Baseline Trials of Carp Control Technologies in Wetlands of the Lower Lachlan River

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Executive Summary

Since the 1970's, European carp have become established as the dominant large bodied fish species across the Murray-Darling basin. Control of this pest species has been identified as a natural resource management priority reflected in catchment, basin, state and federal plans and legislation. Both the Lachlan Catchment Management Authority (LCMA) and the Invasive Animals Cooperative Research Centre (IA CRC) have committed to exploring technologies and methodologies for maximising the physical removal of carp.

This project outlines the first steps in exploring control technologies targeted to specific hot-spot wetlands, where carp are known to breed in large numbers and contribute disproportionally high numbers to the overall catchment population. In particular, the use of carp separation cages (CSCs) and the role of flow in the control of carp were explored within key wetlands of the Lower Lachlan River catchment. This project applied developmental wetland specific carp separation cage designs and strategies to demonstrate their applicability to wetland carp control programs.

An extensive field trial was conducted over a three week period in Spring 2007 with demonstration trials run at Lake Cargelligo, Lake Brewster and the Great Cumbung Swamp. Prototype CSCs and finger style cages, developed under the IA CRC's Freshwater Products and Strategies Program, were tested within inlet and outlet channels at Lake Cargelligo and Lake Brewster with channel flows manipulated after installation in an attempt to stimulate aggregation and spawning migration behaviours. In the Great Cumbung Swamp where flow regulation was not possible, cross country stimulus flows were experimentally applied through constructed bays designed to entice carp from the river into CSCs.

Whilst no carp moved into traps during no-flow periods, stimulus flows resulted in carp movement and the development of spawning activity. However, in contrast to the large migratory aggregations witnessed in the River Murray and other wetland channels, carp responded by forming small aggregations and spawning over local habitat rather moving en-mass into or out of the filling wetland. It was concluded that this behavioural reaction represented a 'low flow' spawning response that may be typical under low flows during drought periods. Therefore bigger migrational aggregations, targeted for large scale carp control actions, may require larger flow events as stimuli.

Results from the Cumbung Swamp re-enforced the need for large flows to attract and aggregate carp. As a result, the application of CSC and other carp trapping technologies must be integrated carefully with flow management to ensure that large aggregations and directional migrations can be stimulated. Equally, cages and traps must be carefully positioned to intercept such movements under relatively high flow conditions.

In addition, the trials found that carp were not likely to use the CSC jumping facility when moving with flow into wetland inlets. A novel 'turn-around' CSC design was trialled to address this problem during a wetland filling at Brenda Park wetland in South Australia. However, the timing of wetland filling resulted in low numbers of carp entering the wetland and the effectiveness of the turnaround facility was not comprehensively assessed. Other data including native fish patterns, auditory cues and an exploration of the commercial utilisation of CSCs were also collected during the trials. The project has resulted in the further refinement of CSC technologies for wetland applications and paves the way for more dedicated control activities targeting carp hot-spot wetlands.

Acknowledgements

This work represents contributions from a wide range of researchers, management, stakeholders, partners and community members, all of whom contributed greatly to the design and delivery of project components and ideas. The authors would like to thank Alan McGufficke, Michelle Jefferies, Chris Glennon and board members from the Lachlan Catchment Management Authority (CMA) for supporting and driving this project from its inception and Steven Lapidge of the Invasive Animals Cooperative Research Centre (IA CRC) for committing to the Lachlan project as the demonstration reach for freshwater pest control.

Field work was carried out by a large collaborative group (Figure 1) consisting of staff from South Australian Research and Development Institute (SARDI), New South Wales Department of Primary Industries (NSW DPI), Kingfisher Research, K&C Fisheries Global, State Water, the Lachlan Catchment Management Authority (LCMA) and the Lachlan Aboriginal Natural Resource Management Group. State Water also provided accommodation at Lake Brewster and generous use of an excavator and operator for the Lake Cargelligo and Lake Brewster sites. The authors acknowledge the significant contributions of Glen McRielly, Keith Bell, Chopper, George, Marlo (not Marlo), Jack, the late great Eddie, Spook, Stan, Ben Smith, Leroy Thwaites, and Cameron McGregor to the field program. Jonno MacLean provided significant support to the Great Cumbung Swamp experiment and provided earth moving equipment and time to the construction of off-channel bays. Katherine Cheshire provided excellent improvements to drafts of the manuscript.

Figure 1. Members of the project field team at Lake Brewster including representatives from SARDI, NSW DPI, Kingfisher Research, K&C Global, LCMA, State Water, Adelaide University and LAMRAG.

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Chapter 1: Trialling Carp Control in the Lower Lachlan

1.1 Introduction

Carp in the Lachlan

Carp are the world's worst invasive species (Stuart *et al*. 2006a) and their range continues to expand across every continent except Antarctica (Koehn 2004). In Australia, carp spread throughout the Murray-Darling Basin (MDB) during the 1970's and they now comprise the majority of fish biomass in many rivers throughout the Basin (Gehrke *et al.* 1995, MDBC 2004).

Carp are highly adaptable, tolerant of the harsh environmental conditions characteristic of Australia's inland waterways and are able to persist in warm, low oxygenated environments that are not suitable for many native fish species (McNeil 2004, McNeil and Closs 2007). They have contributed to the degradation of water quality and riverine/wetland condition across the MDB, they carry diseases and parasites and impact directly and indirectly on native fish species (Roberts *et al*. 1995, King *et. al.* 1997, Driver *et al.* 1997, Koehn *et al.* 2001, Koehn 2001, Driver 2002, Stuart and Jones 2002, Smith 2005). However, the level of impact directly attributable to carp is often difficult to determine from the broader impacts of anthropogenic disturbance related to flow regulation and habitat degradation (Roberts *et al*. 1995, King *et. al.* 1997, Smith 2005).

The highly regulated rivers of central NSW are considered the most severely impacted rivers from carp infestation (Gehrke and Harris 2001). The National Sustainable Rivers Audit (SRA) identified that the Lachlan River possessed the highest abundances of carp in the MDB (MDBC 2004) and high abundances and biomass of carp have been observed in riverine and wetland habitats of the lower Lachlan catchment during recent surveys (Kereszy 2005, McNeil *et al*. 2008). Large aggregations of carp have been reported at Lake Brewster (Keith Bell, K&C Fisheries pers. comm.) and Lake Cargelligo (The Area News, Feb 22, 2006), where large numbers of carp have been harvested by commercial fishermen (Whitehead and Pahlow 1997). The high abundances and biomass of carp has generated significant community concern across the Lachlan catchment and consequently, carp control has been identified as one of the principal pest management issues for this region (Lachlan Catchment Management Authority 2006).

1.2 Carp Control & Management

Since the 1970's there has been a continual effort to develop and coordinate comprehensive, consistent and effective carp management programs (VF&W 1976). In 2000, the Murray-Darling Basin Commission (MDBC) developed a National Management Strategy for Carp Control (CCCG 2000). This strategy highlighted directions for research and guidelines for ranking priority areas; with the aim of preventing the spread of carp, reducing their impacts, exploring eradication and control programs backed by pubic resources and improving community understanding of the pest issue. The CCCG has since been disbanded and there is no longer an action group (Smith 2005). The Invasive Animals Cooperative Research Centre (IA CRC) has since taken over coordinating and directing research into carp management and control. Despite carp control being on the agenda for natural resource management since the 1970's (VF&W 1976), few cost effective carp control techniques are available, with past control efforts being unsuccessful in controlling carp abundance and distribution of the pest (Koehn 2004, Stuart and Jones 2006a).

Considerable effort has been made investigating options for the control and/or eradication of carp from Australian waterways. Netting and chemical poisoning were traditionally utilised in the USA and were the first control methods considered by Australian fisheries managers (VF&W 1976). Other control options include the development of carp specific ichthyocides, viruses (i.e. Spring viraemia) and methods for manipulating spawning events and sterilising offspring through irradiation (VF&W 1976).

Recently, research has considered more long term control options such as daughterless gene technology and koi herpes virus (McColl *et al.* 2007). Whilst these technologies may be extremely effective; they are costly, will not be available for many decades and face considerable regulatory hurdles before they can be released into the wild (Smith 2005). Additionally, these technologies would be more effective if combined with the physical control of carp. Removal programs that reduce the carp population size are likely to facilitate resilience in native fish communities following bio-control actions (Gilligan *et al*. 2010).

Physical control of carp has also been researched and developed to varying degrees. Whilst commercial fishing has proven to be effective in removing large volumes of carp (≈76 tonnes), it is dependant on commercial market processes (Driver *et al*. 2005, Keith Bell - K&C Global pers. comm.). Additionally, the installation of steel mesh carp exclusion screens in wetland flow control structures to restrict access to spawning sites (French *et al.* 1999, Hillyard *et al.* 2010), electrical barriers to restrict movements (Verrill and Berry 1995), innovative jumping traps to target innate carp jumping behaviours (Williams' carp separation cages; Stuart *et al.* 2006a), carp push traps to exploit carps pushing behaviour (Thwaites *et al.* 2010) and water level manipulations have all been investigated and trialled. For example the use of water manipulation to inhibit carp spawning and to desiccate eggs following spawning events has been considered (Gawne *et al*. 1999). Although hydrological manipulation to desiccate eggs is likely to be a key component of carp control strategies, large scale hydrological manipulation is likely to impact on the spawning and recruitment of native fishes and is impractical as a broad scale control approach. It is also acknowledged that the optimal control of carp populations will rely on an integrated approach using multiple control techniques (Brown and Walker 2004).

1.3 Intercepting migrations; Hot-spots and CSCs

Innate behavioural traits of carp may be exploited to maximise the effectiveness of control efforts (Smith 2005). Carp display a number of innate behavioural traits not observed amongst large bodied native fish in the MDB; such as the formation of large spawning shoals that migrate upstream or into wetlands via channels from the main river (Stuart and Jones 2002, Jones and Stuart 2007, 2008). These aggregations have been utilised by commercial fisherman since the 1970's with up to 76 tonnes removed from a single wetland (Driver *et al*. 2005, Keith Bell - K&C Global pers. comm.).

Upstream migrations of large shoals of carp accumulated downstream of Murray River weirs and carp moved upstream through the boat locks and by utilising new fishway structures (Mallen-Cooper 1999, Stuart and Jones 2002, Stuart e*t. al*. 2006a & b). Large spawning aggregations were also observed to occur in and around large floodplain lakes such as Moira Lake and Barmah Lake in the Barmah-Millewa forest region of the Murray River (Stuart and Jones 2002). These wetlands were identified as carp recruitment *hot spots*, as they contributed disproportionately large numbers of larval and juvenile carp into the overall population (Stuart and Jones 2002, 2006a & b; Crook and Gillanders 2006).

Interception of migrating carp through fishways and at wetland hot spots has become a key focus of control technologies and strategies for physical control and removal (Smith 2005). Initial research investigated the feasibility of trapping carp migrating through Murray River fishways, which led to the development of the Williams' Carp Separation Cage (CSC) (Stuart *et al.* 2006a & b). This approach incorporates two innate behaviours; the formation of large migratory aggregations, and the tendency for carp to jump over barriers to upstream migration. The CSC design allows carp to jump upstream over a barrier into a separate holding cage; native fish can be effectively separated as they remain in the original downstream trap. This trap can then be automatically emptied beneath the carp holding cage to allow the free upstream passage of native fishes. The carp can then be removed from their cage, utilised for commercial purposes and the system reset (Figure 2).

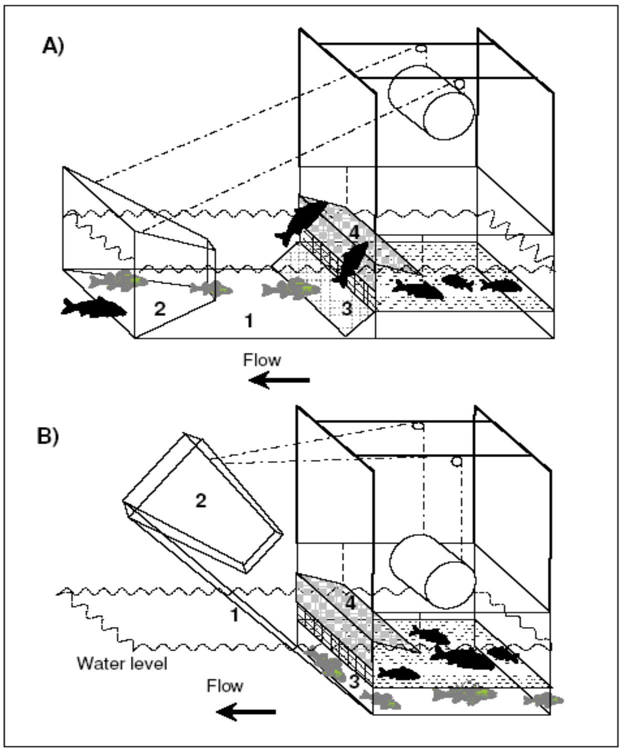


Figure 2. Illustration of the Williams' cage showing; A) the operating position used to catch and separate jumping carp (black fish symbols) and non-jumping Australian native fishes (grey fish symbols), and B) the raised position. The following elements are illustrated in each panel: 1) false lifting floor; 2) cone trap; 3) native fish exit gate; 4) non-return slide. For clarity, all mesh coverings are excluded from the diagram (from Stuart et al. 2006a).

Trials of this technology revealed that CSCs in river fishways could effectively remove up to 88% of trapped carp whilst allowing free passage to 99.9% of native fish (Stuart and Jones 2006b). More recent trials on the Murray River at Lock and Weir 1 have been incredibly successful with the CSC removing 28,000 carp (over 70 tonnes) during an 18 month period from December 2007 (Conallin *et al.* 2008).

The application of CSC's for managing carp around wetland hot spots has been acknowledged (Stuart *et al.* 2006a). Furthermore, this approach may be useful in controlling carp populations in large wetlands (such as the Great Cumbung Swamp [GCS] in the Lachlan catchment) (Driver *et al.* 2005, Smith 2005). However, the application of these technologies has only recently been trialled in river fishways, and is yet to be applied to and tested in wetlands.

