with the sonic device in place, or when it was not (Champion *et al.* 2001). It is possible therefore that the leader fish (possibly used as the single fish) may have been more sensitive to sound than the other carp present, indicating that individual fish may have different reception abilities.

It was noted that after being confronted with the sound device several times, carp became habituated to it and were less affected (Champion *et al.* 2001).

This form of deterrent has definite possibilities for employment at wetland inlet structures to deter carp from entering, particularly as different fish species have different reception abilities. However, as with light, employing this mechanism in the field would require a constant energy source to run the devices, which would increase the cost of construction, add to the amount of maintenance required, and risk of failure through the use of mechanical devices in remote areas. It is recommended that responses of native fish to a sound barrier be investigated further to determine if this form of deterrent is feasible in the field.

Light/sound combination

A combination of light and sound was also investigated to determine if the response elicited in carp was greater when these deterrents were used on their own (Champion *et al.* 2001). Champion *et al.* (2001) found that the carp would act in a similar manner when faced with a combination of light and sound, as they did when faced with either deterrent. Whilst the response produced was not significantly greater than the individual deterrents, it was rarely found to be less.

A combination of light and sound as a deterrent could potentially be useful at wetland inlet structures, however, maintenance, risk of mechanical failure, and set up and running costs are likely to limit their application.

Coarse substrate

The use of coarse grade aggregate (100mm) was investigated by Dooland *et al.* (2000). Coarse substrate was placed either side of a pipe culvert in a laboratory flume, with frequency of carp movement through the culvert determined. Under no flow and flow conditions carp passage through the culvert was actually found to increase when the coarse substrate was present, although a greater amount of time was taken before movement across the substrate under flow conditions (Dooland *et al.* 2000) .

It can be concluded that under laboratory conditions, coarse substrate did not act as an effective deterrent to carp movement. In the lower Murray it is likely that the substrate would act in a similar fashion. Several inlet structures currently in place (eg Lake Littra, Werta Wert Lagoons) have rock rubble (approximately 150mm diameter) surrounding the culvert which does not appear to deter carp movement through the structures. In addition, this form of deterrent would require regular maintenance and reinstatement as the effects of silt would decrease its effectiveness. Coarse substrate is therefore not recommended as an effective deterrent to carp passage at wetland flow control structures.

Bubble curtain

A perforated plastic tube was placed adjacent the entrance to a culvert in a laboratory flume with air pumped through at 100kpa pressure (Champion *et al.* 2001). Groups and single carp were tested to determine if this could be used as an effective deterrent to carp. Champion *et al.* (2001) found that when the group of carp (15 fish) approached the curtain, fish would often turn back and circle, unwilling to move through. On occasion, a single fish from the group would dash through the curtain to the darkened area on the other side, but rarely did the whole group move through. Single fish were not deterred from moving through the culvert with the bubble curtain present. More often than trying to move through the curtain, carp would try to move under the pipe to reach the darkened area, although towards the end of their experimental period, it was noted that some fish became habituated to the curtain (Champion *et al.* 2001).

For this method of deterrent to be used effectively in the field, it would need to have an active power supply (as for light and sound deterrents). Therefore its application in the field environment is limited, and most likely costly. In addition, due to habituation of the test carp to the presence of the bubble curtain, it is probably that over a longer period of time that the animals would become accustomed to it and not avoid it. Therefore it is unlikely that this deterrent could be used practically in the field.

Half barrier

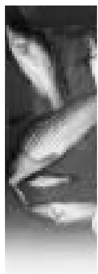
The final deterrent tested was a “half barrier” where chicken wire was reinforced with metal rods and placed across the base of the culvert (Champion *et al.* 2001). The barrier stood 150mm from the base of the flume, with a 17° slope facing away from the culvert. All testing was conducted in a water depth of 600mm under no flow conditions.

This deterrent proved a total barrier to carp during the ten minute trial time employed (Champion *et al.* 2001). Carp were noted trying to push their way through the chicken wire barrier in either direction (sloping or perpendicular face), but never moved over the barrier despite 450mm of water above it.

Further investigations should be undertaken to determine the success of this barrier in the field, and its effects on native fish (in a laboratory and field environment). A previous study has shown that carp are non-directional jumpers, and can jump up to 400mm out of the water (Dooland *et al.* 2000) . This may allow fish to traverse the half barrier, especially at times of flow (when jumping is more prevalent: (Dooland *et al.* 2000)), thereby decreasing the effectiveness of the deterrent / barrier.

Synopsis of carp barriers

Figure 20 indicates the effectiveness of the various deterrents investigated by Champion *et al.* (2001), with the half barrier far outweighing the other forms of deterrents under laboratory conditions. Further investigation of this method of deterrent including in the laboratory for longer periods of time, its effectiveness in the field, and its effect on native fish passage should be undertaken before it is employed as a legitimate method of carp exclusion. It is likely that the half barrier would require regular maintenance in the field (removal of debris) to ensure its effectiveness.



It is possible that a combination of all these deterrents, employed at different times within a cycle, or under a random time frame, would prove successful at totally stopping carp from entering wetlands. Its effectiveness on native fish, and their ability to enter wetlands should further be investigated.

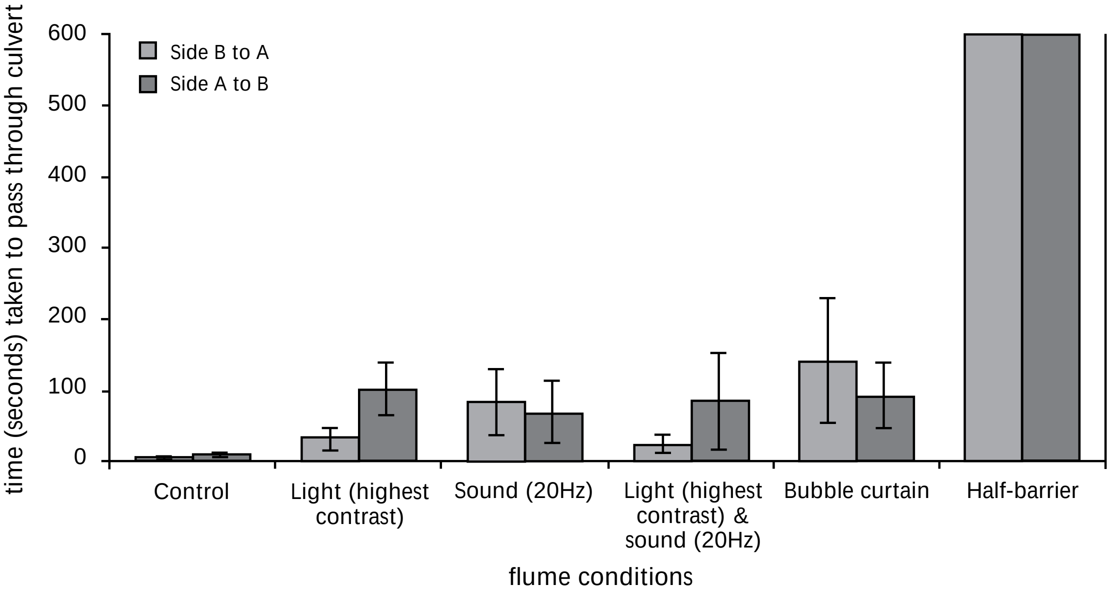


Figure 20. Comparison of all controlled stimuli tested for a group of 15 carp with leader under no flow conditions (mean value with standard error) after Champion *et al.* (2001).

Monitoring movement through structures

An electronic fish counter was developed by Dooland *et al.* (2000), to record and monitor fish movement through culverts. When tested in the laboratory results were promising, with electronic field disturbance recorded for fish moving through a culvert which was distinguishable from that produced by vegetation. However field testing of the device showed that further development was required, with background noise from a generator used to run the device interfering with the actual recordings, and possible blockage caused by debris being an issue (Champion *et al.* 2001). Despite this drawback, with further development the device (or similar) still has the potential to enable monitoring of fish movement through wetland inlet structures without direct sampling of fish, especially in a turbid environment such as that found in the River Murray.

Recommendations for the design and management of structures (previous studies)

Several authors have recommended that the installation of culverts across waterways (including wetland inlet channels and road crossings) incorporate certain characteristics in order to minimise the structure's effects on fish movement.

One of the main obstructions to fish passage, both within the mainstream channel or a wetland inlet channel, is water velocity and water turbulence (Mallen-Cooper 2001). These attributes have a direct effect on fish access through a culvert or structure by impinging on the swimming ability of fish trying to pass through it. When a structure has a high water velocity associated with it fish must employ what is termed “burst speed” in order to navigate laminar flow experienced within it (Mallen-Cooper 2001).

As the name suggests, this swimming type only occurs in short bursts, and cannot be sustained for long periods of time (Mallen-Cooper 1996). Therefore, if the structure is long, as well having high water velocities within it, it can form a physical barrier to fish.

Mallen-Cooper (2001) states that a head loss of only one centimetre can restrict the passage of small fish 40-80mm in length. The situation does not improve greatly for larger fish, with 150mm fish having restricted passage when there is a head loss of between one and five centimetres through a structure (Mallen-Cooper 2001). Mallen-Cooper goes on to state that a head loss of only eight centimetres can be considered impassable by most native fish (Mallen-Cooper 2001).

To minimise the risk of high water velocities present within the structure, it is recommended to maximise the width of the culvert to equal or greater than that of the surrounding channel (Lugg 1997, Fairfull and Witheridge 2003). Mallen-Cooper is more exact, stipulating that the structure should be 1.2 times the width of the channel, more if it is likely to be affected by erosion (such as if the channel is in a process of active movement – this is not of great concern in the lower Murray) (Mallen-Cooper 2001).

In terms of the type of structure used, Anon (1995) suggests that circular culverts (pipes) are the least desirable for fish passage. This is supported by Lugg (1997) who indicates that if the cross sectional area of the stream is significantly less than the cross sectional area of a pipe structure, the high velocities at the pipe would create an unfavourable environment for fish. Lugg (1997) also suggests that box culverts are more appropriate for fish passage if they:

1. approximate the cross sectional area of the stream bed;
2. do not cause elevated flows or water falls;
3. are relatively short <10m in length and
4. contain natural sediments.

Lugg's observations are consistent with studies undertaken in Arkansas USA where little difference in the overall movement of fish was observed between open box, ford crossings and natural reaches (Warren and Pardew 1998).

The length of the culvert is also important, affecting the distance that a fish must travel. Where velocities are high over a long distance fish may be unable to employ burst speed for the entire culvert length, thus being denied the ability to pass. However, in cases where the water velocities are minimised (either through decreasing the culvert length, maximising the culvert width, or both), the physical barrier becomes less. In addition to the physical barrier caused by long culverts, a behavioural barrier may be formed through the lack of light able to penetrate the culvert.

Mallen-Cooper (2001) recommends that a culvert should be:

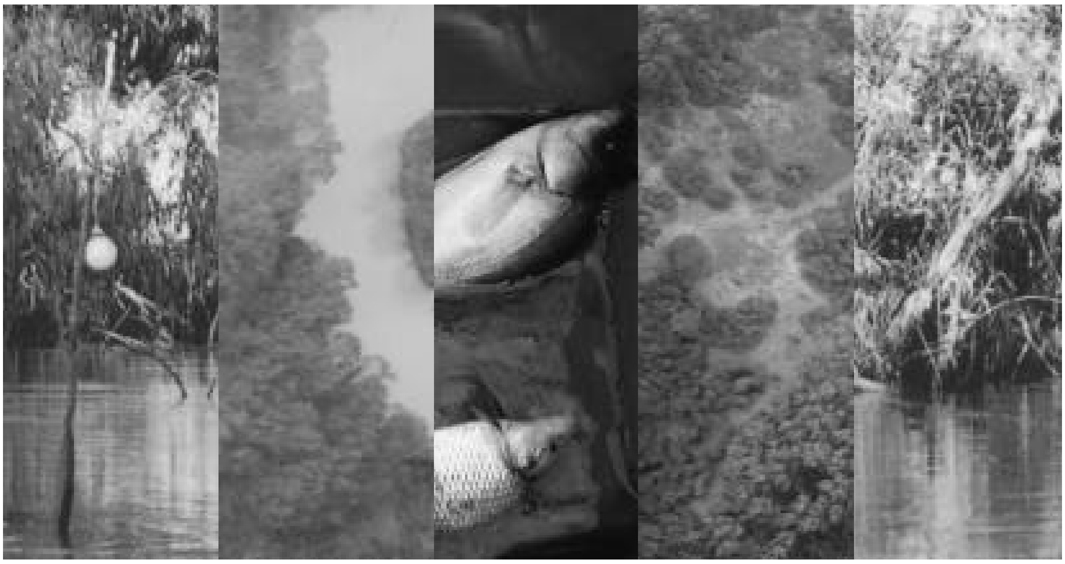
1. at least 1.2 times the width of the inlet channel;
2. relatively high to allow light to enter the structure; and
3. set into the base of the inlet channel by at least 0.3m.

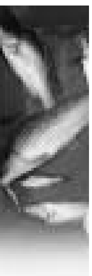
As with recommendations from other studies (Anon 1995, Lugg 1997, Fairfull and Witheridge 2003), a large structure width aims to minimise velocities within the culvert thereby limiting the structure as a physical barrier to fish. Similarly, the setting of the structure also attempts to minimise the culvert as a physical barrier, as well as minimising behavioural avoidance of the structure.

By setting the structure into the channel bed at approximately 0.3m (as per (Mallen-Cooper 2001)), sediment from the surrounding channel can move into the culvert, decreasing the dissimilarity between the surrounding channel and the structure itself, and minimising any potential behavioural avoidance of the structure.

In addition to minimising behavioural avoidance, setting the structure into the channel bed can minimise the structure as a physical barrier. Structures that are set too high compared to the surrounding channel can produce a cascade effect prior to the structure. The high water velocities associated with this structural feature can stop fish from being able to reach the culvert, let alone move through it (Mallen-Cooper 2001).

Another behavioural barrier to fish at a culvert is the lack of light. Mallen-Cooper (1996) found that bony bream were totally inhibited by a darkened passage and would not move through artificially darkened tunnels, leading him to recommend the installation of lit passages (Mallen-Cooper 2001), and other studies to adopt this recommendation (Fairfull and Witheridge 2003).





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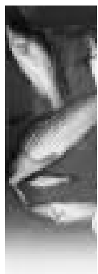

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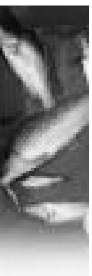

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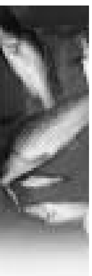

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APPENDICES

Appendix A. Literature review.

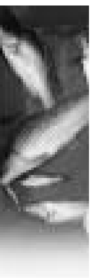
General

It is widely acknowledged that the distribution and abundance of native fish in the Murray-Darling Basin, has declined as a result of a number of impacts (McNee 2000, Walker 1983, Milburn 1995, Wahlquist 1997, Sinclair 1999, Harris and Gehrke 1997, Cadwallader 1978, Gehrke *et al.* 1995). Findings from the New South Wales 'Fish and Rivers in Stress' project demonstrate the severity of these impacts with degraded riverine sites exhibiting decreased biodiversity (Harris and Gehrke 1997).

All fish species within the Basin are known to undertake some degree of movement during their life, thus artificial barriers such as levees, culverts, weirs or flow control structures that obstruct fish movement are likely to make a significant contribution to this decline (McNee 2000). Indeed, the Draft Native Fish Management Strategy for the Murray Darling Basin considers barriers to be a key threat to native fish populations in the Murray Darling Basin (Koehn and Nicol 1999).

In Australia, the need to store water is a major concern. The variability of freshwater flow, rapid agricultural development and concentrated populations in this country has led to Australia storing water at a per capita rate nine times that of any other country (Teoh 1989 cited in Harris *et al.* 1998). Overseas studies demonstrate the consequences of such barriers. Of the nearly 200 European freshwater fish species, 67 are considered threatened by human activity. The major causes of decline were identified for 48 species, and of these, more than half were associated with artificial barriers to migration (Northcote 1998). The impacts of large regulating structures are two fold: while clearly impacting on fish movement, they also change the inherent characteristics of riverine, wetland and floodplain habitats in which these species evolved.

In systems like the Murray-Darling Basin where species have evolved to highly variable conditions, river regulation has a sizeable impact. Research findings suggest that the diversity of fish species decreases as catchments become more regulated (Gehrke *et al.* 1995). For example, changing the timing, duration, and frequency of flooding in the Murray-Darling Basin reduces the reproductive success of native fish by "desynchronizing environmental cycles and the reproductive cycles of native species" (Gehrke *et al.* 1995). The NSW Rivers Survey found that in the Murray catchment exotic species, such as carp and redfin dominated the catch. Stable (regulated) river conditions are thought to disadvantage native species and favour the spread of exotics (Harris and Gehrke 1997).



The floodplain has a critical role in transforming material from the river, Welcomme (1985) notes the productivity of fish in floodplain rivers is linked to interactions between river and floodplain habitats (Welcomme 1985, Gehrke *et al.* 1995). Not only does river regulation alter and often sever this connectivity, it also affects freshwater fish habitat by changing water quality. Examples of such changes include the release of cold, deoxygenated water from large storages, and changes to the proportion of water from the Darling and Murray catchments delivered to the Lower Murray.

The Lower Murray is the most regulated part of the Murray-Darling system. Of the ten mainstream weirs that exist along its length, six occur between the South Australian border and Blanchetown. In addition to these large regulating structures, there are over 300 small structures on the floodplain that are potential barriers to fish movement including causeways, road crossings and wetland inlet structures (Wetland Care Australia 1998). The impacts of these smaller structures are largely unknown.

The stable river levels maintained by the weirs on the River Murray have affected adjoining wetlands. Wetlands that fill at the regulated river level have become permanently inundated rather than fluctuating with the changing levels of the pre-regulated river. In the Lower Murray, the reduction in frequency and duration of floods has meant that wetlands situated at higher elevation on the floodplain do not become inundated as frequently as they would have under natural conditions. When flood conditions occur, the duration of inundation is significantly reduced. Within the constraints of river regulation, local wetland managers are actively managing wetlands to reinstate natural flooding regimes and prevent large carp from entering their wetland. To achieve this they use flow and fish control structures at the wetland inlets.

Wetland inlet structures in the Lower Murray vary in size and dimensions, largely as a result of the absence of guidelines for construction and an ad hoc approach to their design and management. They range from a single 5m long x 70cm diameter pipe with fish screens, to a five laned box culvert structure (each culvert being 1.5 x 1.5m) with a central lit passage.

To date, the construction and consequent management of these fish and flow control structures has been carried out with limited knowledge of their impacts on the passage and recruitment of native fish. Current management has raised community concerns about the exclusion of all large fish from wetlands, with anecdotal information suggesting wetlands are an important part of fish habitat. There are presently no guidelines or recommendations with sound supporting evidence for or against the use of such structures. Through the current project's research we seek ways to gain evidence of the effect of flow control structures and fish gates on fish movement, and determine methods to discourage the passage of carp (*Cyprinus carpio*), whilst promoting the movement of native species. By experimenting with different structures and monitoring the results, we aim to make recommendations for optimal design of new structures and management of existing structures.

But, as reminded by Northcote (1998) we need to think beyond the immediate issue of fish passage. He suggests that in addition to considering fish movement, developing optimal habitats is critical for improving management of fish populations (Northcote 1998). By supporting wetland managers who aim to establish more natural hydrological conditions, and thereby improve habitat this project heeds Northcote's advice, and will encourage fish passage into wetlands of greater habitat value (Northcote 1998).

Status of knowledge of Murray-Darling fish

The ecology of fish and subsequent research into fish biology is a relatively new field in Australia (Pierce 1992). The biology of Australia's freshwater fish fauna is basic at best, with little known about the ecological significance of fish passage obstructions (McNee 2000, WAEPA 1987).

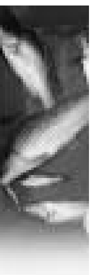
There is a commonly held view that fish (whether larvae, juvenile or adults) native to the Murray-Darling Basin use the inundated floodplain as habitat during flooding periods. There is however little evidence to support this (Humphries *et al.* 1999). Similarly, the relative importance of main river channel habitats to fish reproduction and recruitment is poorly documented (Humphries *et al.* 1999). Despite this, the perceived association between fish productivity and access to floodplain habitats during flooding flows remains (Welcomme 1985). This concept is the basis for the application of the *Flood Pulse Concept* applied to the Murray Darling River system.

The *Flood Pulse Concept* was first proposed for tropical riverine systems (Junk, *et al.* 1989), and applied to the Murray Darling Basin by Walker and Sheldon in 1992. Walker and Sheldon (1992) stated there was a tendency for investigations to underestimate the significance of flooding to aquatic riverine communities. They suggest that flooding is the major force driving the Murray-Darling riverine ecosystem, with the entire floodplain community's productivity and biomass directly dependant on the flood pulse (Walker and Sheldon 1992).

Due to the major impacts of river regulation on flood dynamics, this reliance on the flood pulse to recruit and increase biomass was therefore suggested as a reason for the decline in native fish populations in the Murray (Walker and Sheldon 1992). The decreased occurrence of small to medium floods would probably limit the recruitment of fish that rely on wetlands for spawning, nurseries and larval growth (Walker and Sheldon 1992).

Recruitment hypotheses

It was also thought that flooding may aid species that live and possibly breed in the main channel, through the input of nutrients and plankton assemblages from the inundated floodplain and wetlands (Walker and Sheldon 1992). This part of the *Flood Pulse Concept* was expanded by (Humphries *et al.* 1999) who proposed three life history models for native fish advantaged by high flows, and a fifth, the *Low Flow Recruitment Hypothesis* that suggested flooding was unnecessary for recruitment and survival of some Murray-Darling fish species:



1. Flood/High Flow Advantaged Mode
The first life history scenario is attributed to predominantly larger species, such as Murray cod (*Maccullochella peeli*), trout cod (*Maccullochella macquariensis*) and catfish (*Tandanus tandanus*), but also includes the river blackfish (*Gadopsis marmoratus*). These fish tend to only spawn once a year in late Spring/early Summer. Spawning at this time may coincide with flooding, but is not triggered by it. Coincidence with floods would provide a distinct advantage for larvae and juveniles, as this would provide an additional food supply when plankton is washed into the mainstream.