These technologies are likely to be adaptable in non-riverine situations. Targeting carp aggregations moving into and out of wetlands during spawning migrations may effectively remove spawning and recruitment hot spots. If hot-spots could indeed be shut down by capturing and removing adult spawning migrations the control of key hot spot habitats may provide an excellent strategic tool for managers to implement the physical removal of carp at large scales, reducing the overall abundance of carp systematically throughout a catchment. This approach requires the targeted capture and removal of carp at hot spots, which can effectively be carried out with non-selective trapping or screening technologies (Smith 2005). However these methods do not address the issue of maintaining access to these habitats for native fish, which have overlapping spawning and migratory behaviours (Stuart *et al.* 2006a & b).

The specific advantage of CSCs over traditional trapping methods is that they allow the free passage of almost all native fish whilst maintaining the ability to capture and remove the majority of adult carp (Stuart *et al.* 2006a & b). Consequently enhancing the benefits of wetlands to native fish biodiversity and ecology, by providing ease of access and reducing competition for spawning, larval and juvenile resources in relatively carp free nursery areas. Thus, CSCs combine carp control with the improvement of native fish conservation and enhancement and therefore represent multiple outcomes for natural resource investment.

The aim of this research is to test and assess carp control methodologies currently available at a relevant management scale. The principal aim is to provide a baseline trial of these carp control methodologies and technologies to identified wetland hot spots in the lower Lachlan catchment. This report presents the outcomes of these trials and discusses the results in the context of developing a comprehensive implementation program to demonstrate methodologies for physical carp control in the lower Lachlan.

Specifically this research aims to:

- Test/evaluate current CSC designs to target carp in wetland inlet and outlet channels
- Investigate modifications to improve the utility of CSCs in wetland application
- Trial different approaches and attractant strategies to enhance CSC function
- Investigate the use of wetland channels for spawning and recruitment of carp
- Report on the utility of CSC designs to wetland applications

1.2. General Methods

To address these aims, field trials were carried out at three key sights in the lower Lachlan Catchment; Lake Cargelligo, Lake Brewster and the Great Cumbung Swamp (Figure 3). Field work was carried out by a large collaborative group and trials were run in close coordination with State Water operations so that regulator testing and channel operations were coordinated as much as possible with the flow requirements of the field trials. This allowed for a detailed investigation of the role of channel flows in carp control.

Field assessments were carried out during spring 2007 with approximately one week of fieldwork undertaken at each site. Further trials were conducted at Brenda Park wetland in the Lower Murray River due to the absence of flows in the Lachlan catchment and the rare allocation of water provisions for wetland filling during the prevailing drought conditions. Site details and site-specific trial methods are outlined in detail in the following section.

1.2.1 Williams' Carp Separation Cage

Prototype CSCs (Figure 4) were constructed from 6 x 50 mm aluminium angle and covered with two layers of 40 mm aluminium security grill to create a mesh diameter of approximately 20 mm. The cages were 3 m long, 1.4 m wide and 1.4 m high and were split into equal front and rear sections by an adjustable jumping baffle. The first compartment (*entrance trap*) incorporated a square funnel, 0.7 m high x 1.4 m wide at the entry tapering to 0.4 m square over 0.75 m to the exit into the middle of the entrance chamber. The jumping baffle separated the entrance and collecting cages and was adjustable to suit changing water levels. During trials the baffle was set at ~0.15 m above the water level to maximise carp jumping success without risk of native fish violating the barrier. A pushing trap feature (Figure 5) was also incorporated in this design enabling pushing fish to be collected in a separate collection trap. This feature could be turned on or off and was activated as needed (Thwaites *et al.* 2010).

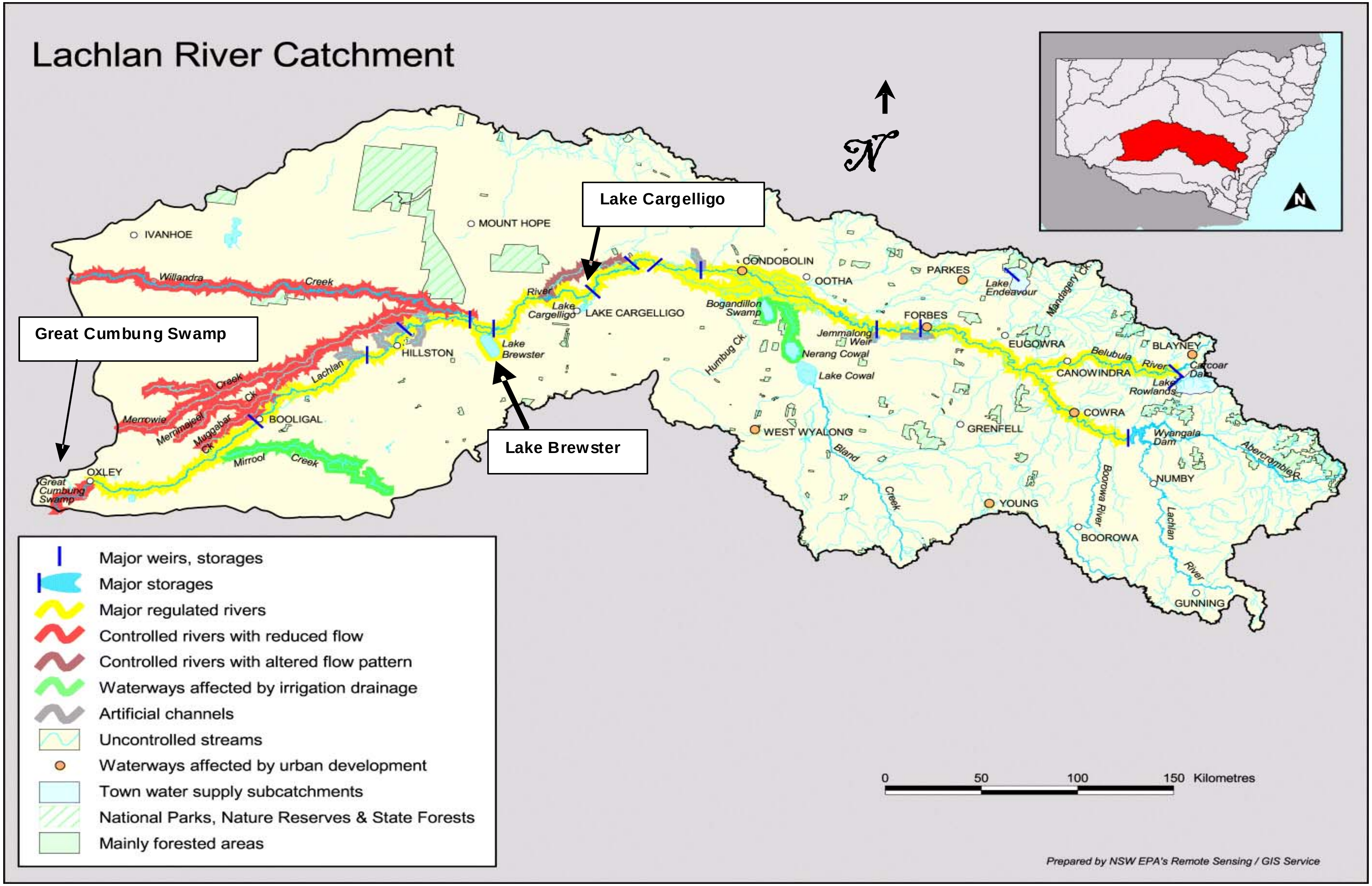


Figure 3. Lachlan catchment showing sampling sites, waterways, flow management areas and major catchment features.

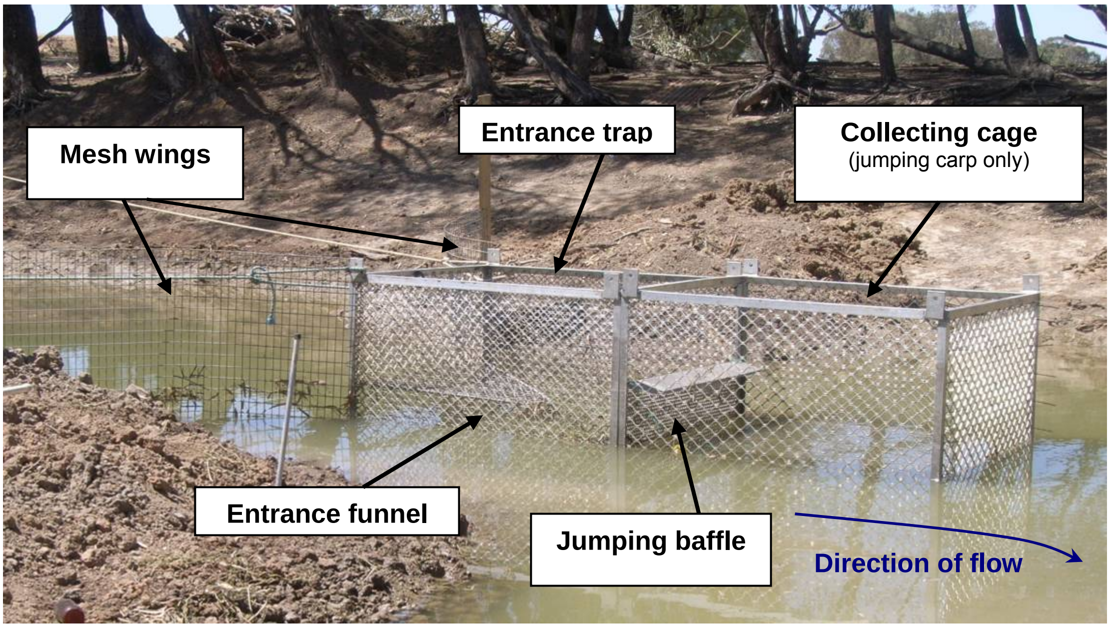


Figure 4. Prototype Williams' Carp Separation Cage used for wetland application trials; adapted from river fishway designs, showing main features. Fish are herded via mesh wings into the entrance funnel and are collected in the entrance trap. Jumping carp will leap over the adjustable jumping baffle and be collected within the collecting cage whilst non jumping natives (and carp) will be collected in the entrance trap. Not shown on this diagram is a pushing trap feature that was submerged beneath the collecting cage which captured pushing fish in a separate collecting cage (see Figure 8).

Figure 5. Finger style pushing trap component incorporated as an option into the prototype wetland CSCs used for the 2007 Lachlan catchment trials.

1.3 Trial Methods and Results by Site

1.3.1 Lake Cargelligo

Lake Cargelligo is situated in the mid-Lachlan River downstream of all major tributary inputs and covers ~1500 ha, holding 36,000 ML of water (Driver 2002). It was originally a natural ephemeral lake, but was regulated to act as an off channel storage in 1902 and it also serves as a recreational water body and town water supply. The lake has historically recorded seasonally poor water quality with high salinity, nutrient and turbidity loads and frequent blue-green algal blooms (Thurtell *et al.* 2003). It receives river flows following significant tributary inputs below Wyangala Dam, or after high volume storage is reached in the reservoir. Water is also provided for town water supply and to maintain the Lake level as an aesthetic and recreational resource for the township of Lake Cargelligo (Ned Hamilton; State Water pers. comm.). Flows enter Lake Cargelligo via a channel system that incorporates two large shallow lakes - Lake Curlew and Sheet of Water - interspersed with sections of channel (Figure 6).

Figure 6: Map of Lake Cargelligo and sampling sites.

Methodology

Lake Cargelligo was the first trial site and as such the key objective was to test the function of a prototype CSC in a wetland channel scenario. The study was aligned with State Water operations so that the CSC could be put into place within the inlet channel (upstream of Curlew Water) for 24 hours with zero flow in the channel. After the initial 24 hours, a small flow of less than 5ML/d was sent down the channel for a period of 72 h before the inlet regulator was closed and a further period of 24 h with very low flow ensued before the trial was stopped. This allowed fish movements and CSC function to be tested under simulated wetland filling conditions. The Lake Cargelligo study consisted of two sections.

The first involved the strategic setting of nets and a CSC to assess the movement of carp before during and after the experimental flow in the inlet channel. Netting stations were set for the entire trial period. The CSC was also trialled; initially catching carp moving upstream (consistent with the fishway CSC scenario) during the first day of flow before being turned to catch downstream moving carp on the second day of flow. Due to the very low numbers of carp moving into the CSC during the first two flow days, nets were set upstream and downstream of the CSC site and the CSC was instead used to experimentally test carp jumping behaviours in upstream versus downstream directions.

Fish Movements

Three experimental sites were selected in the Lake Cargelligo inlet system to gauge fish movement before, during and after the flow event. Netting stations were located: 1) downstream of the inlet regulator, 2) upstream of Lake Curlew and 3) midway between these sites (Figure 7 A & B). The two upstream sites utilised two double wing fyke nets set back to back to sample fish moving in either direction and were set for 24 hour periods, after which nets were checked, processed and all fish caught were identified, and recorded.

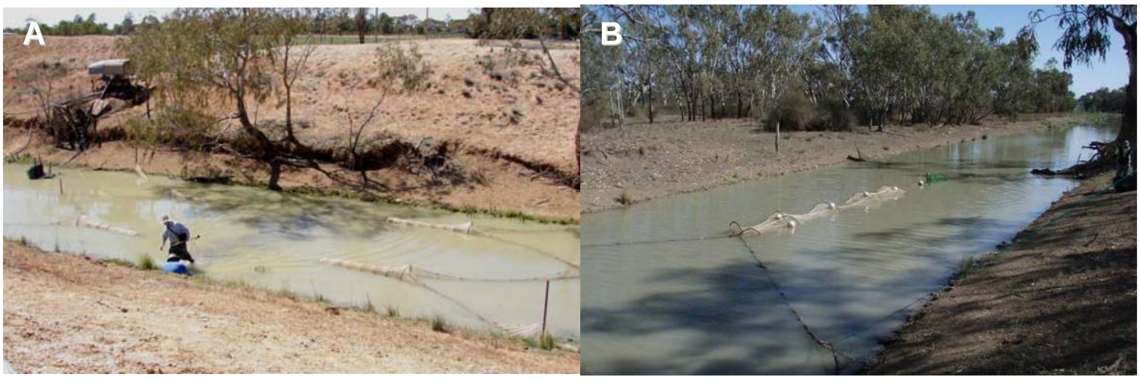


Figure 7. Lake Cargelligo inlet channel between Sheet of Water and Curlew Water with: A) a bi-direction station of four small mesh fykes sampling upstream and downstream movement: B) a bi-directional station of two single fyke nets sampling upstream and downstream movement.

CSC Trials

On the third and fourth days of the flow period, directional jumping experiments were conducted with the CSC lifted and turned to allow comparisons of jumping behaviour in upstream and downstream directions (Figure 8 A & B). Two upstream/downstream jumping experiments were run, the first lasting 8 hours (4 hours in each direction) and the second lasting 24 hours (12 hours in each direction).

Experiments involved placement of experimental carp in the entrance cage, with the number of carp jumping versus not jumping recorded at the end of the experimental period. The carp were then removed, the cage turned and a second set of experimental carp added to the entrance cage jumping in the opposite direction. On the third day of the flow period, 20 carp were used in the four hour trials, and nine carp were used for the 12 hour trials. On the fourth day of the flow period, 21 carp were used in the four hour trials, and 10 carp were used for the 12 hour trials. The uneven numbers occurred because freshly caught carp were used for each experimental trial and number of carp caught varied. Carp were collected from netting sites (3 & 4) and transported to the CSC.

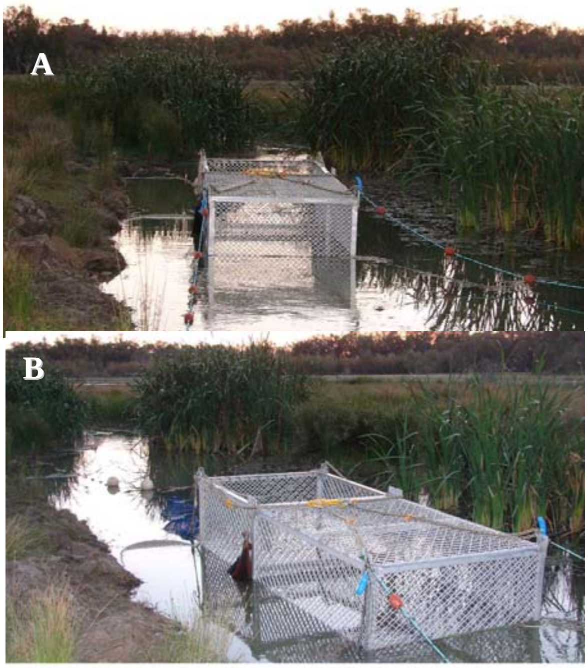


Figure 8. A) Prototype CSC with netting mesh wings set at site 5 in the Lake Cargelligo inlet channel upstream of Curlew Water and B) with fyke net catching fish moving in opposite direction.

Results

A total of 224 carp were captured, as well as a number of native species, with carp the second most abundant species after native carp gudgeons (Table 1). No fish were captured in the CSC, however, large adult carp were observed moving upstream from the lake soon after flows commenced. Carp aggregated downstream of the cage and spawning activity and egg deposits were observed amongst fringing vegetation.

Table 1. Total numbers of fish sampled at Lake Cargelligo.

Common Name	Scientific Name	Total
Small Bodied Natives		
Australian smelt	*Retropina semoni*	85
Flatheaded gudgeon	*Philpnodon grandiceps*	2
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	5
Carp gudgeons	*Hypseleotris* spp.	901
Large Bodied Natives		
Golden perch	*Macquaria ambigua*	1
Bony herring	*Nematalosa erebi*	1
Introduced Small bodied		
Eastern gambusia	*Gambusia holbrooki*	36
Introduced Large Bodied		
Carp	*Cyprinus carpio*	224
Goldfish	*Carrassius auratus*	8

Carp appeared to respond to the flow event by migrating, with the majority of fish collected during days with flow and increasing catch rates over the five day trial period (Figure 9). The Catch per Unit Effort (CPUE) of carp more than doubled by day 3 corresponding with the rise in flows and continued to increase over the following two days. Carp movements occurred in both directions but the majority of fish moved upstream, particularly on day four (Figure 10). CSC directional jumping trials revealed that carp would only jump in an upstream direction when placed in the cage. The two downstream facing CSC trials, 4 h and 12 h, recorded 24% and 67% of the catch respectively jumping upstream into the flow, whilst the two upstream facing trials failed to record any carp jumping in a downstream direction with the flow (Table 2).

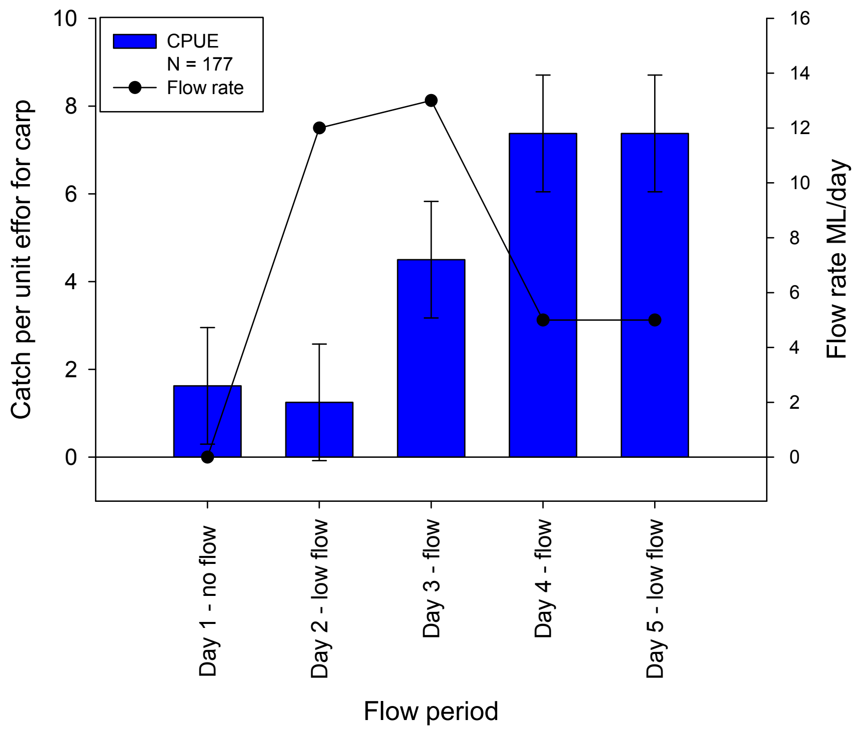


Figure 9. Catch per Unit Effort of carp for bidirectional fyke nets in relation to flow rates at Lake Cargelligo field site.

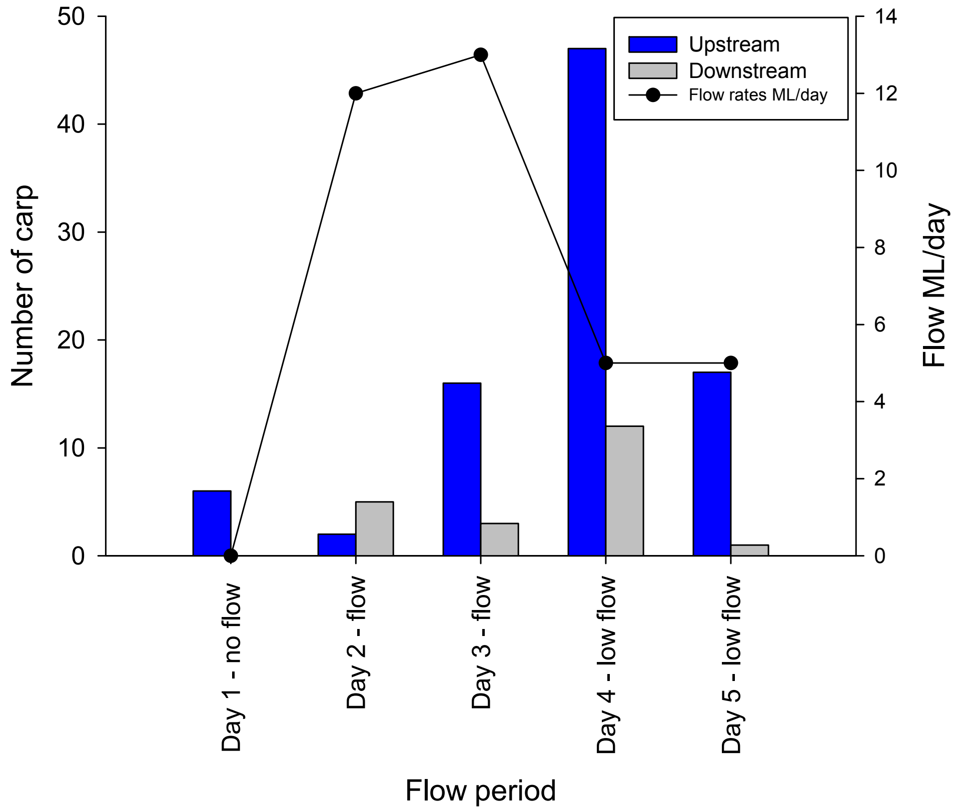


Figure 10. Carp movements during different flow scenarios over a five day period at site 4 in Lake Cargelligo.

Table 2: Lake Cargelligo CSC trials indicating the number of carp, the number of carp that jumped and the separation efficiency of each trial.

Trial No.	Time period	No.carp	Cage direction	No. jumped	Separation efficiency
1	12 hrs	9	Downstream	6	67%
2	4 hrs	21	Downstream	5	24%
3	12 frs	10	Upstream	0	0%
4	4 hrs	20	Upstream	0	0%

1.3.2 Great Cumbung Swamp (GCS)

The GCS is the terminal wetland of the Lachlan catchment, receiving all remaining river flow into a large series of wetlands and in very high flows, distributing this water to the Murrumbidgee River. The GCS is held as freehold land and is utilised predominantly for cattle grazing. Dense stands of *Phragmites*, *Cumbungi*, lignum and other aquatic plants remain in reasonable condition and respond positively to wetland filling under high flows (Driver 2002). Recently, dry conditions have resulted in extended parching of the swamp with the exception of the river channel itself in the centre of the swamp, where remnant water and carp remain. Historically, the GCS held water in a more permanent fashion and was called the great “Calare”, meaning permanent water (Roberts and Sainty 1996, R. MacFarlane pers. comm.).

After filling, the swamp inundates around 50,000 ha and represents an enormous potential as fish habitat. There has been considerable commitment towards returning wetland function to the GCS by state and federal agencies as well as from private industry and landholders (Driver 2002, Coulthart 1997). The GCS is a principal target for the delivery of unregulated flows as an environmental water allocation. The Integrated Monitoring of Environmental Flows (IMEF) program run through NSW Department of Environment and Climate Change (DECC) continues to collect detailed data on wetland processes and vegetation in response to inundation but does not collect data on fish. At the time of the trials, river flows at the Great Cumbung Swamp were extremely low with no perceivable flow present at the trial site, which was situated at the end of the fence track within Juanbung Station on the north bank of the river toward the upstream extent of the swamp.

CSC Trials

As a result of the lack of river flows at the GCS site, within channel CSC trials were not feasible. It was therefore decided to construct two off-channel bays in which to submerge prototype CSCs and to experimentally manipulate flows through these cages. The experimental hypotheses were that flowing bays would attract carp over non-flowing bays and that jumping success would be higher in flowing over non-flowing bays. To maximise the attraction potential of the flow, river water was first pumped across several metres of paddock to accumulate earth and vegetation odours. It was also anticipated that attractant flows would disperse downstream with river flow, drawing fish towards the trial site.

Off stream bays approximately 3 m wide, 10 m long and 1.5 m deep were excavated into the bank approximately 50 metres apart and perpendicular to the river channel and a CSC was placed into each bay. Both bays were left for 24 hours with no flow to either cage after which time fish were measured and removed. An 8 inch diesel pump positioned 50 m upstream or downstream of the study site was then used to pump water onto the floodplain (Figure 11A & B). Floodplain flows were positioned so that water flowed across 10 m of vegetation and soil before entering the experimental bay (Figure 11C), providing a flow treatment through one of the CSCs at a time, leaving the other as a no flow control. Flow was applied for 24 hours to the downstream bay and subsequently switched to the upstream bay for the remainder of the trial period.

Backpack electrofishing was used to detect carp within bays that may not have entered CSCs. Additional electrofishing was conducted within the main river channel adjacent to the experimental area to detect any accumulations of carp in the river that may have been attracted to the channel flow but which had not entered the experimental bays.

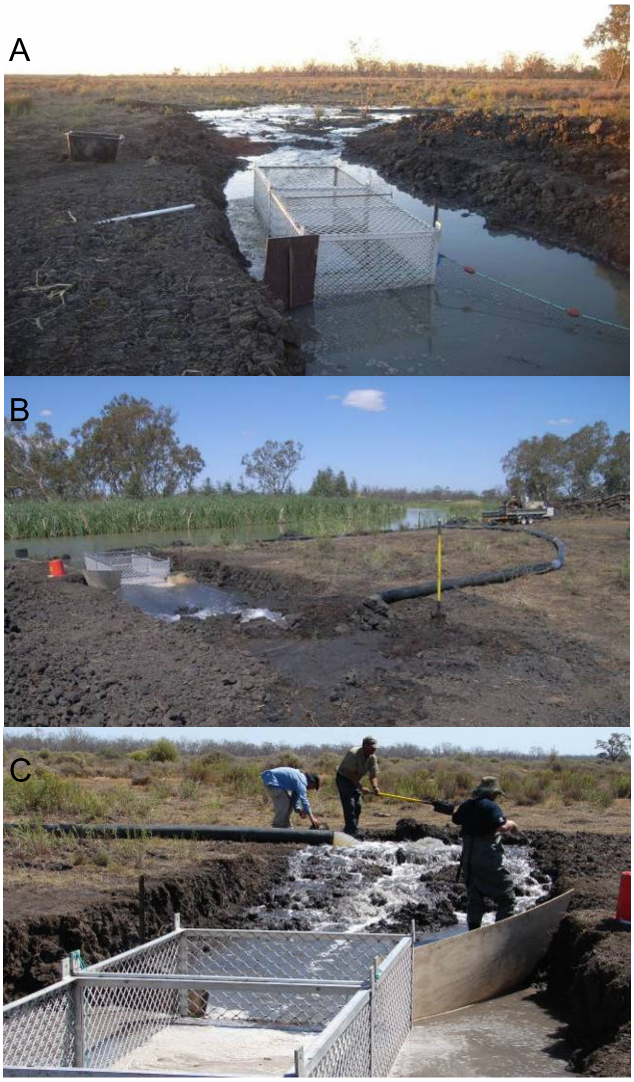


Figure 11. CSC experiments in the Great Cumbung Swamp. A. River water was pumped onto the floodplain B & C. Pumped water flowed through specially constructed CSC bays and into the river channel.