2. Flood/High Flow Related Mode
The second scenario applies to the relatively large species such as golden perch (*Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*). These species spawn only

once, in late Spring, early Summer, however can delay spawning until appropriate conditions are present. Spawning in these species is thought to be linked to rises in flow and later flooding, and therefore also related to changes in temperature. A larval period exists for these fish, requiring a reliable source of food that would be supplied in high densities in backwaters that held water for longer periods of time. This life history is the same as the traditional views held in the *Flood Pulse Concept*.

3. Flow Independent, Repeat Spawning Mode
This mode applies to fish such as the Australian smelt (*Retropinna semoni*) and flathead gudgeon (*Philypnodon grandiceps*). These species are mostly small and repeatedly spawn from Spring to early Autumn. Spawning is thought to be unrelated to flow, although a threshold temperature may be required. The larvae of these fish possess a small gape size and start feeding around 2-3 days after hatching. The larvae therefore rely on high densities of small prey (eg phytoplankton) for their first feeding (they therefore may also be advantaged by high flows accessing temporary wetlands and producing high plankton densities).

4. Flow Independent, Single Spawning Mode
Members of this mode are also generally small fish, and include carp gudgeons (*Hypseleotris* spp.), Galaxias (*Galaxias* spp.), crimson spotted rainbow fish (*Melanotaenia fluviatilis*), and southern pygmy perch (*Nannoperca australis*). These fish breed late Winter / early Spring or Summer for about 2 months. Their larvae's small gape size also rely on small prey (such as microinvertebrates or algae) for their first feeding.

5. Low Flow Recruitment Hypothesis
This mode represents a major diversion from the established *Flood Pulse Concept*. This theory rationalises that in addition to high flows, there are also low flows occurring in the variable Murray-Darling system. Since it appears that some fish have adapted to flooding in this system, it seems appropriate that some species would take advantage of low flow periods to complete their life cycles. This theory follows that at low flow periods, phytoplankton and zooplankton densities are greater due to the smaller volume of water present, its greater residence time and higher temperature. Species that spawn during the low flow periods are therefore advantaged, as a ready supply of food is available for their larvae and juveniles. A disadvantage associated with this strategy is that these species could be affected by poor dissolved oxygen levels and increased solute concentrations, such as salt.

As with the *Flood Pulse Concept*, little evidence exists to prove or disprove this theory. However, a recent study by (Mallen-Cooper 1996) suggests that native fish recruitment was greater during periods when waters were confined to the main stream.

Despite the uncertainty regarding reproductive modes, it is generally acknowledged that many of Australia's native fish are "potadromous", only migrating within the river system (WAEPA 1987, Harris *et al.* 1998).

A definition given by Northcote (1998) explains that migration "*usually involves, at some stage in the life cycle, both upstream and downstream movements to reach the appropriate habitats*". The fact that this definition refers to both upstream and downstream movement is important, because to date most of the information collected on migration has focussed on upstream movements. The reason for this is unclear, but may be a response to the focus of research primarily on commercially or recreationally important species (Northcote, 1998). Overall, there remains a lack of information on the capabilities, behaviour and migratory requirements of native species (Northcote, 1998).

Current knowledge of fish movement

Little is known about the downstream movement of fish, how barriers affect downstream movement, when it occurs and what the environmental or behavioural cues are. It is generally assumed that downstream movement is a form of “passive drift”, due to the susceptibility of early life stages (eggs or larvae) to displacement by flows (Harris 1985, Northcote 1998). Further studies are required to determine the effects of mainstream weirs and floodplain barriers on this downstream migration of native fish (Humphries *et al.* 1999).

Similarly, there has been a focus on longitudinal movement of fish within the mainstream, whilst the lateral movement of fish onto and off of the floodplain and its wetlands, and how these movements differ in response to flow, other environmental variables or behavioural cues (Humphries *et al.* 1999) remain a mystery.

Lateral movement of native fish remains a “vexed question” (Humphries *et al*. 1999). A recent open forum on fish passage in Australia (All Participants 1992), identified the need to investigate fish movement onto and off the floodplain in relation to changing water levels, and the effects of levee banks {culverts and causeways} on this movement.

If we are to manage and conserve the Murray-Darling’s (and Australia’s) fish fauna, it is essential that we understand how the biology of native and introduced fish is influenced by flow, within both the main channel and the floodplain (Humphries *et al.* 1999).

Mallen-Cooper (1994) notes that it is critical to understand fish behavioural patterns and swimming abilities in order to design effective fishways. This information is of equal importance to ensure that flow and fish control structures on wetland inlets do not inhibit the free passage of native fish. The management and construction of wetland inlet structures need to take into account the requirements of native fish to complete their life cycles. Although this project is primarily focused on the small scale (localised) lateral movement and the use of wetland habitats by fish, if fish do use floodplain wetlands, then it also becomes important to consider large scale migrational movement especially at times critical for native fish reproduction. Existing information for fish found in the Lower River Murray is summarised in Table 16.

Longitudinal Fish Movement

Fish may move for any number of reasons, however in the Murray Darling Basin movement is largely related to spawning and dispersal (Humphries *et al.* 1999). As highlighted in the previous section, research to date has focused on longitudinal, rather than the lateral movement of fish within the Basin.

The upstream migration of fish is generally dominated by juveniles and includes large native species such as callop, silver perch, Murray cod and smaller species like Australian smelt (Humphries *et al.* 1999, Mallen-Cooper 1994). The upstream migration of freshwater fish is influenced by temperature, photoperiod, water level and the presence of food (Humphries *et al.* 1999) and tends to take place as floodwaters arrive and water temperatures increase during spring and summer. For many Murray-Darling fish, migration can occur during flood and non flood years, however spawning may be variable if flooding conditions do not prevail (see Table 16 for details). Carp are also a migratory species whose migratory habits are characterised by short random movements that are unrelated to spawning (Humphries *et al.* 1999, Reynolds 1983).

Localised and Lateral Movement

Localised fish movement, be it lateral or longitudinal, can be influenced by local water quality or light conditions. In wetlands in the Lower River Murray that are currently being managed with fish and flow control structures it is possible to influence these conditions. (Koehn and Burchmore 1993) identified turbidity, salinity, temperature and dissolved oxygen as factors that influence the physiology and behaviour of fish. Salinity, turbidity and dissolved oxygen levels in wetlands are related to the management of the water regime. For example, if wetlands are left to dry during spring - summer when the germination of plants on the dry lake bed is rapid and abundant, the breakdown of abundant plant matter will influence the dissolved oxygen levels in the wetland as it re-fills. Conversely if a wetland is dried during cooler months plant growth would be less abundant and have less impact on the water quality as the wetland re-filled. The poor water quality prevailing in the wetland (ie. low oxygen levels) would, as suggested by (Humphries *et al*. 1999) make it undesirable for the larvae of callop and possibly other species and influence their distribution and use of the wetland habitat.

Light conditions have also been identified as affecting localised fish movement. Adult callop and silver perch were recorded by (Gehrke 1990) as swimming towards a light source. Such observations have implications for structure design. It has also been noted that bony bream (*Nematolosa erebi*) did not move through tunnels (Mallen-Cooper 1994). Although this observation may be related to turbulence and or velocity at the structure, it is feasible that their movement may have been influenced by the absence of a lit passage.

Several native fish species have been recorded moving through mainstream fishways during the day (bony bream, silver perch, and Australian smelt), with callop moving predominantly during dawn and dusk (Mallen-Cooper 1992, Mallen-Cooper 1994). Longitudinal day-night movement is well documented, however day-night movement onto and off of the floodplain is not.

Pilot research at sites in the Lower Murray recorded callop, bony bream, carp gudgeons and fly specked hardyheads *(Craterocephalus stercusmuscarum)* moving onto the floodplain exclusively during the day. The exotic species - goldfish *(Carassius auratus)* and carp were noted moving off of the floodplain exclusively during the night (Pierce 1997). If these findings are observed under a range of flow conditions, there are likely to be opportunities to confidently manage fish control structures to encourage the passage of native fish whilst excluding exotics.

Apart from a few studies (Pierce 1991, Pierce 1997), the localised movement of fish into and out of wetlands and the floodplain is largely undocumented. Preliminary findings from a study conducted in Lake Littra, a temporary lake on the Chowilla floodplain in the Lower Murray demonstrate the patterns of fish migration out of the wetland. After breaching a temporary bank that held water in the wetland post flooding over 90% of the fish in the wetland migrated out during the first 48 hours (Pierce 1991). Furthermore, virtually all of the adult carp migrated out of the wetland during this period (Pierce 1991). Contrary to these observations, (Wilson 1999) noted that carp moved onto the floodplain 2-3 days prior to the native fish and as water levels dropped, stayed after the natives had migrated out. Further investigation and conformation of these findings would provide excellent opportunities to refine the management of fish control structures on wetland inlets (Wilson 1999).

Despite what is known, there are still significant gaps in our basic knowledge of Murray-Darling fish biology (Table 16). To further complicate current knowledge (Humphries *et al.* 1999) pp. 131 note that "studies of life history traits, spawning cues, movement and migration, habitat use and recruitment vary widely among species and may not even be consistent for one species across different regions". To take the management of wetland inlet structures forward, we assume that the migration and habitat requirements of fish summarised in this review are consistent for the Lower River Murray.

Habitat use by fish

Due to the confines of their surroundings, freshwater fish are more dependant on their habitat than marine fish (Koehn 1992), making them more susceptible to habitat changes occurring within a river system.

Changes to river and wetland habitat through river regulation can have disastrous effects for the survival of native species by breaking the links between the floodplain and the river channel (Gehrke *et al.* 1995) through changes to environmental stimuli, aiding the colonisation of aquatic habitats by introduced species, and prohibiting access to areas as a result of the installation of physical barriers (weirs, dams, water control structures: Gehrke *et al.* 1995).

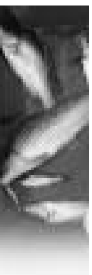
A diversity of habitats is essential to the suite of native species in the Murray-Darling Basin, and to individual species at different stages of their life cycles (Koehn 1992).

Current information on fish habitat use is summarised in Table 1, with the key information outlined below:

Mainstream
The mainstream of any river provides the focus of the system's energies: acting variously as a source, sink and conduit for water, nutrients and biological matter.

The main river channel also provides migration paths for many species undertaking longitudinal migration as part of their breeding cycle or colonisation of new habitats (Gehrke *et al.* 1995). It is for this reason that concern has been so great regarding the effect of mainstream barriers such as weirs and dams (Gehrke *et al.* 1995). In addition, regulation of the mainstream flows has changed the nature of both mainstream and wetland habitats – both directly through habitat modification, and indirectly by promoting better conditions for introduced species (Gehrke *et al.* 1995). Several studies have shown that with a greater degree of river regulation, the lower the fish species diversity the river will have (Gehrke *et al.* 1995).