Additional trials were run to test pushing trap components, not previously tested in the field. A separate unit was placed at a site several kilometres upstream of the CSC site and over two 24 hour periods was alternately faced in upstream and downstream directions. Sound recordings were also taken of the floodplain flows using a special hydrophone. These sound recordings were stored in a digital database to be used in later trials exploring the role of acoustic attractant technologies in carp control. The results of these studies are not presented in the current report but were used to develop methodologies and trials reported elsewhere (see Thwaites *et al.* 2010).

Results

Few large bodied fish were caught in the two CSCs and in the bi-directional fyke nets during the trials at the GCS in October 2007. No fish were collected using the backpack electrofisher despite over 1000 seconds of sampling. Low river flows limited dispersion of channel flow to within 100 m of the cages. Only five fish - four carp and one goldfish - were caught over the four days, all of which were collected from the CSC (site 1, Table 3). The five fish that entered the CSC only entered once flow was directed through the CSC bay.

No flow was directed through the CSC for the first 72 hours and no fish were caught in the CSC bay. During the first 24 hour period of flow two carp and one goldfish entered the trap however no fish jumped into the holding cage. In the second 24 hour period with flow, two carp entered the CSC and jumped into the holding cage, i.e. 100% separation efficiency. No fish were caught in the CSC at site 2 (Table 4) over the four day period despite flow being present for the final 24 hours.

Table 3: Flow trials conducted at site 1 CSC over a five day period.

Date	Flow	Funnel end	Trap	Separtion efficiency	Cage Channel EF	Lachlan channel EF
9-10/10/07	No	0	0	0%	0	0
10-11/10/07	Yes	2 carp, 1 goldfish	0	0%	1 carp 1 goldfish	0
11-12/10/07	Yes	0	2 carp	100%	0	0
12-13/10/07	No	0	0	0%	0	0

Table 4: Flow trials conducted at site 2 CSC over a five day period.

Date	Flow	Funnel end	Trap	Separtion efficiency	Cage Channel EF	Lachlan channel EF
9-10/10/07	No	No fish	No fish	NA	No fish	0
10-11/10/07	No	No fish	No fish	NA	No fish	0
11-12/10/07	No	No fish	No fish	NA	No fish	0
12-13/10/07	Yes	No fish	No fish	NA	No fish	0

1.3.3 Lake Brewster

Lake Brewster (Figure 12) is a natural ephemeral lake near Hillston and covers around 15,000 ha, holding ~153,000 ML of water when full (Driver 2002). In the 1950's, Brewster weir on the Lachlan River and a series of levees and channels were constructed to utilise the lake as a short-term off channel storage for downstream irrigation supply. This utilisation for rapid filling and emptying, interspersed with high levels of grazing (and some cropping) pressure, resulted in extremely poor water quality (high salinity, turbidity, nitrification, algal blooms) as well as the loss of wetland processes and vegetation beds (Thurtell *et al.* 2003).

More recent management under an Environmental Flows policy has targeted water to sustain wetland function and waterbird populations and nurseries (for pelicans and cormorants) in the lake (Whitehead and Pahlow 1997, Eco-logical 2007). Significant modification of the Lake Brewster storage is being planned (State Water 2007) and it is anticipated that regulation and physical engineering works will greatly increase the management of the storage for water quality and biodiversity (LCMA 2006).

Figure 12: Map of Lake Brewster with sampling sites.

Lake Brewster inlet channel (Figure 13) provided the most suitable conditions to trial CSC designs *in-situ* as well as to study the response of carp to wetland channel flows. Lake Brewster trials were coordinated with State Water operations and a test opening of the Brewster inlet regulator was incorporated into the field experiment. With methods similar to the trials at Lake Cargelligo, CSCs and nets were deployed 24 hours prior to the onset of flow allowing comparisons between zero flow (day 1) moderate flow (days 2-4) and declining flow (day 5). Prior to flow initiation, the Lake Brewster channel held remnant pools no deeper than 0.5 m, the majority below 0.3 m in depth. Carp were observed within remnant pools both upstream and downstream of intended trapping sites.

Figure 13: Lake Brewster (Ballyrogan) inlet channel within the Lake area showing the Lachlan Range in the background.

An experimental flow rise was delivered by opening the inlet regulator, following an initial no-flow period. The Brewster inlet regulator was undershot with deep water (~4m) on the upstream side, making it possible for carp to move in from the Lake Brewster weir pool, through the regulator and downstream into the inlet channel. In addition, the outlet regulator was fully opened to allow free upstream movement of carp from Mountain Creek through the study reach (although this would have required the successful ascension of Benson's drop weir, which presents a barrier to upstream movement approximately 0.5 m high. This height is well within the jumping capacity of carp and would not represent a complete barrier to the upstream movement of carp, particularly during higher flows. The area around Benson's drop was therefore used as the downstream extent of the field site with CSC trial and netting (and electrofishing).

Fish Movements

Fish movements throughout the study area were assessed using multiple netting stations. CSCs were used to sample fish movements upstream into the Lake Brewster outlet (Mountain Creek) from the Lachlan River and downstream into the Lake Brewster (Ballyrogan) inlet channel from the Lake Brewster weir pool. Each CSC was accompanied by a double winged fyke net set to collect fish moving in the opposite direction, allowing bi-directional sampling at these sites. Between CSCs fish movements were assessed with bi-directional netting stations. Fyke net stations were set at sites 2, 3 and 4.

For each station, two nets were joined at each site to cover the entire width of the channel. Prior to the managed flow event, a large residual pool was present between the two CSC stations and was observed to contain significant numbers of carp. The pool encompassed a junction of the inlet/outlet channel with a channel leading towards the middle of the lake (‘dead space’) that was blocked off with an earthen levee 500 m from the junction. Subsequently, fyke stations were set up to capture carp moving out of this residual pool in all three directions; upstream towards Brewster Weir (site 2), downstream towards the ‘dead space’ and downstream towards Benson’s drop (Site 4). At the end of every 24 hour period the nets were checked, emptied and all fish caught were identified and recorded.

CSC trials

CSC trials were conducted in the inlet and outlet channels of Lake Brewster. This matches the proposed trapping strategy suggested for the site (McNeil 2007) with the inlet trap catching fish moving downstream into the lake from Brewster Weir and the outlet cage trapping fish attempting to move upstream from the Lachlan River into the lake. Both CSC stations were set up at the beginning of the field trials and were not moved or turned throughout the course of the trials. Each CSC was paired with a double wing fyke net sampling fish moving in the opposite direction to that sampled by the CSC. No nets were set upstream of the inlet CSC or downstream of the outlet CSC, allowing free movement of fish towards the trapping site. The inlet CSC site (Site 1) was located on the boundary of the lake approximately 4 kilometres downstream of the inlet regulator. This station sampled carp moving downstream from remnant pools upstream in the inlet channel and any carp moving into the channel through the Brewster Weir undershot regulator. The CSC was dug into the centre of a block bank constructed previously by State Water so that flows passed directly through the cage (Figure 14A). After the initiation of flows, the cage moved significantly breaching the structure (Figure 14B) but was re-secured and provided with additional steel mesh wings (Figure 14C).

Figure 14: A) Inlet Cage at Lake Brewster sunk into earth block bank prior to channel flows; B) researchers despair as flows breach the earth bank and shift the cage and C) the inlet cage was secured with steel mesh wings added, and was functional for the remainder of the trial.

The outlet CSC (Site 5) was positioned directly under Benson's Drop Weir, which was sandbagged to direct flow through the CSC (Figure 15A). The outlet cage sat on a solid concrete base with 20 mm mesh net wings. Additional flow through the CSC was provided through two 20 centimetre diameter siphon tubes (Figure 15B). The outlet CSC sampled fish moving upstream into Mountain Creek (toward the Lake) from the Lachlan River (downstream of Brewster Weir).

Figure 15: Outlet cage at Benson's Drop A) showing netting wings and sandbagging on weir wall directing flow through CSC and B) close up showing siphons (yellow) and fyke netting above weir wall.

Low flow spawning response

Whilst CSCs and netting stations captured large scale carp movements, these passive sampling techniques were not sufficient to pick up smaller movements or localised spawning aggregations between sampling sites. Visual surveys revealed that following the initiation of flow, small aggregations or "cohorts" of spawning carp were gathering within the channel without forming large aggregations or making migrational movements. To capture this local response to low flows a transect survey was carried out along the entire length of the channel between the inlet and outlet regulators. Data was recorded every 1 km with sites consisting of a 100 m stretch of channel. A total of 15 sites were sampled throughout the reach. At each site the presence of carp, spawning behaviours, number of carp, the number of spawning cohorts, number of fish per cohort, number of individuals outside of cohorts and direction of movement were recorded. A range of site information including the percentage of bare habitat, riparian, emergent and submerged vegetation, the average maximum depth and turbidity level was also recorded. Visual estimates of carp numbers were also made for reaches between each site.

Additional sampling was conducted in the Brewster channel during a related study (focusing on olive perchlet) in February 2008. This survey used the same number of identical fyke nets as the carp sampling although netting stations were distributed more evenly throughout the channel. The results have been included here as a comparison of carp abundances and size distribution before and after the spawning events reported during the 2007 study.

Results

A total 90 carp were caught at Lake Brewster, 74 in the bi-directional fyke nets and 16 in the CSCs, eight other fish from three species were also collected (Table 5). A total of 16 carp entered the traps, seven in the inlet CSC, facing upstream and nine in the outlet CSC facing downstream. The CPUE increased daily in relation to an increase in daily flow rate (Figure 16). This increase in CPUE over time can be seen also in carp moving into the CSCs in both the inlet and outlet channels (Tables 6 & 7).

The carp that entered the inlet CSC did so on the fourth day of the trial when flows and water levels were receding, but did not separate by jumping with the flow into the holding cage (Table 6). However, they were observed orientating themselves towards the flow and jumping upstream into the wall of the cage above the funnel in an attempt to escape. At the outlet site, carp entered the CSC on the third and fourth days of the trial once flow had been continuous for 24 h (Table 7). On the third day a total of five carp and one goldfish entered the trap with carp jumping into the holding cage with 60% separation efficiency and on the fourth day four carp entered the CSC with two carp jumping with 50% separation efficiency.

Table 5: Total numbers of fish sampled at Lake Brewster.

Common Name	Scientific Name	Total
Small-Bodied Natives		
Olive perchlet	*Ambassis agassizii*	1
Large-Bodied Natives		
Bony herring	*Nematalosa erebi*	6
Introduced Large-Bodied		
Carp	*Cyprinus carpio*	90
Goldfish	*Carrassius auratus*	1

Table 6: Lake Brewster CSC trials facing upstream in the inlet channel (Ballyrogan).

Date	Flow	Funnel end	Trap	Separtion efficiency
13-14/10/07	none	No fish	No fish	NA
14-15/10/07	low	Cage overwhelmed by trash and water level		
15-16/10/07	High	No fish	No fish	NA
16-17/10/07	high	7 carp, 2 bony herring	No fish	0%
17-18/10/07	low	Cage replaced with drum net (2 carp and 1 bony herring)		

Table 7: Lake Brewster CSC trials facing downstream in the outlet channel, Bensons Drop.

Date	Flow	Funnel end	Trap	Separtion efficiency
14-15/10/07	none	No fish	No fish	NA
15-16/10/07	low	No fish	No fish	NA
16-17/10/07	High	2 carp, 1 goldfish	3 carp	60%
17-18/10/07	high	2 carp	2 carp	50%
18-19/10/07	Low	No fish	No fish	NA

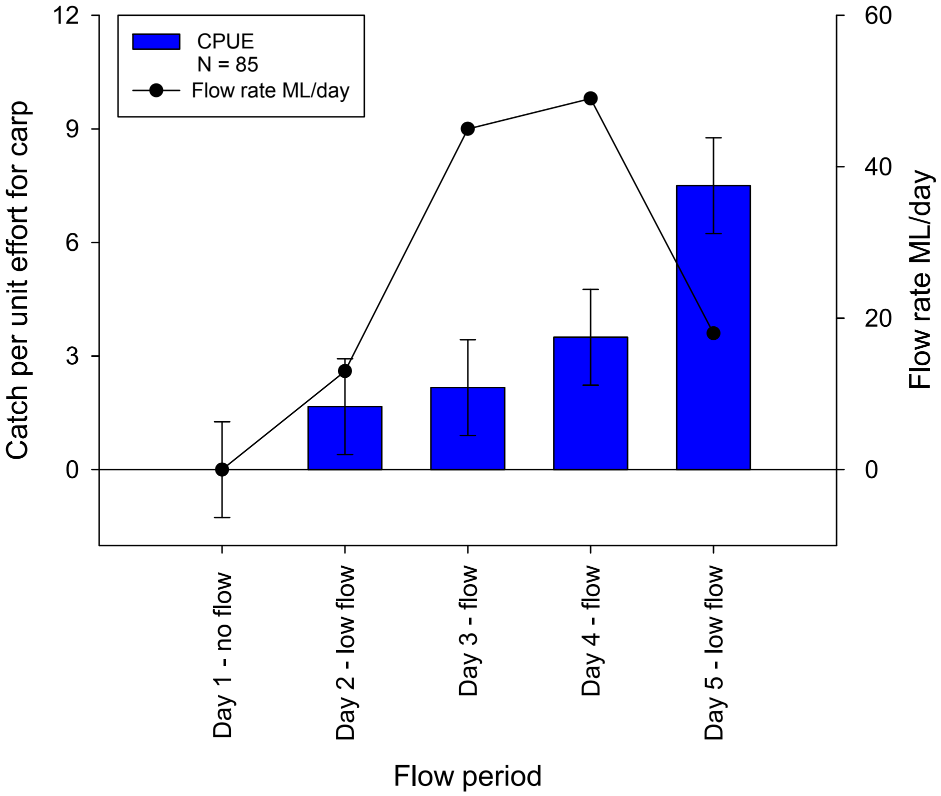


Figure 16: Catch per Unit Effort of carp in CSC trials in relation to flow rates over a five day period.

Low flow spawning response

Following an initial zero flow period, the release of water into the Lake Brewster channel lead to an observed increase in carp activity. After 2-3 days of flow, this increased activity was associated with the formation of small aggregations and observations of spawning activity. A short study was conducted in the Ballyrogan channel assessing the spawning response of carp within 15 100 m transects (Figure 17), spaced 1 km apart for the length of the channel.

An additional 200 m transect (site 16) was assessed between Sites 2 and 3 where a large aggregation of spawning carp were observed between the transect sites. Over the fifteen original transects, 173 fish were observed. 145 of these fish were observed within 43 independent spawning cohorts, which showed non-directional localised movement patterns (Table 8).

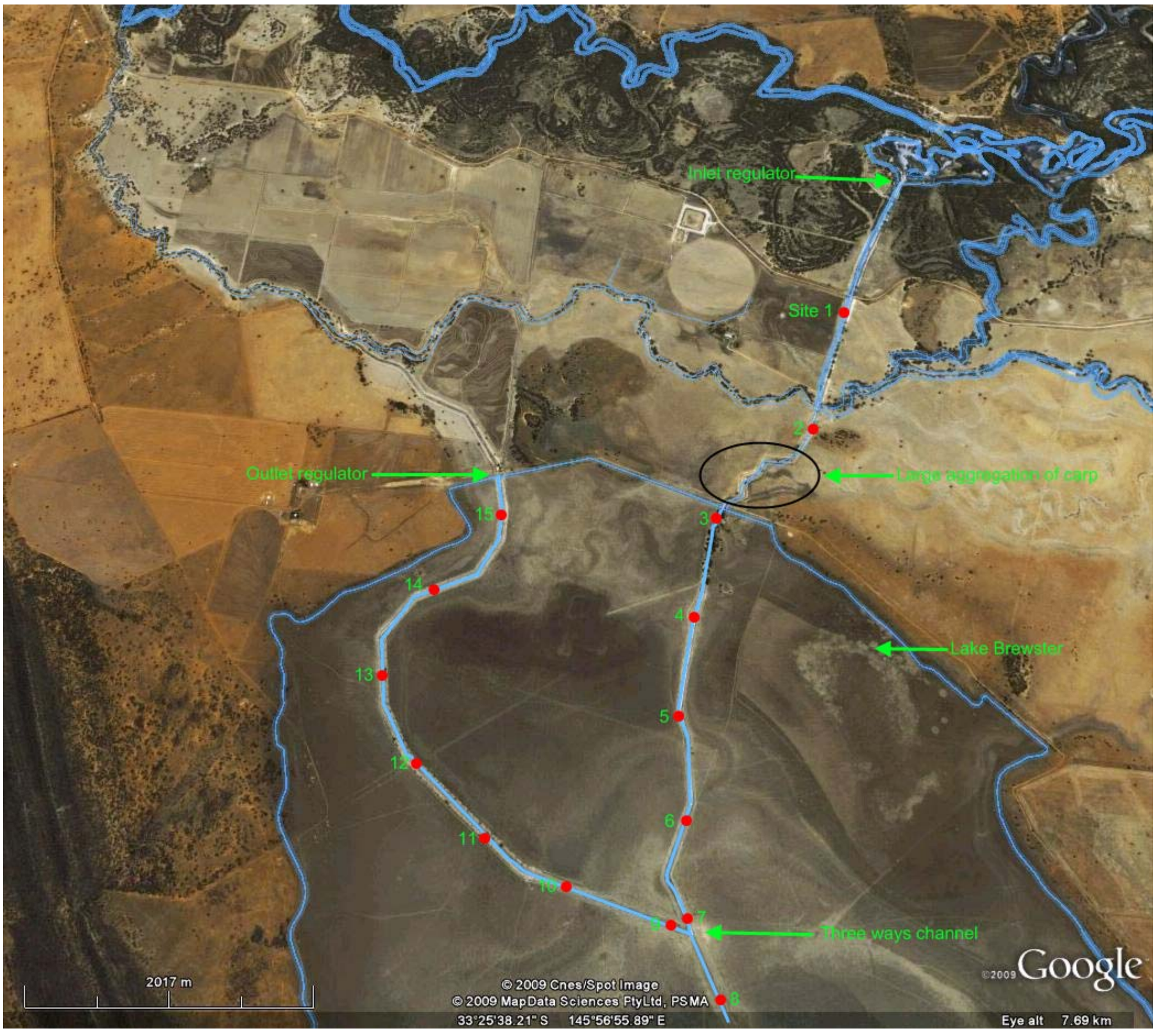


Figure 17: Google Earth image of Lake Brewster showing spawning response transect sites. Black circle shows the additional site where a large congregation of spawning cohorts was observed (site 16)

During the transect survey carp were observed using local spawning habitat varying from macrophyte beds, stones, sampling equipment, bare ground and even cow manure. Spawning behaviour was observed at over 50% of transect sites, with submerged macrophytes recorded at all sites where spawning was observed. Sampling under the CSC trials captured 90 carp in the inlet and outlet channels; four months later there were 1,596 carp caught, a 177% increase in abundance (although CPUE was not calculated, both represent a comprehensive netting of available habitats in the channel). However, the majority of the carp sampled in the 2008 survey were young of year fish (< 150 mm) with only several larger carp sampled (SARDI unpublished data; Figure 18).

Table 8: 100 m transect sites in Lake Brewster Channel, indicating number of carp, number of cohorts and spawning cohorts. Sites are numbered from the inlet (1-8) and outlet (9-15) channels with the additional site 16* representing a 200 m transect.

No. of sites	No. of fish	No. of cohorts	No. of loners	Spawning
1	0	0	0	Absent
2	21	6	3	Present
3	20	4	1	Present
4	5	1	3	Present
5	0	0	0	Absent
6	7	5	1	Present
7	7	2	2	Present
8	28	8	0	Present
9	5	2	0	Present
10	3	1	0	Absent
11	7	1	1	Absent
12	0	0	0	Absent
13	0	0	0	Absent
14	0	0	0	Absent
15	0	0	0	Absent
16*	73	17	16	Present

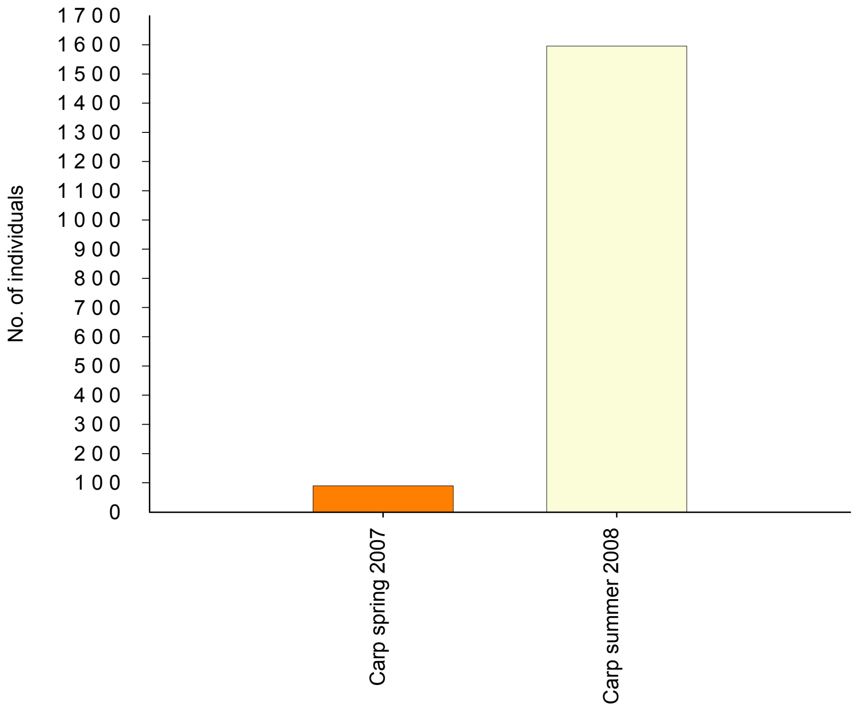


Figure 18: Carp abundance in Lake Brewster Channel surveys before (2007 results) and after (from McNeil et al. 2008) a low flow release.

1.4. Discussion

1.4.1 Carp Spawning and aggregation in the lower Lachlan

The Lachlan River possesses the highest proportion and biomass of carp in any catchment in the Murray-Darling Basin (Driver *et al.* 1997). However, during the 2007 three week study conducted in the Lachlan catchment, numbers of carp captured were very low. Carp aggregation, migration and spawning is closely linked with environmental conditions (Lucas and Baras 2001) such as season (October–April), water temperature (>16°C), day length (>10 h daylight) and habitat availability leading to the onset of spawning during spring under Australian conditions (Sivakumaran *et al*. 2003, Smith and Walker 2004b, Stuart and Jones 2006b). Spawning is a major driving instinct for many fish to migrate (Lucas and Baras 2001) and fish motivation has been identified as a critical factor in relation to migration (Mallen-Cooper 1999). These environmental cues have been recently highlighted as opportunities for targeting spawning and migrational aggregations of carp to maximise the effectiveness of control activities and harvesting (Stuart and Jones 2006b).

The 2007 trials were conducted under appropriate water temperature and day length conditions with good levels of available spawning habitat. However, a key environmental cue regarded as being potentially important for carp aggregation is flow (King *et al.* 2003) and the study was conducted during Australia's worst drought on record (Lake *et al.* 2008). Spring flows in the lower Lachlan River are almost entirely dependant on supply from upstream reservoirs. Flow conditions during the trial, and for several preceding seasons, were therefore extra-ordinarily low for several years. As a result, the natural flow conditions that would regularly occur within the lower Lachlan River were not being met at the time of the study and this is the most likely explanation for the low catches when compared to previous density data (Gilligan *et al.* 2010). The 2007 season represents a low point in carp abundance since their spread across the Murray-Darling Basin in the 1970's with low numbers of adult carp persisting in refuge habitats (McNeil *et al.* 2010).

However, with other environmental cues met, the addition of experimental flow manipulations provided an opportunity to investigate the response of carp to the resumption of flow following drought as well as allowing the testing of carp separation cage technologies. The results clearly outlined a spawning and movement response to the resumption of flows, even though those flow volumes were very small. Carp, which were not observed moving in any numbers prior to the addition of flow, moved, and were caught in high numbers following experimental flows. Additionally, carp were observed gathering in spawning aggregations and eggs masses were collected two to four days after the addition of flows, consistent with the rapid development of ovaries and reproductive behaviours once conditions become ideal (Billard 1999, Sivakumaran *et al*. 2003, Smith and Walker 2004a & b).

The 2007 spawning and movement response did not follow previous models for carp responses, notable was the absence of large scale aggregations of the scale observed in Murray River fishways (Conallin *et al.* 2008). Instead, the response of carp was to form smaller aggregations within which cohorts of up to five individuals would gather and spawn over local substrates, primarily, littoral vegetation recently inundated by the slight rise in water level. The localised small scale aggregation is seen as a “Low Flow” spawning response and builds on previous observations that carp larvae are produced even during low flow periods, or following minor river rises in the Murray River Channel (Brown *et al* 2005). This low flow response model differs form previously recorded (high flow) responses where very large shoals of carp form and migrate to spawning ‘hot-spots’ where large numbers of recruits are produced (Gilligan *et al.* 2010).

The observed “Low Flow” response would maintain a high level of resilience within the carp population throughout dry periods so that once drought eases, carp populations can spread and build very quickly (McNeil *et al*. 2010). This low flow spawning response is likely to add significantly to the wide range of adaptations that carp possess for invading and dominating the harsh and variable systems such as those of inland Australia, even under highly regulated environments (McNeil and Closs 2007, Jones and Stuart 2009). Given the very large number of juvenile carp recorded from test sites in the year following trial releases (McNeil *et al.* 2008), it is likely that this low flow spawning response is extremely effective way of building dominance during periods of isolation and it is hypothesised that this ability will lead to an explosion of carp numbers if resumption of wetter climatic patterns occurs soon after low flow spawning opportunities.

Importantly, the ability of carp to respond strongly to even very small flow pulses emphasises the critical importance of flow management in relation to the maintenance of carp and subsequent control activities. Even small flows such as those observed during regulator maintenance or due to leakage at the Lake Brewster inlet may be maintaining and building resilience into carp populations as the channel does not completely dry out, maintaining spawning capacity within channel refugia. It is suggested that total drying of channels and wetlands be considered in an attempt to eradicate refugia from which carp may expand, or to protect against the addition of flow pulses during carp spawning period (October – April) in managed waterways such as Lakes Brewster and Cargelligo.

The timing of transferring and releasing of water between the main river channel and water storages in the Lachlan catchment and the maintenance of regulators, is likely to be an intrinsic factor in the successful management of carp populations. Water operations should be designed to either minimise the opportunities for carp to spawn and recruit or should target pre-spawning aggregations using removal techniques such as Wetland CSCs. Potential carp responses should be considered when designing and planning water transfers in the Lower Lachlan, acknowledging that these factors must be balanced with other requirements and restrictions to flow delivery.

1.4.2 Carp Separation Cages (CSCs)

Overall catches of carp during the 2007 trials were extremely low compared to past data. This pattern was also reflected in the performance of CSCs that were trialled at inlet and outlet channel sites at Lakes Brewster and Cargelligo, and in experimental bays constructed at the Great Cumbung Swamp. Whilst the carp catch at the great Cumbung Swamp was almost zero, numbers of adult carp were continually observed moving around CSCs at the other sites and enormous masses of eggs were deposited over CSCs and associated netting and structures. The actual number of carp moving into CSCs was however extremely low compared with the number observed outside of the cages.

Trap shyness has been highlighted as a significant issue in the application of CSCs to river fishways (Stuart *et al*. 2006a & b, Conallin *et al*. 2008), with even large aggregations of carp avoiding movement into CSCs for several days until their migrational drive overcomes this trap shyness. The reasons for trap shyness and mechanisms for overcoming this problem have not been well explored, but are likely to be a significant factor in maximising the effectiveness of CSC design. Under the 2007 trials, it is likely that trap shyness was further exacerbated by the ‘low flow’ response of carp, whereby fish did not appear to move in uni-directional shoals but sought out local spawning habitats in small cohorts. Under a higher flow scenario where climatic conditions are wetter, CSC function in wetland channels may be greatly improved, especially where large migrational aggregations are driven to migrate through trap structures.