Until recently little attention has been given to the significance of mainstream habitats – especially for rearing juveniles (Humphries *et al.* 1999). This is despite several species having no apparent relationship between high flow and maturation, spawning or rearing of young, and knowledge that the larger species – callop, silver perch and Murray cod – generally prefer the river environment (Humphries *et al.* 1999, Harris and Rowland 1996, Merrick 1996) and successfully spawn in the main river channel (Cadwallader 1977), sometimes on mass over a short period of time (Humphries, *et al.* 1999).



These observations led to the proposal of the "low-flow recruitment hypothesis" discussed above which suggests that several species are adapted to the river environment, spawning and recruiting at times of low flow (Humphries *et al.* 1999). This hypothesis is compatible with findings from several studies including Lloyd and Walker (1986), who found species diversity to be greater for "river edge" sites rather than "backwater", "billabong" or "stream" habitats (Lloyd and Walker 1986).

Table 16. Summary of existing literature on fish habitat requirements, movement, and spawning cues for fish found in the Lower River Murray.

Species Name	Name	Key Habitat	Mig?	Mig^n habits	Mig^n Season	Mig^n Cues	Day / Night Mvt	Spawning location	Spawning cues	Spawning time	Type of spawning	Other
Maccullochella peeli	Murray Cod	Mainstream[4], anabranch creeks[6]	Y[10,3,6]	upstream for spawning[10,3,6], not all move at same time, same pattern every year[6]	Sum, Aut & Win (local mvt) Win/ Spr (major mvt)[6]	flood & non flood years			+/- 1-2 weeks of flood peak[14], approx annually, rise in river, min temp[4]	Oct-Dec[4]	single spawn[4]	Cod generally don't move onto floodplain[6], fishermen never caught juvenile cod in billabongs or flood plain[14,6], young caught in low flow habitat near spawning site[14,3], young only caught in river channel[6], migrate upstream 120km[6]
Maccullochella macquariensis	Trout Cod	Mainstream[4] with fast current[12]	Y[6]	upstream for spawning[22,6]		major flood (1993)[6]		approx annually,	Oct-Dec[4] min temp[4]	single spawn[4]		
Macquaria ambigua	Callop / Golden Perch	Mainstream[4], lake, anabranch[12]	Y[10]	upstream mig^n of juveniles adults & sub adults [10,11,14] continue mig^n with falling water levels[11], sub adults preferentially use floodplain during high flows[15], adult fish swim towards light[16], young move downstream independent of light[7]	Spr / Sum[9]	temp >16C[11], strong diel mvt[8]	move at dusk & dawn[8], move onto floodplain in day[16], swim towards light source[1]	can spawn on floodplain[5]	risingwater level, min temp[4]	Oct-Mar[4]	variable single spawn[4]	250mm water level drop=drop in spawning in SA, density related to high DO[1], can travel up to 1000km upstream[9], attracted to chemicals released by redgums[3]
Nematolosa erebi	Bony Bream / Bony Herring	wide range of habitats, mainstream – wetlands[22]	Y[10]	upstream[10], continue mig^n with falling water levels[11]		flood & non flood[11], temp >16C[11]	day mvt[9], move onto floodplain in day[16] on floodplain[5]	backwaters, before rise in flow[4], can spawn		Spr-Sum[22]	single spawn[22]	juveniles use floodplain, did not move through tunnels[9]
Bidyanus bidyanus	Silver Perch	fast flowing waters[23]	Y[3,9]	upstream mig^n of juveniles[3,9], continue mig^n with falling water levels[11]	Spr / Sum[9]	small rise in water level[9], temp >16C	day mvt[9], swim towards light source[1], young move downstream independent of light[7]	can spawn on floodplain[5]	rising water level, min. temp[4]	Oct-Mar[4]	variable single spawn[4]	travel up to 500km upstream[9]
Tandanus tandanus	Freshwater Catfish	anabranch / lakes (low flow conditions)[24]	N[3]					shallow parts of main river / quiet backwaters[4]	approx annually, min temp[4]	Oct-Dec[4]	single spawn[4]	
Hypseleotris spp.	Carp Gudgeon	permanent wetlands[4,25]	N[25]				move onto floodplain in day[16]			Late Win / Sum[4]	short single spawn[4]	uncertain spawning cues[4]
Melanotaenia fluviatilis	Rainbow Fish	rivers, creeks, wetlands (low flow conditions)[4,26]	N[26]						stimulated by warm temps[26]	Spr - early Sum[26]	short single spawn[4] over several days[26]	uncertain spawning cues[4]
Retropinna semoni	Australian Smelt	permanent wetlands[4] (low flow conditions)[27]	Y[3]	upstream migration[3], juveniles migrate upstream[9]	Spr / Sum in SA[9,27]	small rise in water level[9]	day movement[9]		around 15ºC[27]	Oct-March[4]	long, repeat spawn[4]	uncertain spawning cues[4]
Philypnodon spp.	Dwarf Flathead Gudgeon	anabranch/lakes (low flow conditions)[25]	Y[3]									nothing known about breeding[25]
Philypnodon grandiceps	Flathead Gudgeon	anabranch/lakes (low flow conditions)[25]	N[25]							Spr - Sum[25]	long, repeat spawn[4]	spawning cues uncertain[4]
Ambassis castelnaui	Western Chanda Perch	river, creek & wetland[28]	N[28]						approx. temp. 23ºC[28]	Nov & Dec[9]		
Craterocephalus stercusmuscarum	Fly specked Hardyhead	anabranch/lakes (still - gently flowing water)[29]	N[29]				move onto floodplain in day[16]			Mid Oct. - Mid Feb[29]	long breeding season[29]	
Craterocephalus fluviatilis	Murray Hardyhead	little known, likely habitat, still - gently flowing water[29]	N[29]									
Nannoperca australis	Southern Pygmy Perch	anabranch/lakes (low flow conditions)[30]								late Win / Sum[4]	short single spawn[4]	uncertain spawning cues[4]

Species Name	Name	Key Habitat	Mig?	Mig^n habits	Mig^n Season	Mig^n Cues	Day / Night Mvt	Spawning location	Spawning cues	Spawning time	Type of spawning	Other
*Perca fluvialitis**	Redfin Perch	still-gently flowing water[31]	N[31]						temp.> 12ºC[31]			
*Gambusia holbrooki**	Plague Minnow / Mosquito fish	wide range of habitats[32]	N[3]							All warm months (peak in spring)[32]	repeat spawning, live bearer[32]	wide range of environmental tolerances[19]
*Carassius auratus**	Goldfish		N[3]				move off floodplain at night[16]			Sum[33]		
*Cyprinus carpio**	Carp	dislike steep drop offs & course habitat[21], juvenile carp use floodplain[2], prefer shallow low flowing habitats[33]	Y[17]	upstream, short random mvt[17], mig^n unrelated to spawning[11], primarily migrate during low flow years[11]	Spr / Sum	flood & non flood[11], rise in water temp & increases in river level stimulate upstream mig^n [11]	move off floodplain at night[16]	shallow water <30-40cm deep[20]	lengthening photo period, temp. increase >17ºC, rising or stable water[13]	Spr / Sum[18]	single major spawn[13]	juv carp out of nursery within 12 months[17], carp move onto floodplain 2-3 days before natives & stay after natives have left[17], spawn at lower temps. than natives thus earlier in season[20]

REFERENCES

1 (Gehrke 1990)
2 (Gehrke *et al.* 1995)
3 (Harris *et al.* 1998)
4 (Humphries *et al.* 1999)
5 (Koehn and Burchmore 1993)
6 (Koehn 1995)
7 (Lake 1967) in (Dooland *et al.* 2000)
8 (Mallen-Cooper 1992)
9 (Mallen-Cooper 1994)
10 (Mallen-Cooper *et al.* 1995)
11 (Mallen-Cooper 1996)
12 (Harris and Rowland 1996)
13 (Mills 1991)
14 (Pierce 1991)
15 (Pierce 1992)
16 (Pierce 1997)
17 (Reynolds 1983)
18 (Smith 1999)
19 (Vargas and de Sostoa 1996)
20 (Wilson 1999)
21 (Dooland *et al.* 2000)
22 (Briggs and McDowall 1996)
23 (Merrick 1996)
24 (Pollard *et al.* 1996)
25 (Larson and Hoese 1996)
26 (Allen 1996a)
27 (McDowall 1996a)
28 (Allen 1996b)
29 (Ivantsoff and Crowley 1996)
30 (Kuiter, Humphries et al. 1996)
31 (McDowall 1996c)
32 (McDowall 1996b)
33 (Brumley 1996)

ABBREVIATIONS

Mig$^{(n)}$	=	Migrate
Mvt	=	Movement
Spr	=	Spring
Sum	=	Summer
Aut	=	Autumn
Win	=	Winter
Juv(s)	=	Juvenile(s)
Temp(s)	=	Temperature(s)

It is therefore feasible that "river improvement" activities such as snag removal, channelisation, and removal of riparian vegetation could have a profound effect on riverine fish fauna – especially those species that are directly reliant on physical features for protection, spawning sites, or orientation within their range (Cadwallader 1978, Koehn 1995).

Wetlands

There is a general lack of information relating to wetland and floodplain use by fish. It is thought however, that for many species, wetlands provide feeding, spawning, and nursery areas (Koehn and Burchmore 1993), and that a range of fish species use different floodplain habitats at different times and life stages (Humphries *et al.* 1999). Despite this view, few studies have shown evidence that adult or larval fish use non-permanent floodplain habitats in the wild (Humphries *et al.* 1999).

There is also a lack of distinction between the inundated floodplain and temporary wetlands in the literature, making it difficult to determine fish usage for the different habitats.

There are two main wetland types in the Lower Murray. Permanent (those filling at regulated river level), and temporary (wetlands that fill during high flow conditions). It is probable that permanent wetlands have permanent localised fish communities that do not undergo immigration or emigration (Humphries *et al.* 1999). Examples of species commonly found in permanent wetlands include gudgeons, rainbowfish and Australian smelt (Humphries *et al.* 1999). There are also likely to be fish that migrate between the wetland and mainstream. Changing the water regime of permanent wetlands is likely to significantly alter the make up of the permanent fish community. This is supported by (Pierce 1997) who found that exotic species, such as redfin, carp and gambusia, dominate permanent water at sites on the Chowilla Floodplain in South Australia. He suggests that native fish favour temporary waters and the inundated floodplain, and that impounding temporary wetlands to create permanent water is unfavourable, as it leads to a dominance of exotic species (Pierce 1997).

While catfish are often found in the mainstream environment, they have a preference for slow flow conditions during spawning and have been observed using both wetlands and low flow portions of the mainstream for this purpose (Humphries *et al.* 1999). Similarly, bony bream also prefer backwaters and wetlands over mainstream habitats (Humphries *et al.* 1999). Bony bream have been recorded spawning in backwaters during floods, but it has been observed that only juveniles use the floodplain (possibly wetlands) proper (Humphries *et al.* 1999).