A further consideration is raised by the generally high quality of water chemistry throughout the study reaches, both within wetland channels, but also within downstream and upstream environments, which may negate the need for carp to migrate away from poorer water quality into incoming flows. Especially at Lake Cargelligo, the frequent deterioration of water quality in the main lake is likely to lead to large scale upstream migration of carp into the freshwater flows coming out of the inlet channel. It is hypothesised that such water quality differentials will contribute strongly to carp migration into wetland channels, and greatly reduce trap shyness and improve the function of wetland channel CSCs. It is therefore suggested that CSCs positioned at the junction of the inlet channel and Lake Cargelligo may be used effectively in combination with inlet channel flows to draw carp out of the lake and into CSCs.

Whilst water quality was relatively poor in the Great Cumbung Swamp, the flows provided by pumping of water through CSCs and into the river channel were believed to be insufficient to provide adequate fresh inflows to attract carp upstream into the fresher water. Future experiments of this kind should utilise flows of at least 1 ML per day in order to ensure appropriate water quality differentials and to serve as attractant flows for the use of CSC technologies. Similarly, attractant qualities of this flow, which were maximised by pumping water across the floodplain before flowing through CSCs, were reduced by the poor ability of those flows to move into the river and move downstream under the very low gradient of the Great Cumbung Swamp. The few carp and goldfish caught in CSCs at the site are likely to represent fish that were located proximally to the experiment bays and were attracted into cages even under the relatively low flow rates, suggesting more adequate flows may yet be effective attractants to draw carp upstream. Future research into the use and composition of attractant flows is required before this technique can be effectively used to improve CSC function. At the Great Cumbung Swamp, it is likely that optimal attractant flows will be provided only through Lachlan River inflows and that CSCs placed in the main channel downstream of Oxley may benefit from these inflows and be effective trapping locations for carp drawn out of the Great Cumbung Swamp after the resumption of river flows.

1.4.3 CSC Experiments

The experimental manipulation of CSC direction indicated that carp would enter CSCs against the flow of water, as documented for riverine situations (Stuart *et al.* 2006a & b). However, the trials also found that carp entered CSCs whilst moving downstream with the flow, which had not previously been described. Whilst trapping of carp appeared to work in either upstream or downstream directions, the function of carp separation was not equal in both directions. The results of experimental manipulations suggest that the jumping behaviour of carp, central to the concept of CSC design, does not apply to downstream migration situations, such as fish moving into wetlands through inlet channels during filling. Once trapped, downstream moving carp were observed to re-orient themselves rheotactically into the flow. Behaviours often associated with jumping of trapped carp into a separation chamber were instead directed towards escaping the trap in an upstream direction, away from the jumping baffle. Downstream migrating carp showed signs of damage to the head and were observed jumping into the upstream mesh of the trap. These patterns indicate that downstream moving carp may need to be turned to allow upstream jumping behaviours if separation is to be successful and it is recommended that ‘turn around’ CSC designs be investigated to cater for upstream and downstream applications in wetland channel applications.

CSC trials were extremely informative regarding design and infrastructure requirements for wetland applications. Several failure points were discovered during trials. The first of these is the need for solid anchoring of CSC structures into channels or banks. Even the relatively low flows applied at Lake Brewster were sufficient to undermine the earthen wall constructed to hold one of the CSCs and cause the cage to wash away. In contrast, the outlet cage at the same site was placed on a solid concrete base at Benson’s drop and was unaffected by the same flows. Concrete culverts and platforms will be required to house any CSC infrastructure in the future.

In addition, the use of rigid and dug in wings was found to be essential for preventing possible by-passing of carp that appeared to burrow under nets that were weighted but not dug into the substrate. The use of steel mesh wings negated this behaviour and future CSC designs should incorporate solid and well fastened wings to prevent trapping inefficiencies. Finally, very large amounts of debris and trash were mobilised under the increased flow and caused significant fouling of the trap entrance when fishing downstream moving carp. Significant attention must be directed towards ensuring that trash management is maximised, especially looking forward to automated designs where ongoing manual removal of trash will not be cost effective. Current designs of trash management should be considered and adapted into future CSC designs.

Finally, with very few large bodied native fish captured throughout the trials, it is likely that CSC function may be less important during periods such as early spring, when carp spawning can be stimulated. Although under automated designs, separation facilities are essential for maintaining native fish passage, targeted trapping of carp during times of peak aggregation and movement, especially in response to early spring flows, may be made more efficient through the removal of jumping baffles, allowing larger volumes of carp to be caught and removed. It is suggested that future CSC designs incorporate flexibility so that carp removal can be maximised during periods where large native fish are not being caught.

Chapter 2: Brenda Park Cage Trials

2.1 Introduction

The wetland trials outlined in the previous chapter provided a number of recommendations for the design and installation of CSCs for wetland applications. One of the key outcomes was the discovery that, whilst carp could be trapped moving downstream with flow, they were unable or disinclined to jump into the separation cage when moving downstream. Instead, a turn around cage facility was suggested to enable carp captured moving downstream, to turn into the flow and to jump upstream, as is the case in existing CSC designs. However, the effectiveness of such a turn around mechanism was not trialled during the Lachlan study. As a result, a project was developed and funded by the Lachlan CMA to modify prototype wetland CSC designs to allow for turning and jumping of downstream moving carp. The aims of the extension project were to:

1. Design an experimental turn-around facility for existing CSC designs.
2. Trial the turn around design experimentally in a wetland inlet during filling.
3. Determine the upstream versus downstream jumping preference of carp moving into wetlands with the flow direction.
4. Investigate the movement of carp and native fish into wetland inlet channels during filing events.

2.2 Methods

2.2.1 Site

Due to drought conditions, there was no wetland filling operations within the Lachlan Catchment during 2008/09 in which to trial the CSC turn around design. However, an opportunity arose in the River Murray to trial the turn around design developed from the Lachlan trials. A trial was organised to take place commencing on the 14/4/2009 in conjunction with the filling of the Brenda Park wetland (latitude 34°05’27 S and longitude 139°40’08 E), near Morgan, in the lower River Murray in South Australia (Figure 19). The single inlet/outlet channel consists of a wide creek section, narrowing to a regulator structure with three culverts (1.59 m in width) containing carp screens that can be opened and closed during water operations.

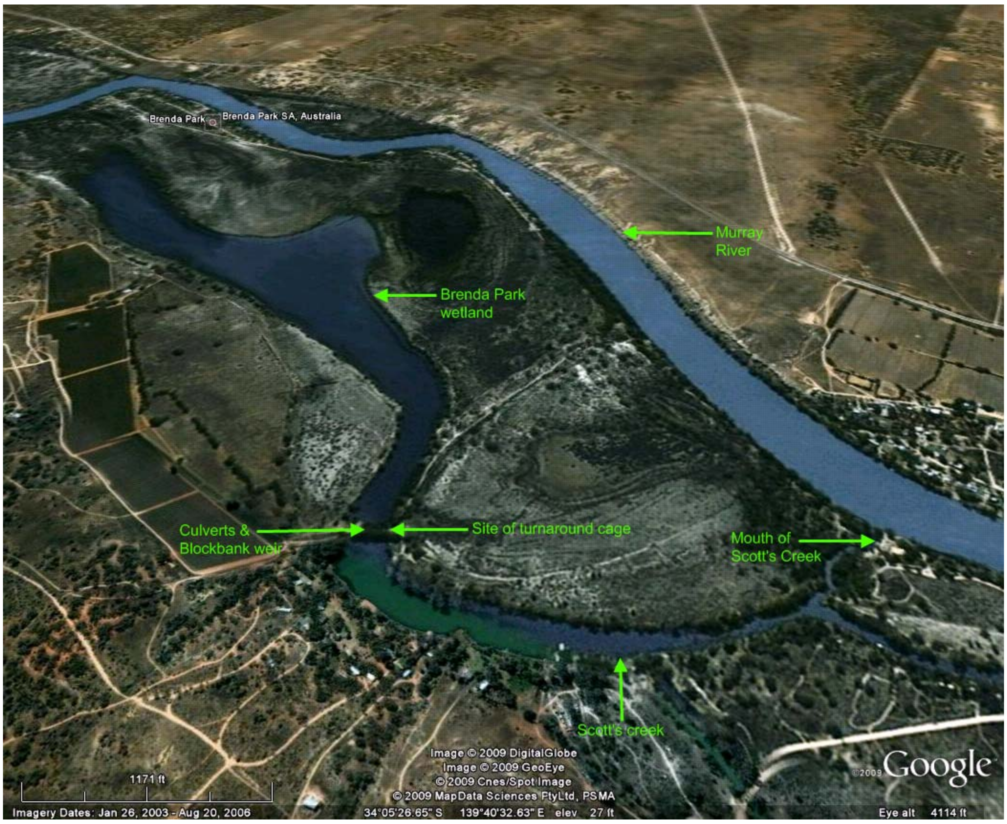


Figure 19: Brenda Park wetland, the site of the CSC turn around cage trials in 2009.

2.2.2 Turn around cage

The carp separation cage was designed and constructed to work within the centre culvert of the inlet/outlet channel at Brenda Park (Figures 20A & B). The other two culverts were closed off fish entering the wetland would have to enter via the cage. The trial cage (3.5 metres long x 1.4 metres wide x 1.4 metres high) was split into three cells (1 metre, 1.5 metres, 1 metre) with two jumping baffles set at 0.15 metres above the water level dividing the cage. The first cell incorporated a square funnel, 0.7 metres high x 1.4 metres wide at the entry tapering to 0.4 metres square over 0.75 metres to the exit in the middle of the first cell.

Fish entered the trap moving downstream with the flow direction through the funnel and into the middle cell (holding area) (Figure 21). Once the fish were in the middle cell they were then able to either jump with the flow into the downstream cell, jump against the flow into the upstream cell or stay in the middle cell. A gantry with a block and chain was installed at the site to allow the cage to be lifted to inspect the catch and to fill/empty the trap (Figures 22A & B).

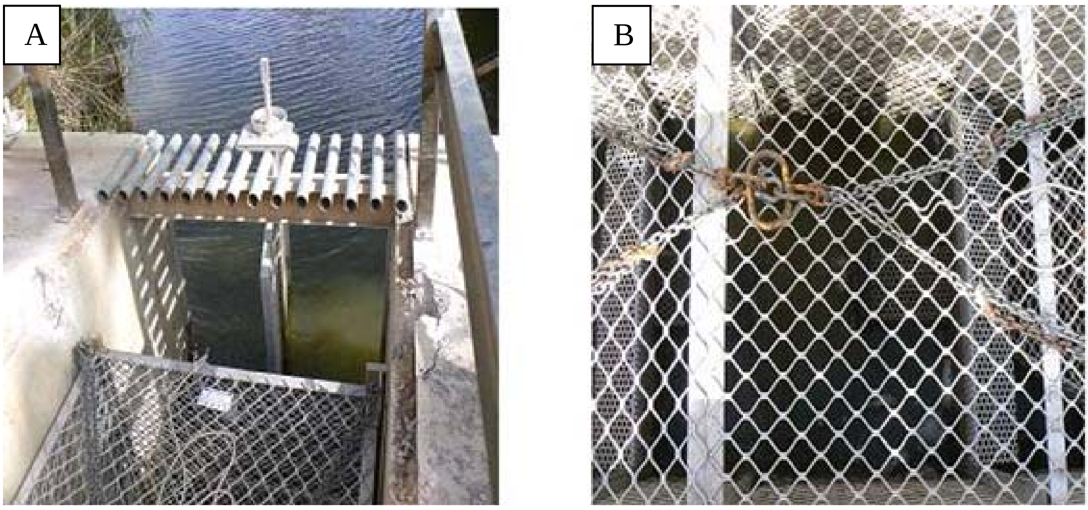


Figure 20: A: Entry point of culvert and B: the central holding area with jumping baffles upstream and downstream.

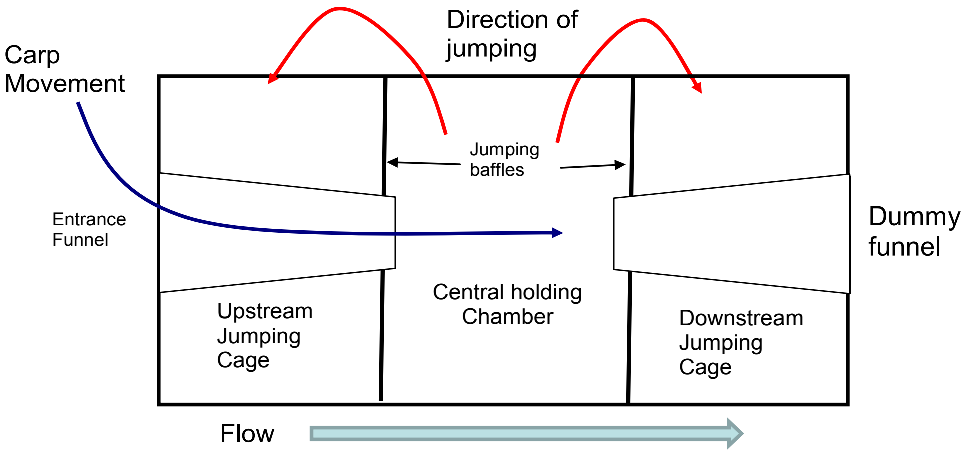


Figure 21: Turn around cage design for Brenda Park Wetland trials

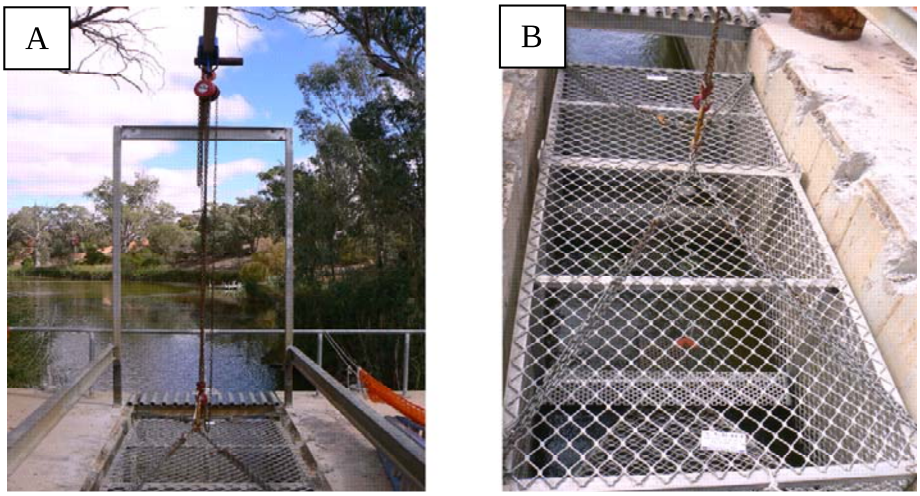


Figure 22: A: Lifting gantry and B: trial turn around cage in the inlet culvert at Brenda Park wetland.