Floodplain

Use of the floodplain by native fish is also largely unresolved due to lack of information, particularly the nature of feeding on the floodplain by native fish (Humphries *et al.* 1999). There is little confirmatory evidence of the use of temporary habitats by fish larvae, juvenile or adults, although there is a perception that the inundated floodplain is an important habitat (Humphries *et al.* 1999). Similarly, there is insufficient data on whether the densities of microinvertebrates are higher on the floodplain compared to the mainstream, and whether these densities can support fish larvae (Humphries *et al.* 1999). Plankton blooms on the floodplain, resulting from the new availability of nutrients, are thought to be a source of food for larval and juvenile fish of species such as silver perch, callop, bony bream, and spangled perch that can spawn on the floodplain (Koehn and Burchmore 1993).

There is evidence to suggest that sub adult callop prefer temporary floodplain water to the permanent backwaters and preferentially use floodplain areas during high river flows (Pierce 1991, Pierce 1992). Similarly, (Geddes and Puckridge 1988), found that accumulation of juvenile bony bream at the flood fringe occurred in the Cooper Creek system, suggesting that this habitat is important for younger age classes of this species. In addition, (Koehn 1995) called for the protection and enhancement of riparian vegetation due to its use as habitat under high flow conditions, and the protection it provides for juvenile fish (especially), given that juvenile fish can be displaced by flows as little as 150mm/second (Pierce 1997). Furthermore, these findings indicate that barriers (such as levee banks, road culverts and possibly flow control structures on wetland inlets) on the floodplain have the potential to disrupt movement of sub adults and potentially cause fish kills (Pierce 1992, Geddes and Puckridge 1988).

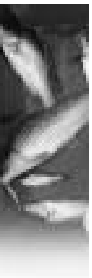
Current knowledge suggests that use of the floodplain may only be restricted to periods of high flow, as the habitat may not be suitable for native fish during small scale inundations that occur under regulated conditions (Gehrke 1990; Gehrke 1991). This viewpoint has been reiterated by several authors, who claim that fish movement along floodplain channels only occurs during times of “measurable” flow (Pierce 1991), and when the connection between the river and the floodplain habitat is strong (Humphries *et al.* 1999). Once the connection between the river and floodplain appears to be weakening, native fish move back to the mainstream or anabranches (Humphries *et al.* 1999). A fish survey during a Spring flood that covered most of the floodplain of the Murrumbidgee catchment, recorded few fish on the floodplain except large numbers of juvenile carp that were found in the lake habitat of Green Swamp (Gehrke *et al.* 1995), throwing doubt onto the use of the floodplain by any fish at any flows (large or small).

The question of whether water quality conditions on the floodplain are favourable to native fish during flooding remains (Humphries *et al.* 1999). Low dissolved oxygen concentrations and high tannin concentrations make the environment unattractive to many fish (especially the younger stages), although the opposite is true for some fish (eg. callop) (Humphries *et al.* 1999).

It is clear that more research is required into the timing and conditions required for fish to move onto (and use) the floodplain. The swimming ability of fish will determine the conditions under which it is possible for fish to move. Current information is detailed in the following section.

Swimming ability of Australian fish

Most of the research on fish swimming abilities in Australia relates to fishways and the ability of fish to move through them. In South Australia there is only one such fishway, located on the mainstream River Murray channel at Weir Six (of vertical slot / baffle design) near the South Australian border.



Early designs of these structures are based on overseas structures, which usually aimed to allow the passage of Salmonid fish during their annual migration. Australian native fish are different from Salmonids, generally being slower and smaller, most lack the ability to leap, and live in streams or rivers with a naturally greater seasonal fluctuation in water level (WAEPA 1987). The importance of understanding swimming abilities of native fish is that it provides an indication of their ability to overcome water velocities and head differences. This information is useful for managing wetland structures, for example when fish attempt to move against the current when a wetland is draining, or the wetland becomes part of a larger flow path during a flood, and therefore acts as part of a migration route.

As with Australian migration studies in general, fishway studies have focussed on fish movement against the current (upstream), the behaviour of downstream migration is poorly understood and often regarded as occurring by passive drift (Northcote, 1998).

Most fish differ in their ability to swim against a current, with size-dependant changes within a species (Gray 1953, Bainbridge 1958 *in* Northcote 1998). The swimming speed of fish is estimated at between 9 and 21 body lengths per second, however this is largely based on Salmonids (Mallen-Cooper 1994). At these rates, using burst speed swimming, the fish's white muscle power is used. The use of white muscle can not be maintained for longer than approximately 10-15 seconds, after which the red muscle is employed for sustained swimming (Northcote, 1998). This becomes the limiting factor in a fish's ability to traverse a differential head or escape predation.

During monitoring of three weirs, (Mallen-Cooper 1992) observed large numbers of sub adult callop moving upstream during high flows (Mallen-Cooper and Harris 1992). The sub adult fish were able to pass through head losses of up to 53cm (at a flow of 14,100 ML/day) at Brewarrina Weir, a head loss of less than 50cm (at a flow of 10,000 ML/day) at Bourke Weir, and a head loss of less than 10cm at Menindee Weir (Mallen-Cooper and Harris 1992).

Adult callop (44cm) and silver perch (25cm) have also been recorded moving through a vertical slot fishway when water velocity was 1.8m per second or less (Mallen-Cooper 1994). However movement is not only restricted to large fish, with small fish such as Australian smelt and gudgeons recorded moving through fishways on the east coast (Mallen-Cooper 1994).

Of species introduced to the Murray, the only information available relates to carp, although this is also minimal (Dooland *et al.* 2000). In general, most Cyprinids have been noted to have poor leaping and swimming abilities to overcome small rises or areas of rapid water movement (Northcote, 1998). However, carp have been reported to jump heights of 1m (Merrick and Schmida 1984, Tucker 1999). Australian native fish have not been recorded as jumping to such an extent (WAEPA 1987). Despite their apparent enhanced jumping ability, it is believed that carp and native fish have similar swimming abilities (based on fish of similar body size) (Mallen-Cooper 1994). Therefore any structural enhancement to a fishway or flow control structure that prevented carp movement based on their swimming ability, would also prevent most native fish movement (Vilizzi 1997). If discrimination against carp is required, it may be useful to investigate behavioural characteristics rather than swimming ability (Dooland *et al.* 2000).

Wetland rehabilitation projects

Over the last ten years in South Australia there has been a movement in wetland rehabilitation to implement drying cycles on permanently indundated wetlands and wet droughted wetlands for longer periods of time during high river conditions. The premise behind implementing wetting and drying regimes is to replicate the natural flood - drought conditions that would have affected wetlands prior to river regulation.

By drying permanent wetlands out for periods of time, sediment can become consolidated, nutrients can become fixed, and dry phase vegetation can become established, creating structural diversity and an additional food source for macroinvertebrates and fish once the wetland is re-wet. By keeping droughted wetlands wet for longer periods, aquatic vegetation, invertebrates and fish are given the chance to complete their life cycle, riparian vegetation is maintained, and long lived vegetation are given a reprieve from long term drought conditions.

In order to manage water to and from wetlands flow control structures are installed on wetland inlet and outlets. To date these structures have been designed and installed in an ad-hoc fashion based on available knowledge, materials, and (often most importantly) funds. This has led to many different structure types being installed as part of approximately 20 established rehabilitation projects, and with over 90 more proposed (Goodman 2003).

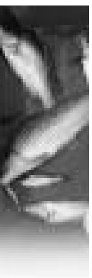
Structure types used include large and small box culverts, pipe culverts of varying dimensions, and open-topped box culverts.

Wetland inlet structures: impacts on fish movement

As early as the 1970's, it was recognised that 11 species of Australian freshwater fish were seriously threatened or considerably reduced in distribution as a result of dams and weirs blocking migration paths (Lake 1971*cited in* Northcote 1998). In South Australia, the construction of the Torrens Weir has been implicated in the extinction of the short-headed lamprey and the decline in Congolli numbers from this river (Pierce 1992).

Just as large regulating structures need to provide adequate fish passage for the upstream and downstream movement of fish (Koehn 1995), wetland inlet structures need to provide fish passage into and out of wetlands during low flow conditions. During high river flows these wetlands may begin to form part of a fish migration route, however, at this time the structures are 'decommissioned' as they are overtopped by flood waters. Overseas and Australian studies have focused on fishway construction in streams and rivers. These studies have shown that there are a number of changes produced by structures that are likely to influence fish passage. These factors include: flow rate, high turbulence and velocity at and within the structure, water quality (such as turbidity, temperature and dissolved oxygen levels), water depth in the culverts, noise and light conditions (Koehn and Burchmore 1993, WAEPA 1987, Bates 1997, Mallen-Cooper 1996). As with large regulating structures, culverts at wetland inlets alter the 'natural' physical conditions of flow into the wetland. On this smaller scale, it is unclear if and how, fish movement is affected by these structures.

Wetland inlet structures can present a physical barrier to fish, preventing or limiting movement of different species and size classes through the structure due to physical swimming abilities or behavioural preferences (Harris 1985). Structures may also alter the local water quality through increasing water velocity, turbulence and noise, or changing water oxygenation and temperature so that the structure surrounds are unsuitable to some or all fish (WAEPA 1987, West 1992). Similarly, unsuitable design or location could see fish being "instinctively reluctant" to enter into the unnatural environment of a culvert (Lugg 1997), or into a naturally or man-made fish "danger area" (Mallen-Cooper 1992).



Precluding fish movement through a structure can cause congregation of fish on one side or the other, leading to delays in migration (and possibly spawning), and possibly death through increased predation or competition from other species (Harris *et al.* 1998).

Correct management of structures can often lead to an improvement in fish movement, and given fish movement may only occur at certain times (Pierce 1997), management of the structures may be as important as the design of the structures themselves (Dooland *et al.* 2000).

In a perfect world, structure design and management would allow free passage of native fish through all engineered structures. In order to achieve this, however, we must expand our knowledge of the swimming ability and behavioural characteristics of Murray Darling fish.

There are generally two parts to wetland inlet structures: flow control structures, that control water movement into and out of wetlands; and fish control gates that aim to limit exotic fish access to the wetlands. Many flow control structures have been installed throughout Australia, each consisting of culverts and screens of varying dimensions. Due to the nature of South Australian wetlands, nearly all managed wetlands in this section of the River Murray are fed from inlet creeks that connect to the mainstream.

1. Flow Control Structures

Velocity is one of the key abiotic factors that influence fish movement, whether in the mainstream, through a fishway, or through a wetland control structure. It has been shown in the mainstream of the River Murray that sub adult and adult native fish can pass through fishways with water velocities of 1.8m per second (Mallen-Cooper 1994). However, on the floodplain, juvenile fish were displaced by water velocities as low as 0.15m per second (Pierce 1997). It is therefore important to design structures with a range of fish species and life stages in mind to ensure all the fish that want to move can move, and that those smaller species or life stages can survive the experience.

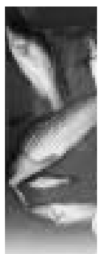
While unsubstantiated for Australian fish and Australian conditions, there are options identified in American fish passage guidelines for reducing velocity at culvert structures which could potentially be applied to wetland inlet structures after investigation into the suitability to Australian fauna and conditions. However, it is noted that by reducing velocity, turbulence within the culvert may increase to create a further barrier to fish passage (Bates 1997).

Options for managing velocity include: creating flow refuges within the culvert structure by installing baffles, increasing the roughness of the culvert wall, or placing streambed material on the culvert floor (Bates 1997).

As is the case in fishway design, conditions leading up to the entrance of a wetland inlet (both upstream and downstream of the structure) may be equally important for the passage of native fish as the design of the structure itself (Harris *et al*. 1998). If there is a steep gradient downstream of the wetland inlet for example, it will become virtually impossible for fish to negotiate their way out of the wetland as the wetland drained or dried. Furthermore, extensive reed growth in the feeder channel either side of the wetland structure could potentially limit fish movement before they reach the inlet structure. If this is the case, the design and management of the structure is irrelevant as the fish are unable to reach it.

The way a fishway / culvert / flow control structure is managed will also influence the ability of fish to move past these obstructions. These changes may be no more difficult than leaving the gates on a lock chamber ajar for a longer period than normal, resulting in a forty-fold increase in the number of fish passed (Mallen-Cooper 1994).

Attractant flows are often used in fishway design to draw fish to the fishway entrance and ensure unimpeded passage (Harris *et al.* 1998). In the case of fishways, structure leakage can lead to false attractant flows and delay fish from finding the correct entrance (Harris *et al.* 1998). Similarly, water used to provide attractant flows must be



managed to provide the right cues for migration and spawning, or the structure (although having the physical capacity to move fish) will remain inhibitive to fish movement (Mallen-Cooper 1994). In the case of wetland inlets where there is a head difference between the inlet and outlet it would be possible to create attractant flows to encourage fish movement out of the wetland before a drying cycle was to proceed.

It is important to manage structures correctly over a range of flow conditions, and ensure fish passage (if required) is possible over the full range (Mallen-Cooper 1992). Once a structure is "drowned-out" management of the structure is not possible. It must be ensured therefore that the structure itself does not form an obstruction during this time (Mallen-Cooper and Harris 1992). Regular maintenance of the structures and fish screens will also minimise problems with debris collecting within or in front of flow control structures and effectively blocking fish access (Northcote, 1998).

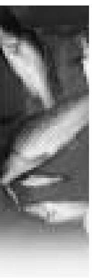
2. Fish Control Structures

Fish control structures (screen gates that attach to the flow control structures) have been used in wetland rehabilitation projects over the last 10 years to control the movement of large, breeding sized carp into wetlands in the Lower Murray. Very little research has been undertaken to determine the best options for designing these gates. Assessment of the size, shape and orientation of the mesh that would best prevent the passage of large carp is required to further refine their design and minimise the impacts on large native fish who, by default, are also excluded. Current management involves setting the structures in place and leaving them for the duration of wetland opening until river flows increase and native fish show signs of movement.

There have been no published data within Australia and few studies are cited in overseas literature on the effects of fish control screens on native fish populations. In the United States one study investigated the use of three different screen types: circular, rectangular and vertical bar grates to limit carp access, whilst allowing Northern Pike (*Esox lucius*) access to a waterway (French *et al.* 1999). It was noted during the study that the carp were able to compress their abdomens to allow passage through circular openings smaller than their height, and pass though rectangular grates by swimming diagonally (French *et al.* 1999). It was indicated that vertical bar grates were the most successful for carp exclusion, as it appeared that the size of the fish's head was the restrictive factor in their movement (French *et al.* 1999). These findings have implications for the design of new fish control structures on River Murray wetland inlets, although it must be ensured that native fish are not further disadvantaged by their use. Similarly, changes to the way the screens are managed may provide further options for carp control.

It can therefore be acknowledged that our basic knowledge of habitat use by Australian native fish, and of species introduced into the Australian system, needs to be improved dramatically. The impacts of large mainstream structures on fish movement and migration within the main river channel are beginning to be addressed through the installation of fishways or differing management protocol to enhance movement.

Similar moves are required to determine the impacts of flow control structures on fish access to these areas. Through monitoring fish movement at various locations, and at different structure types, better management and construction techniques can be developed to minimise the impacts of wetland rehabilitation projects on the native fish fauna whilst simultaneously controlling introduced species.



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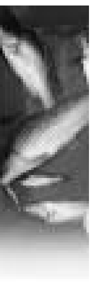

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Appendix B. GPS location of nets.

Lake Littra

SITE	NET	EASTING	NORTHING
Lake Littra (Punkah Creek)	1	499717	6244214
Lake Littra (Punkah Creek)	2	499650	6244188
Lake Littra (Punkah Creek)	3	499468	6244165
Lake Littra (Punkah Creek)	4	499397	6244165
Lake Littra Inlet (mouth)	*none*	*499599*	*6244213*
Lake Littra Inlet (creek side)	5	500112	6244355
Lake Littra Inlet (creek side)	6	500107	6244349
Lake Littra structure	7 or 8	500107	6244363
Lake Littra Inlet (wetland side)	9	500107	6244374
Lake Littra Inlet (wetland side)	10	500102	6244374
Lake Littra wetland	11	499997	6244535
Lake Littra wetland	12	499897	6244553
Lake Littra wetland	13	499738	6245686
Lake Littra wetland	14	500102	6245456

Werta Wert Lagoons

SITE	NET	EASTING	NORTHING
Werta Wert Creek (Monoman)	1	488756	6243583
Werta Wert Creek (Monoman)	2	488791	6243509
Werta Wert Creek (Monoman)	3	488795	6243375
Werta Wert Creek (Monoman)	4	488696	6243311
Werta Wert Inlet (mouth)	*none*	*488776*	*6243467*
Werta Wert Inlet (creek side)	5	488628	6243681
Werta Wert Inlet (creek side)	6	488621	6243676
Werta Wert structure	none	488621	6243683
Werta Wert Inlet (wetland side)	7	488615	6243694
Werta Wert Inlet (wetland side)	8	488607	6243688
Werta Wert wetland	9	488093	6245136
Werta Wert wetland	10	487989	6245182
Werta Wert wetland	11	488027	6245322
Werta Wert wetland	12	488199	6245383

Chowilla Oxbow

SITE	NET	EASTING	NORTHING
Chowilla Oxbow creek (Chowilla)	1	487315	6239089
Chowilla Oxbow creek (Chowilla)	2	487412	6239082
Chowilla Oxbow creek (Chowilla)	3	487372	6238700
Chowilla Oxbow creek (Chowilla)	4	487292	6238467
Chowilla Oxbow inlet	5	487466	6239000
Chowilla Oxbow inlet	6	487476	6238999
Chowilla Oxbow wetland	7	487643	6238971
Chowilla Oxbow wetland	8	487813	6239021
Chowilla Oxbow wetland	9	487915	6239044
Chowilla Oxbow wetland	10	487673	6238942

Pilby Creek Lagoon

SITE	NET	EASTING	NORTHING
Pilby Lagoon River	1	492492	6241411
Pilby Lagoon River	2	492660	6241283
Pilby Lagoon River	3	492846	6240744
Pilby Lagoon River	4	492710	6240697
Pilby Inlet Mouth	none	490373	6239833
Pilby Inlet River side	5	490119	6239488
Pilby Inlet River side	6	490129	6239474
Pilby inlet structure	7 or 8	490094	6239473
Pilby Inlet Wetland side	9	490062	6239483
Pilby Inlet Wetland side	10	490072	6239466
Pilby Wetland	11	489885	6239230
Pilby Wetland	12	489899	6239004
Pilby Wetland	13	489764	6238917
Pilby Wetland	14	489733	6239188
Pilby Outlet	15	489670	6239334
Pilby Outlet	16	489683	6239341
Pilby Outlet structure	none	489660	6239381

Lake Merreti

SITE	NET	EASTING	NORTHING
Ral Ral Creek (perm inlet)	1	477114	6233273
Ral Ral Creek (perm inlet)	2	477100	6233220
Ral Ral Creek (perm inlet)	3	476971	6233203
Ral Ral Creek (perm inlet)	4	476931	6233205
Merreti perm inlet (creek side)	5	477044	6233240
Merreti perm inlet (creek side)	6	477036	6233238
Merreti permanent structure	7	477046	6233260
Merreti perm inlet (wetland side)	8	477035	6233338
Merreti perm inlet (wetland side)	9	477028	6233354
Merreti wetland	10	477244	6234843
Merreti wetland	11	477257	6235600
Merreti wetland	12	478168	6235590
Merreti wetland	13	477982	6234707

Lake Merreti upstream inlets

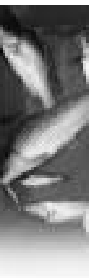
SITE	NET	EASTING	NORTHING
Ral Ral Creek (temp inlet)	1	478913	6232512
Ral Ral Creek (temp inlet)	3	478850	6232557
Merreti top inlet (mouth)	*none*	*478868*	*6232542*
Merreti top temp inlet (ck side)	5	478875	6232567
Merreti top temp inlet (ck side)	6	478873	6232578
Merreti top temp inlet structure	7	478877	6232586

Gurra Control Wetland

SITE	NET	EASTING	NORTHING
Gurra Creek	1	463068	6202579
Gurra Creek	2	463125	6202490
Gurra Creek	3	463070	6203262
Gurra Creek	4	463046	6203168
Gurra Control Inlet	1	463169	6202216
Gurra Control Inlet	2	463155	6202257
Gurra Control wetland	3	463216	6202235
Gurra Control wetland	4	463352	6202054
Gurra Control wetland	5	463289	6202111
Gurra Control wetland	6	463213	6202185