2.2.3 Long Term Turn around CSC Trials

The turn around CSC was placed into the wetland regulator on the 14/4/2009 and the regulator opened to allow wetland filling to commence. The CSC was lifted every 24 hours for four days, fish were identified and measured (Fork Length, mm), and the jumping status/position (upstream, centre, downstream) was recorded. The fish were then released into the wetland unharmed. After the initial four day sampling period the cage was set and checked on a weekly basis for 11 weeks by SARDI staff. The cage was finally lifted out of the culvert on the 2/07/2009 and the trial stopped. The CSC was in place during the entire filling of the wetland and water levels were stable for over a week prior to the cessation of the trial.

2.2.4 Twenty-four hour trials

Two experimental trials were conducted following wetland filling to estimate the percentage of fish jumping upstream versus downstream using carp stocked into the CSC in known quantities. Twenty carp were introduced into the central holding cell of the turn around cage and the number of carp in each cell was recorded after 24 hours. All carp used for these trials were captured using boat electrofishing from the adjacent area of Scott's creek and the main channel of the River Murray. The cage was set with the gate closed on the culvert allowing water to move through the cage but restricting any other large bodied fish from entering the cage, other than the experimental carp. The cage was then lifted the next day and the distribution of fish in the upstream, central and downstream chambers was measured.

2.2.5 Fish survey

A detailed fish survey was conducted in Scott's Creek to assess the carp and native fish population abundance. Two sites were sampled, with first site within Scott's Creek between the inlet regulator and the River Murray. The second site was around the mouth of Scott's Creek, adjacent to the main channel of the River Murray. The survey consisted of fyke netting (3 mm mesh) set around littoral habitats (submerged macrophyte beds, emergent macrophyte beds, woody debris, bare banks). Nets were set for 24 hours and checked the following day. All fish were identified, measured (Fork Length, FL millimetres) and assessed for spawning condition before being released at the site of capture.

A boat mounted electrofishing unit was also used to sample both sites. Standard Sustainable Rivers Assessment (SRA) electrofishing protocols (Davies *et al*. 2008) were used whilst sampling i.e. twelve 90-second shots sampling all available habitats.

All species captured were identified, measured (FL mm), assessed for reproductive condition and checked for disease before being released at the site.

2.3 Results

2.3.1 Catch summary

During the four day survey conducted in April 2008 at Brenda Park a total of 7,342 fish were sampled. A total of twelve species of fish were captured, eight native species (Table 9); [carp gudgeon (*Hypseleotris spp*.), unspecked hardyhead (*Craterocephalus stercusmuscarum*), flatheaded gudgeon (*Philypnodon grandiceps*), dwarf-flatheaded gudgeon (*Philypnodon macrostomus*), Murray-Darling rainbowfish (*Melanotaenia fluviatilis*), bony herring (*Nematalosa erebi*), Australian smelt (*Retropinna semoni*) and golden perch (*Macquaria ambigua*)] and four introduced species (Table 9); [common carp (*Cyprinus carpio*), eastern gambusia (*Gambusia holbrooki*), goldfish (*Carassius auratus*) and redfin perch (*Perca fluviatilis*)].

The majority of fish sampled were small bodied native fish (<100 mm TL), with native carp gudgeon (n = 4,228) being the most dominant taxa, followed by unspecked hardyhead (n = 2487) (Table 9). Eastern gambusia (n = 212) was the most dominant introduced species of fish, with larger bodied fish including bony herring (n = 222) and carp (n = 33) being the highest captured large bodied species (Table 9).

Table 9: Fish species and total number of species captured during sampling.

Common name	Scientific name	Number captured
Australian smelt	*Retropina semoni*	11
Bony herring	*Nematalosa erebi*	190
Carp gudgeon	*Hypseleotris spp.*	4228
Dwarf-flatheaded gudgeon	*Philypnodon macrostomus*	2
Flatheaded gudgeon	*Philypnodon grandiceps*	80
Golden perch	*Macquaria ambigua*	10
Murray-Darling rainbowfish	*Melanotaenia fluviatilis*	34
Unspecked hardyhead	*Craterocephalus stercusmuscarum*	2487
Common carp	*Cyprinus carpio*	33
Eastern gambusia	*Gambusia holbrooki*	212
Goldfish	*Carassius auratus*	21
Redfin Perch	*Perca fluviatilis*	2

2.3.2 Long Term trial of Turn around CSC

Very few carp were found to attempt entry into the Brenda Park wetland over the 11 weeks of filling. No carp were captured within the turn around CSC during the four days subsequent to the start of wetland filling. The only large bodied fish that entered the cage were native bony herring, which were low in abundance with a total of 32 fish caught over the three days of sampling. Barely any carp at all were captured moving into the wetland, and of the five carp that were, four were caught on the last day that the cage was set. Two of these carp jumped upstream from the central holding chamber, and two jumped downstream, although by this date, flow through the culvert had become minimal (Table 10).

Table 10: Species of fish that entered the turn around CSC, numbers of fish that jumped and direction (upstream versus downstream).

Common name	Scientific name	No. of fish	No. jumped	Upstream	Downstream
Bony herring	*Nematalosa erebi*	143	0	0	0
Common carp	*Cyprinus carpio*	5	4	2	2
Goldfish	*Carassius auratus*	1	0	0	0

2.3.3 Twenty-four hour trials

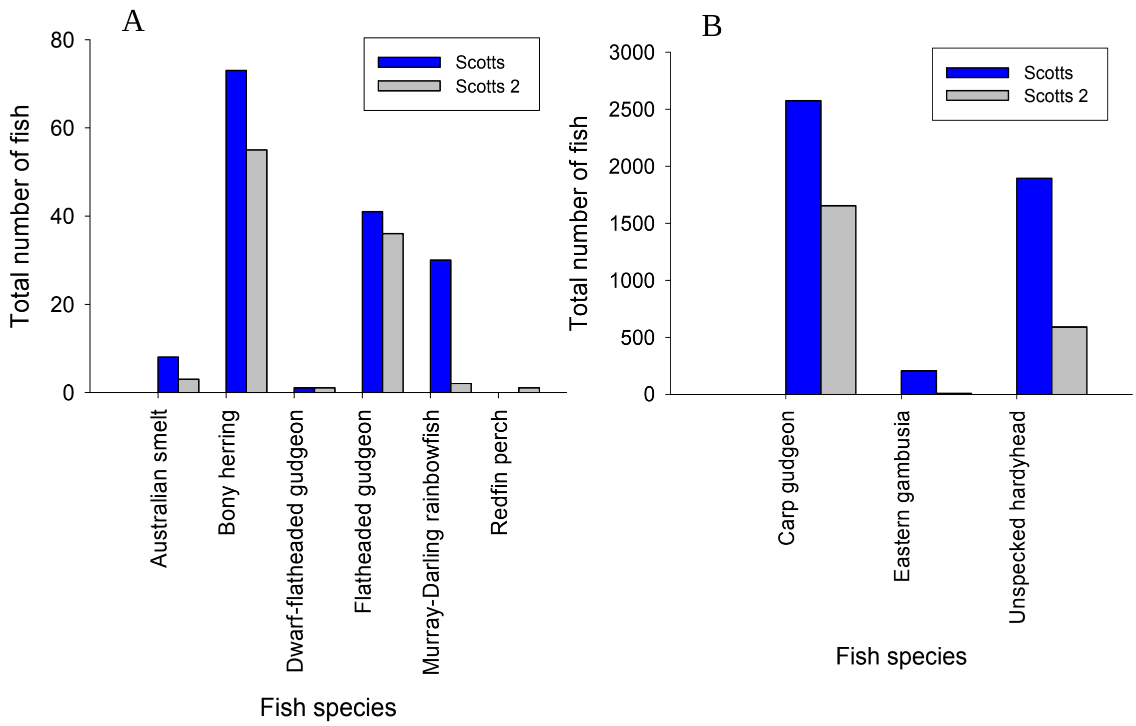
Few carp were found to jump out of the central holding cage during the two 24 hour trials, with one and three carp respectively jumping in an upstream direction, and no fish jumping downstream (Table 11).

Table 11: Turnaround cage 24 hour carp directional jumping trials.

Trial	Time period	No. of carp	No. jumped	Upstream	Downstream
1 - 17/4/09	24hrs	20	1	1	0
2 - 24/4/09	24hrs	20	3	3	0

2.3.4 Fish survey

A large percentage of the total number of fish sampled were caught using fyke nets (98%), the majority of these fish were small bodied natives and introduced species. A total of nine species were caught in fyke nets, two of these being introduced species (Figure 23A & B). Electrofishing yielded a lower total number of fish (2%), but a higher diversity with ten species of fish sampled, four species of which were introduced (Figure 24). The majority of fish sampled with electrofishing were larger bodied fish, consisting of golden perch, carp and goldfish. These three species were not caught using fyke nets. Of the 33 carp sampled there were no young of year fish present and the size range of captured carp extended between 200 and 700 mm in length (Figure 25).



Figures 23A & B. Total abundance of fish sampled using fyke nets at the sampling sites Scotts (Scott's Creek) and Scotts 2 (Scott's Creek mouth).

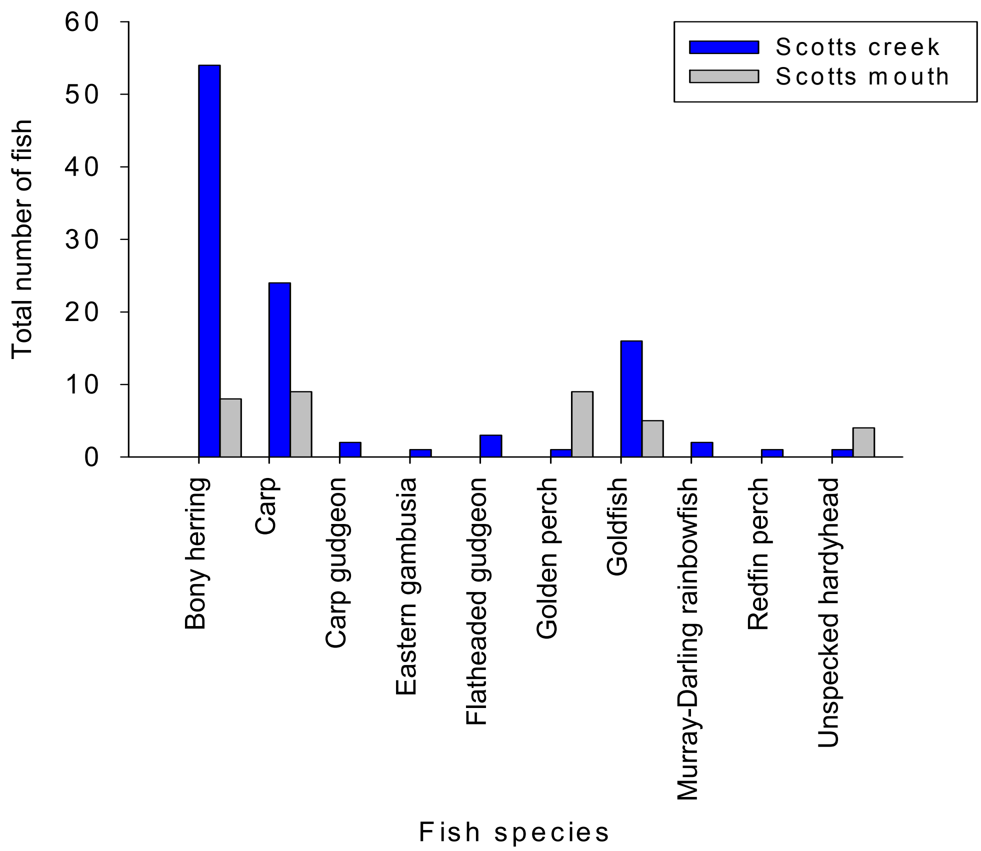


Figure 24: Total abundance of fish sampled using electrofishing at the sampling sites Scotts (Scott's Creek) and Scotts 2 (Scott's Creek mouth).

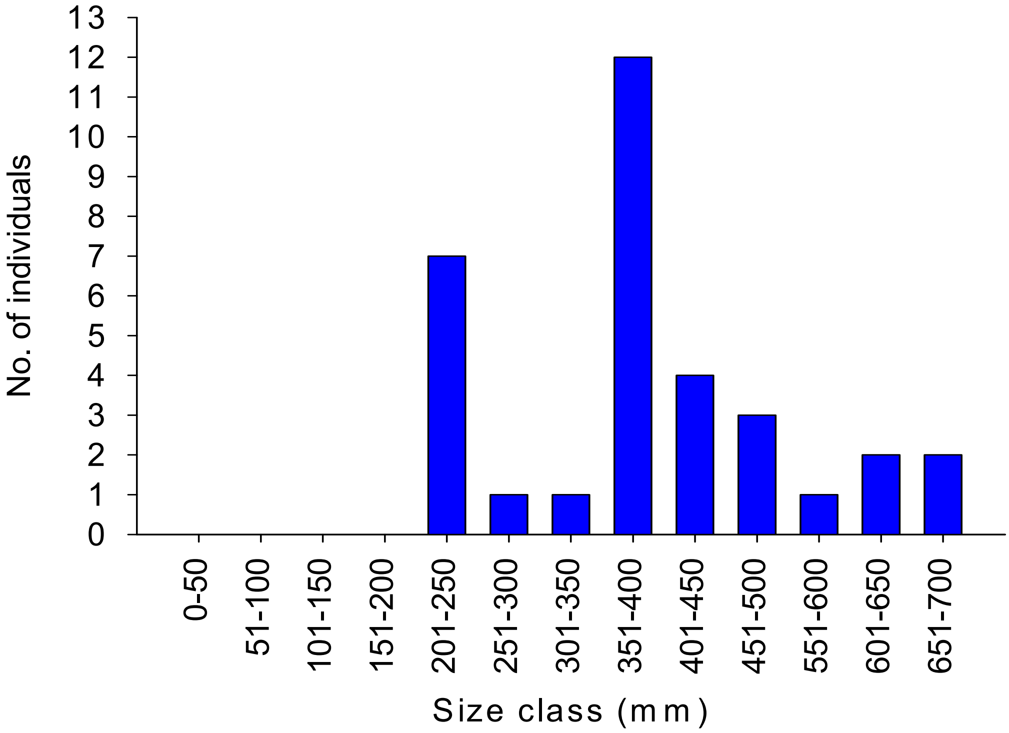


Figure 25: Size frequency of carp caught in Scott's Creek using fyke netting and electrofishing.