Little Duck Lagoon

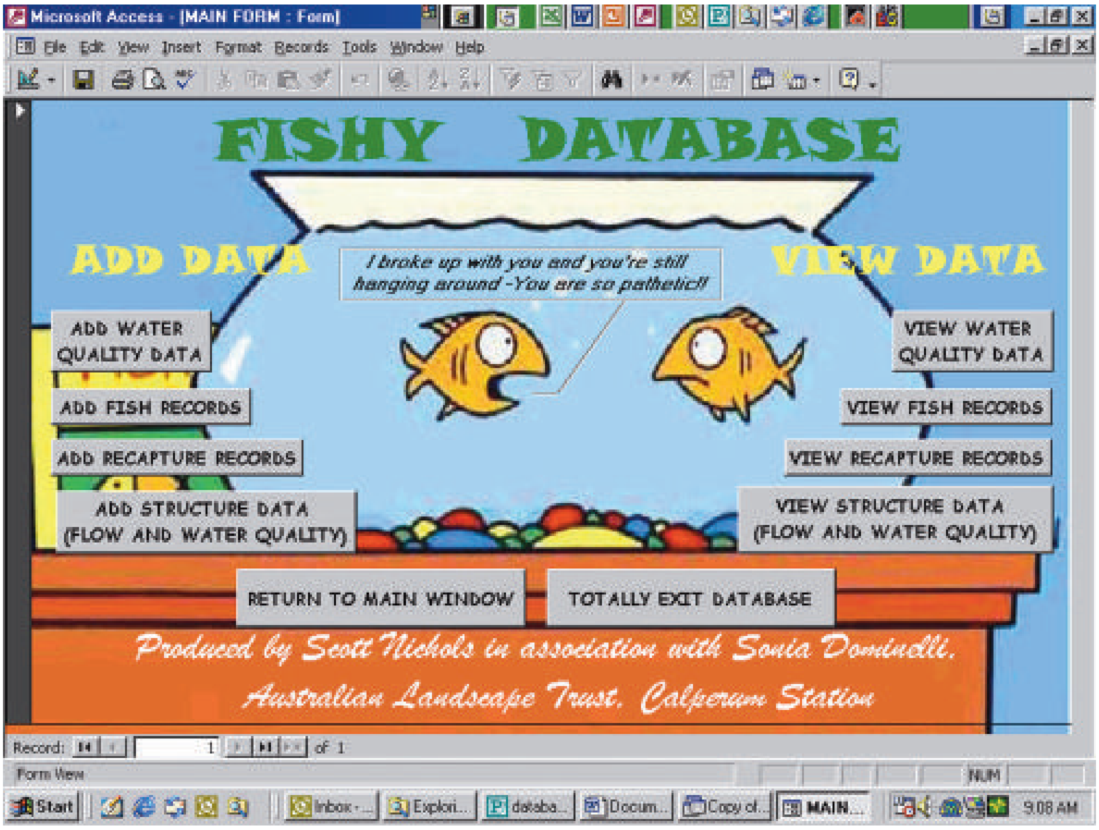
SITE	NET	EASTING	NORTHING
Gurra Creek nets (as above)	*as above*	*as above*	*as above*
Little Duck Inlet (creek side)	5	462808	6203291
Little Duck Inlet (creek side)	6	462808	6203291
Little Duck structure	7 or 8	462790	6203305
Little Duck Inlet (wetland side)	9	462809	6203321
Little Duck Inlet (wetland side)	10	462779	6203308
Little Duck wetland	11	462647	6203422
Little Duck wetland	12	462549	6203572
Little Duck wetland	13	462544	6203612
Little Duck wetland	14	462689	6203499

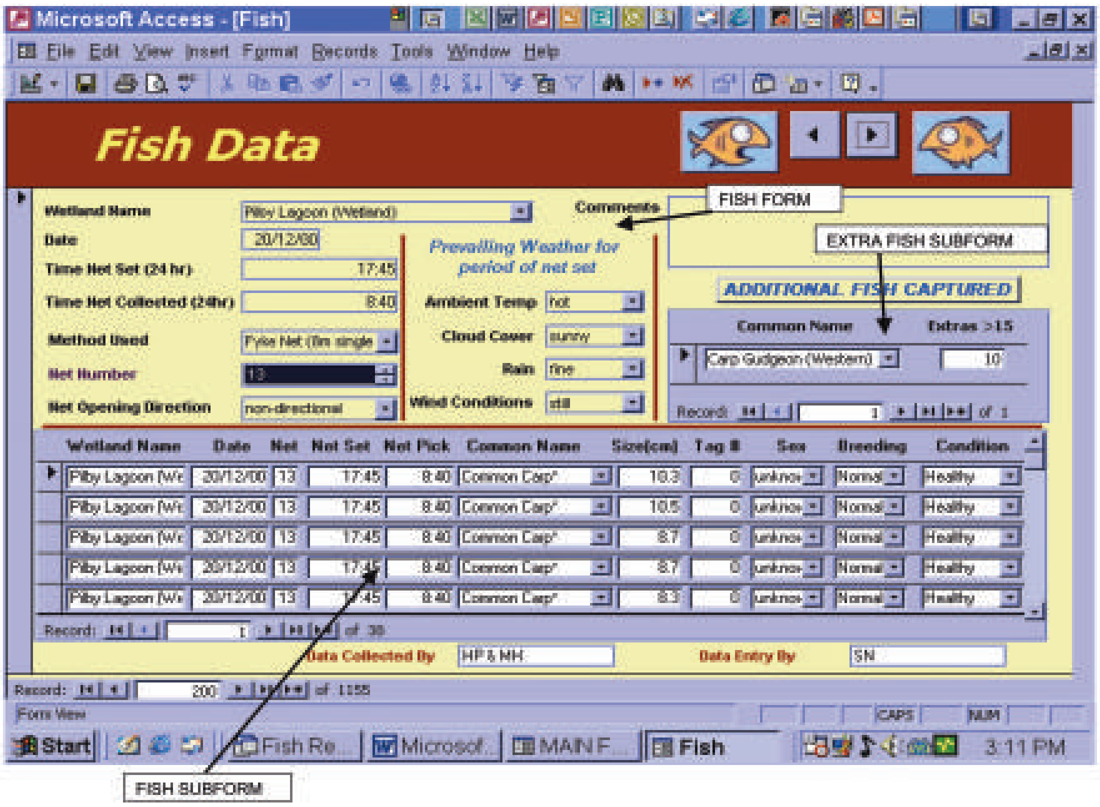


Loveday Wetlands

SITE	NET	EASTING	NORTHING
Loveday River	1	443524	6208511
Loveday River	2	443597	6208319
Loveday River	3	443804	6208195
Loveday River	4	443963	6208295
Loveday Inlet (creek side)	5	443666	6208066
Loveday Inlet (creek side)	6	443657	6208061
Loveday structure	none	443657	6208049
Loveday Inlet (wetland side)	9	443660	6208028
Loveday Inlet (wetland side)	10	443668	6208031
Loveday wetland	11	443717	6207912
Loveday wetland	12	443809	6207858
Loveday wetland	13	443887	6207706
Loveday wetland	14	443636	6207867

Appendix C. Entry pages for Access database.





Appendices

DATA FROM THE ABOVE FORM IS STORED IN 3 SEPARATE TABLES THAT ARE LINKED BY WETLAND NAME, DATE, NET NUMBER & TIME OF NET SET AND COLLECTION.

THE FOLLOWING IS AN EXAMPLE OF HOW THE DATA SHOWN IN THE ABOVE FORM IS STORED IN THE TABLES.

FISH FORM:

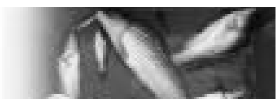
Wetland Name	Date	Time Net Set	Time Net Collected	Net Number	Net Opening Direction	Method	Comments	Ambient Temperature	Cloud Cover	Rain	Wind Conditions	Data Entry By	Data Collected By
Pilby Lagoon (Wetland)	20/12/00	17:45	8:40	13	non-directional	1		hot	sunny	fine	still	SN	HP & MH

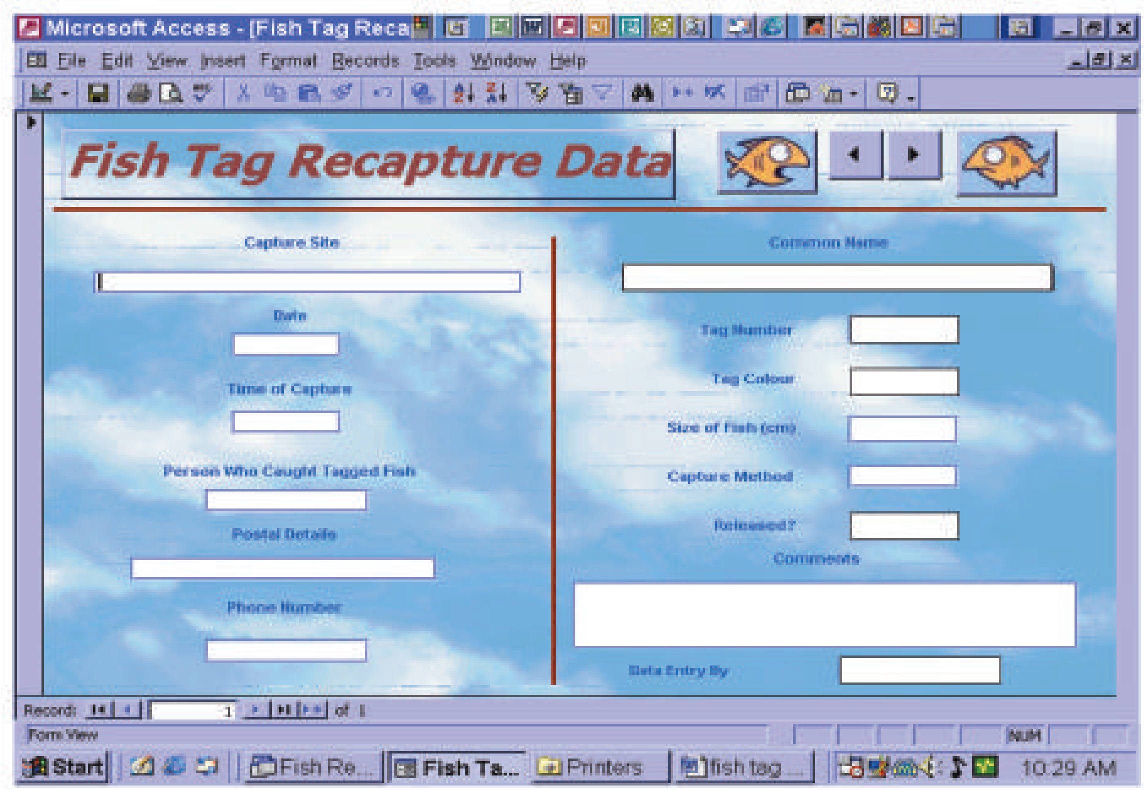
FISH SUBFORM:

Wetland Name	Date	Net Number	Time Net Set	Time Net Collected	Common Name	Size	Tag #	Breeding ?	Sex	General Condition
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Common Carp*	9.50	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Common Carp*	10.00	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Carp Gudgeon (Western)	4.50	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Carp Gudgeon (Midgely's)	4.20	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Flathead Gudgeon	4.20	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Carp Gudgeon (Midgely's)	2.90	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Common Carp*	9.60	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Common Carp*	6.00	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Common Carp*	11.10	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Goldfish*	15.00	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Fly Specked Hardy Head	4.20	0	Normal	unknown	Healthy
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Carp Gudgeon (Midgely's)	3.90	0	Normal	unknown	Healthy

EXTRA FISH SUBFORM:

Wetland Name	Date	Net Number	Time Net Set	Time Net Collected	Common Name	Extras
Pilby Lagoon (Wetland)	20/12/00	13	17:45	8:40	Carp Gudgeon (Western)	10
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Common Carp*	11
Pilby Lagoon (Wetland)	20/12/00	14	17:40	8:10	Carp Gudgeon (Western)	28





Microsoft Access - [Fish Tag Reca
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Fish Tag Recapture Data
Capture Site
Date
Time of Capture
Person Who Caught Tagged Fish
Postal Details
Phone Number
Common Name
Tag Number
Tag Colour
Size of Fish (cm)
Capture Method
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Data Entry By
Record: 1 of 1
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fish tag ...
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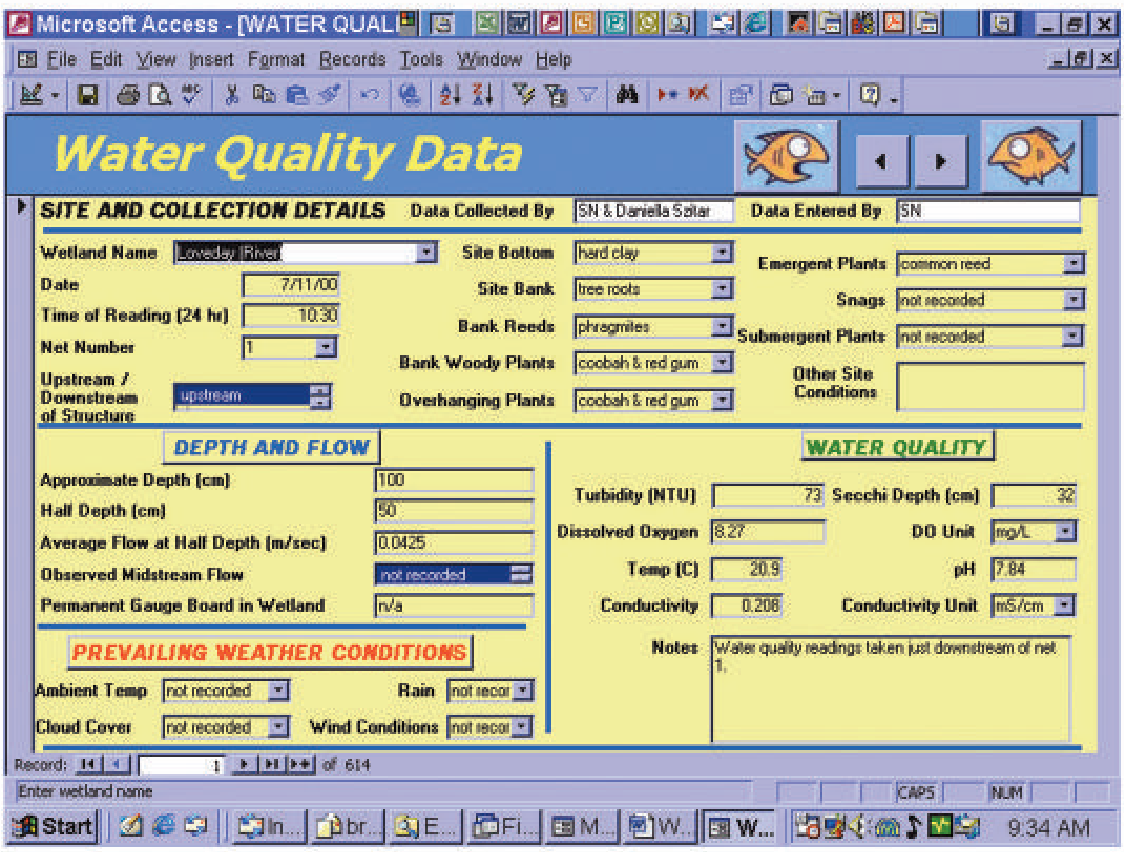

Microsoft Access - [WATER QUALI
File Edit View Insert Format Records Tools Window Help
Water Quality Data
SITE AND COLLECTION DETAILS
Data Collected By
SN & Daniella Szilar
Data Entered By
SN
Wetland Name
Loveday River
Date
7/11/00
Time of Reading (24 hr)
10:30
Net Number
1
Upstream / Downstream of Structure
upstream
Site Bottom
hard clay
Site Bank
tree roots
Bank Reeds
phragmites
Bank Woody Plants
coobah & red gum
Overhanging Plants
coobah & red gum
Emergent Plants
common reed
Snags
not recorded
Submergent Plants
not recorded
Other Site Conditions
DEPTH AND FLOW
Approximate Depth (cm)
100
Half Depth (cm)
50
Average Flow at Half Depth (m/sec)
0.0425
Observed Midstream Flow
not recorded
Permanent Gauge Board in Wetland
n/a
PREVAILING WEATHER CONDITIONS
Ambient Temp
not recorded
Rain
not recor
Cloud Cover
not recorded
Wind Conditions
not recor
WATER QUALITY
Turbidity (NTU)
73
Secchi Depth (cm)
32
Dissolved Oxygen
8.27
DO Unit
mg/L
Temp (C)
20.9
pH
7.84
Conductivity
0.208
Conductivity Unit
mS/cm
Notes
Water quality readings taken just downstream of net 1.
Record: 1 of 614
Enter wetland name
CAPS
NUM
Start
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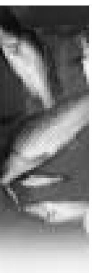

Appendix D. Engineering student's journal papers

Year 2000 students: David Murchland, Kane Scott, Shannon Dooland, Jonathan Giesecke, supervised by Martin F. Lambert and Keith F. Walker.

A ten-year record of fish passage at the Lock 6 fishway, River Murray, SA.

David Murchland[1,3], Kane Scott[1,4], Shannon Dooland[1,5], Jonathan Giesecke[1,6], Martin F. Lambert[1] and Keith F. Walker[2]

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[6]Present address:

Abstract
Records from the Lock 6 fishway, on the River Murray near Renmark, South Australia, identified differences in the environmental factors affecting fish movement at the fishway. The movement at the fishway of native species callop (or golden perch: *Macquaria ambigua*) and silver perch (*Bidyanus bidyanus*), and the alien carp (*Cyprinus carpio*) seems related to spawning and therefore to the movement of each species into riverine wetlands. Carp were found to be active only until December, whereas the native fish activity was centred around January. The influences of other factors including water temperature, flow, and fluctuations in water temperature and level were considered. Management recommendations for managed wetland inlets in the region were made with regard to the times of year at which screens should be employed.

KEYWORDS: migration, fish, carp, callop, silver perch, weir, wetland, river, Murray-Darling Basin

Wetland flow control and fish exclusion structures on the River Murray, SA.

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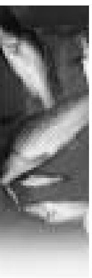
Abstract

Wetland inlet structures are located on a number of wetlands along the River Murray to exclude the common carp (*Cyprinus carpio*) and to manage a simulated flooding and drying regime that would otherwise be permanently inundated in an effort to promote the re-establishment of natural wetland ecosystems. Existing structures exclude all fish and have maximum filling velocities in the order of 1.9m/s.

Fish exclusion screens on these structures restrict the access of both native and exotic fish species to the wetlands. Management of the screens so that they are in place during times of high carp activity, and removed when native fish movements are greatest may serve to further promote a truly natural wetland ecosystem.

Filling velocities, obtained through hydraulic analysis of a structure at Causeway Lagoon, should be slowed to reduce the amount of carp entering the wetland. Existing structures can be modified to reduce filling velocities by varying the structure materials and finish, or by artificially increasing the downstream water depth. In addition to these measures, future structure should be constructed with a mild slope to reduce filling velocities. Velocities may also be reduce by undertaking the filling at low river levels.

KEYWORDS: wetland, fish, exclusion, carp, circular culverts, Murray-Darling Basin



Swimming behaviour of common carp (*Cyprinus carpio*) in relation to wetland inlets on the River Murray, SA.

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Abstract

The swimming ability of carp was examined with regard for ways to discourage access to wetlands linked to the River Murray via low-level flow regulators. Carp of 302±94 mm total length (TL) had a burst speed of 2.6 m s^{-1}, and their maximum escape velocity was a function of body length. Carp of 250-400 mm TL jump to heights of about their body length, given a similar water depth. Jumping is non-directional, and is encouraged by turbulence associated with high flows. The fish face into an induced flow and endeavour to swim against the current, but their endurance is limited. They are hesitant to leave darkened areas when presented with a dark/light boundary, but they are gregarious, at least under laboratory conditions, and individuals may excite groups of fish to act in unison. Some wetland inlets on the Murray consist of single or multiple culverts that would discourage carp migration under moderate flow rates. Carp appear to be indifferent to the presence of coarse rocky substrata near the entrances to culverts. The optimal configuration to discourage carp access to wetlands is to employ a filling velocity of 0.4m/s, and to employ shallow, open topped box culverts that allow light to penetrate the entire water column. Turbulent conditions should be avoided during filling, and fish screens (diamond grille 100x35mm) should be employed at all regulated inlets, extending 400mm above the inlet water surface.

KEYWORDS: carp, Cyprinidae, burst speed, swimming behaviour, fish passage, fishways, fish attractors, Murray-Darling Basin

Year 2001 students: Timothy Champion, James Cox, Amy Ide, and Nadine Kelly, supervised by Martin F. Lambert and Keith F. Walker.

Species-specific barriers: the response of carp (*Cyprinus carpio*) to behavioural deterrents.

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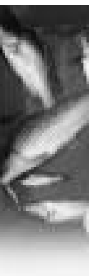
Abstract

Carp are responsible for degradation of riverine wetlands. Current exclusion devices consist of mesh screens that physically exclude all fish, including natives. We investigated behavioural responses of carp to light, sound, a bubble curtain, and a half barrier in the laboratory, as an alternative means of excluding them from wetlands. A well-lit culvert entrance acted as a deterrent to carp passage, rather than a barrier. Carp responses to a speaker emitting frequencies of 5-1000 Hz indicated that sound of 20 Hz is a deterrent. Bubbles significantly reduced carp movement through the culvert and a half barrier completely stopped them. Field studies are required to assess the effectiveness of these barriers in excluding carp from entering wetlands, while still allowing native fish access.

KEYWORDS: behavioural barriers, fish deterrents, species-specific, carp, acoustic, light, hearing, bubble curtain, wetland, Murray, culverts.



Environmental conditions affecting migration of carp (*Cyprinus carpio*) and callop (*Macquaria ambigua*) through Lock 6 fishway, SA.

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Abstract
Migration of fish through river systems is well known, and many fishways have been built in the River Murray to reduce the impact of weirs on migratory paths. The introduced carp which can account for up to 90% of the fish biomass in some parts of the Murray-Darling basin, has a devastating effect on riverine wetlands, by uprooting native aquatic plants and displacing native fish. In this study daily data on fish movement, flow and temperature form Lock 6 fishway were analysed in an attempt to differentiate between the migration cues of carp, and the native fish callop. It was found that carp migrate on an annual basis, stimulated by a rise in water temperature, and that the migrations probably related to spawning, but rather driven by a need to disperse and colonise. In contrast, the migration of callop is not an annual event, but is initiated by a rise in water levels, particularly floods, and is related to spawning. The relationship between migration upstream and into riverine wetlands for these fish is not clear. Further research is needed in this area to enable wetland managers to reduce the impacts of carp on wetlands, while not severely restricting access to callop.

KEYWORDS: migration, fish, carp, callop, golden perch, *Cyprinus carpio*, *Macquaria ambigua*, spawning, colonisation, fishway, fish passage, wetland, Murray, river.