2.4 Discussion

The turn around wetland carp cage trials at Brenda Park took advantage of one of the very few wetland filling events in the southern Murray-Darling Basin during 2008/09. Although these trials were planned and intended to be held in the Lachlan catchment, the shortage of water in the catchment made this impossible. It is anticipated however, that with an identical suite of species the results of the trials at Brenda Park would be largely transferable to wetland filling events in the Lachlan catchment. Brenda Park trials began under conditions conducive to carp spawning, with water temperatures over 16°C within a spawning period previously identified for the species in the Lower Murray (Smith and Walker 2004b). As a result, the wetland filling at Brenda Park provided carp with access to wetland spawning sites under conditions conducive to spawning. However, during the filling of Brenda Park, no spawning aggregations or behaviours were observed nor were any ripe fish collected.

It is therefore evident that the filling of Brenda Park wetland did not provide the stimuli necessary to cue carp spawning or migrational behaviours. Few fish moved into the CSC during the 11 week sampling period, a pattern un-representative of the scenario of large shoals of migrating carp moving into wetlands to spawn. The result does however help to inform on the delivery of water and wetland filling protocols aimed at minimising the movement of carp into wetland habitats. By timing wetland filling events to periods where carp are unmotivated to aggregate, move and spawn, and when very few young of year fish are present, wetland filling is likely to introduce few carp, particularly if carp screens are utilised to exclude the few adult fish that do to enter the wetland.

For the Lachlan catchment therefore, the results indicate that water management procedures for filling known hot spot wetlands such as Lakes Brewster and Cargelligo and the Great Cumbung Swamp should incorporate timing aspects that are outside of the principal spring and early autumn spawning periods for the species. Furthermore, the results indicate that wetland filling may represent a much reduced opportunity for fish to move into wetlands when compared to fish moving upstream into outlet channels during emptying. Recent studies have found many orders of magnitude more carp moving into River Murray wetlands via outlet operations compared to inlets (Ben Smith, SARDI pers. comm.)

In the earlier Lachlan River field trials, carp only exhibited jumping in an upstream direction and the majority of carp at Brenda Park also jumped in an upstream direction. At Brenda Park, a small number of carp did jump in a downstream direction; however this occurred under relatively low flow conditions towards the end of wetland filling and may not represent their ability for downstream jumping under higher flow scenarios. These results further demonstrate the need for turn around facilities to be included in CSC designs. By turning captured carp into the flow and allowing them to jump upstream into a holding cage, carp moving downstream into wetlands can be captured and separated from native fish in a similar manner to standard riverine CSC designs. The present study tested only a single prototype design and further trials to develop and refine turn around capabilities are strongly recommended to assist in the broad application of CSCs into wetland channel situations.

Carp collected around the Brenda Park wetland were not found to be in spawning condition, even though the environmental conditions and season were consistent with carp spawning conditions. This result has been discussed as a possible factor in the low numbers of fish entering the wetland, but it may also explain the tendency for fish in the Brenda Park trials not to jump. With reduced ‘drive’ to migrate, non-spawning fish may be less likely to jump. This finding has implications for the use of CSCs during periods where native fish and carp are moving into CSCs, but neither is jumping. If jumping efficiency is reduced for non-spawning fish, CSC catches may need to be manually sorted outside of carp breeding seasons to ensure large numbers of non-jumping carp are not being released with the native fish.

2.5 Conclusion

In summary, a number of findings from the Brenda Park CSC turn around trial are relevant to the Lachlan Carp Control Program:

- Turn around facilities will improve the separation efficiency of CSCs used to capture downstream moving carp.
- Water transfers and wetland filling during late autumn-winter are likely to transport fewer carp than during spring and summer. Monitoring of carp reproductive status may be used to identify appropriate filling times and risks for carp introduction.
- There is a need for the development of a management plan for the transfer of water between river and wetland systems for both inflows and outflows.
- Effort should be made to target carp control activities to peak spawning times for carp so as to maximise catch rates.
- Operations for CSCs may need to be different during autumn/winter to account for non-jumping carp.
- In wetland inlet channels exclusion screens may be used in place of CSCs during times where small carp are not abundant, with CSCs becoming operational in spring when fish movement and spawning begins.
- Inlet channels are likely to deliver fewer carp into wetlands during filling than will move into wetlands via outlet channels during emptying.

Chapter 3: Proof of Concept – Carp Separation Cage Trials & Designs

3.1 Introduction

The application of CSCs to riverine and fishway scenarios continues to develop with improvements in cage design and function made with each new application. Since the initial wetland CSC trials in the Lachlan River in 2007 there have also been a number of studies carried out further testing the efficiency of Carp Separation Cages at wetlands. Advances have also been made in the automation of cage lifting, although this remains costly and limited by the OH&S aspects of CSC function and use. The results of these studies are detailed below to provide a summary of the status CSC technologies at the time of writing. The Lachlan River CSC trials have contributed significantly to developments in cage design and recommendations for installation of CSCs in the Lachlan must take into account these developments.

3.2 Banrock Station Wetland Carp Separation Cage trial

A CSC trial was undertaken in South Australia in Banrock Station Wetland which is connected to the Murray River via an inlet and outlet channel. A CSC was placed in the inlet and outlet channels of the wetland over a six month period from June to December 2008, with each CSC set and checked on a weekly basis. During the six months that the inlet channel CSC was set, only four carp had entered the CSC with the flow and none of these fish jumped. The outlet channel CSC however, caught 1870 carp, with 1495 carp jumping (separating) and 395 carp remaining in the funnel section, with a separation efficiency of 79.95% (unpublished data, SARDI Aquatic Sciences & Adelaide University). The separation efficiency is higher than the trials conducted in the Lachlan catchment 2007 with the Banrock trial catching significantly higher numbers of fish. These results further demonstrate the potential for CSC installation in similar wetlands in the Lachlan such as Lake Brewster. The results very closely match those for the Lachlan and Brenda Park Trials suggesting that carp moving upstream into emptying or flowing wetlands are must be a primary target for trapping and CSC installation.

3.3 Murray River Carp Separation Cage trial.

From November 2007 to February 2008 a study was undertaken at Blanchetown on the Murray River testing the efficiency of a CSC installed in the Lock 1 fishway (Figure 26) over four distinct periods of sampling. The CSC was checked every 24 hours through each of the study periods and the daily catch was weighed as a proxy indicator of fish abundance (due to the large quantities of fish moving through). In the first two trials the separation efficiency of carp was 83 and 72% respectively and by the third and fourth trials the efficiency had dropped to 57 and 41% respectively.

This decrease in efficiency was attributed to the biological and physiological changes in the carp populations, with a higher number of fish being in prime spawning condition at the beginning of the study and the decrease in their spawning condition towards the end. The overall separation efficiency of the study was 61%, with 5,426 carp entering the cage and 3,349 of these carp jumping into the separation cage (Conallin *et al.* 2008). The results indicate that even with a large number of fish moving into the CSC, this setup can separate carp from non-jumping natives at an efficient rate providing commercial quantities of carp. This study also highlights the importance of higher flows in the stimulation of large scale carp migrations and emphasises the need for synchronisation of operations with peak carp spawning conditions.

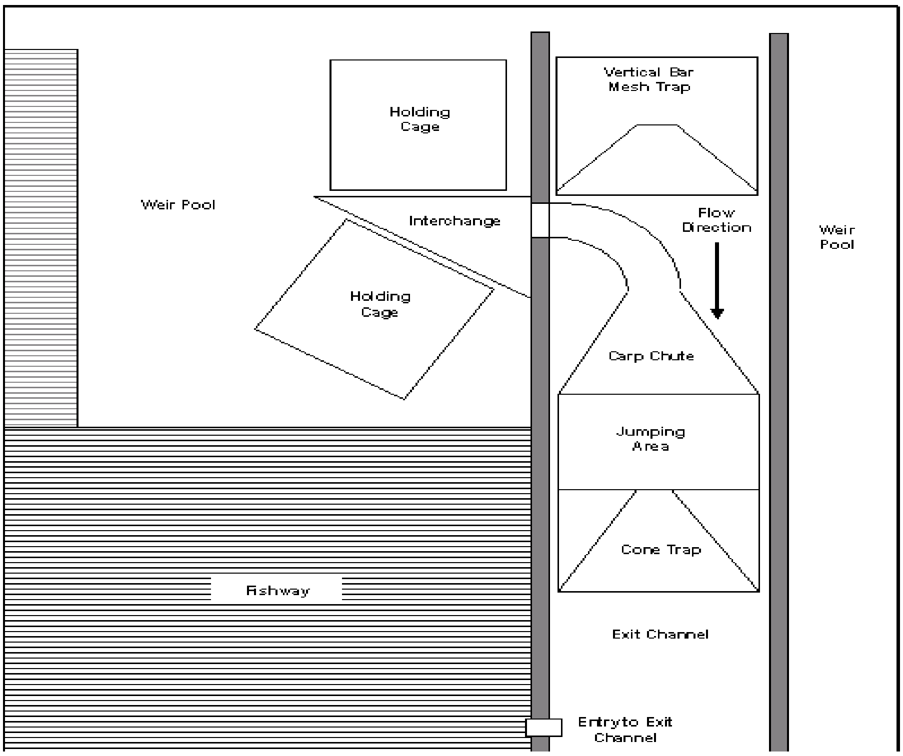


Figure 26: Schematic of the Lock 1 carp control setup in relation to the fishway, weir pool and exit channel.

3.4 Carp Cage designs

There are a number of new carp cage designs that are currently in operation for the application to fishways in the main river channel and new carp cage designs are being applied to wetlands with a prototype cage trialled at Lake Bonney in South Australia in 2010.

3.4.1 Williams' carp separation cages

The Williams' cage was named after Alan Williams, a weir keeper at Torrumbarry, who designed the initial carp separation cage based on his observations of carp behaviour. Mr Williams noted that carp jumped out of the water in a bid to escape, whereas this behaviour was not displayed by native fish. The Williams' cage is designed to separate jumping carp from non-jumping native fish. This aids the selective removal of carp from waterways while allowing passage of native species. Williams' cage designs have undergone five iterations. This discussion describes the design and use of these prototypes including the fifth iteration, the 'Mark V Williams' cage'.

3.4.2 Mark IV

As of December 2010, the Mark IV Williams' cage is operational in three vertical-slot fishways, with long exit channels, along the Murray River (Table 12; Figures 27 & 28), with plans for installation in another two fishways. In 2007, the Mark IV cage removed 80 tonnes of adult carp (Figure 29) at Lock 1 (SA) with negligible by-catch of native fish (Conallin *et al.* 2008). This cage also incorporates vertical-bar mesh for constant passage of small-bodied native fish and laterally compressed fish.

Table 12. Mark IV Williams' cage design operating in a number of locations

Mark IV Fishway	Operation
Lock 26	Torrumbarry Weir fishway (Vic)
Lock 1 fishway	Blanchtown (SA)
Lock 10 fishway	Wentoworth (NSW)
Lock 3 fishway (in design)	Waikerie (SA)
Lock 6 fishway (in design)	Renmark (SA)

Figure 27: The Mark IV Williams' cage at Lock 10. This cage can only be used within the fishway exit channel.

Figure 28: The Lock 1 Mark IV carp separation cage

Figure 29: Catch of adult carp from Mark IV Cage at Lock 1.

3.4.3 Mark V

The success of the Mark IV Williams' separation cage was somewhat reduced at many fishways because the technology was only suitable within a long (4-6 m) open fishway channel. It was not applicable in Denil, lock or vertical-slot designs where the baffles extended to the exit.

To redress this deficiency, Mr Williams of Goulburn-Murray Water built a scale physical model of a new weir pool separation cage (Mark V) in 2007. This model operated as a proof-of-concept. The Mark V design could potentially advance the 'within-channel' Mark IV cages which had a limited rollout. The Mark V design works on the same 'carp jumping' principle but is operated in the weir pool as this location negates an extra long and expensive fishway exit channel.

In addition, the Mark V design (Figure 30) has several other advantages over the Mark IV version: it can operate on the exit of any fishway type (Denil, vertical-slot, lock) and exit configuration, more carp and native fish biomass can be held, the trapped biomass can be held in lower water velocity conditions, native fish are exited into the weir pool rather than into the fishway, the Mark IV cage is more transferable among exits or different fishways, and access and removal of carp is more efficient.

Figure 30: The Mark V Williams' cage tested at Lock 10 in April 2008. This cage is used within the weir pool and is shown in the 'tipped' or fish release position. The carp holding cage with the adjustable jumping baffle remains upright in the background.

In late 2008 and early 2009, two Mark V Williams' carp cages were constructed and these are operating at Lock 10 fishway (Murray River, NSW; Figure 30) and Island Creek fishway (Lachlan River system, NSW; Figure 31).

Figure 31: The Island Creek Mark V Williams' carp separation cage on the Lachlan River system.

3.4.4 Conclusion

Each fishway requires a specific cage design, though with the Mark IV and V technology there is now great flexibility in application of carp cages. Both designs are now being adopted by industry and river management agencies and constitute a major carp management tool. Disposal of carp still remains an issue to be resolved at some sites and this is best managed with careful planning and cooperative industry/community partnership.

3.5 Lake Bonney Wetland Carp Cage

A prototype wetland carp cage was trialled at Lake Bonney in South Australia by the SARDI Aquatic Sciences Invasive species sub-program. A full outline of the Lake Bonney Cage Design and installation can be obtained in a report by Thwaites and Smith (2010). The cage was developed to operate within wetland systems and Figure 32 is a schematic of the setup trialled at Lake Bonney, a wetland with a single inlet/outlet channel. The cage was designed to work within a culvert and may be adapted to suit specific locations and was also designed to be less labour intensive with an automated winch (run by a generator) to lift the cage. The gantry framework allows the cage to be emptied into a trailer that is parked. The cage and gantry setup meets all Occupational, Health and Safety guidelines. These automated designs have proven to be extremely expensive with price tags in excess of $150,000 for prototype structures. Future research and refinement will be required to make unit prices affordable, or to develop transportability to allow multiple positioning of automated towers across a number of sites.

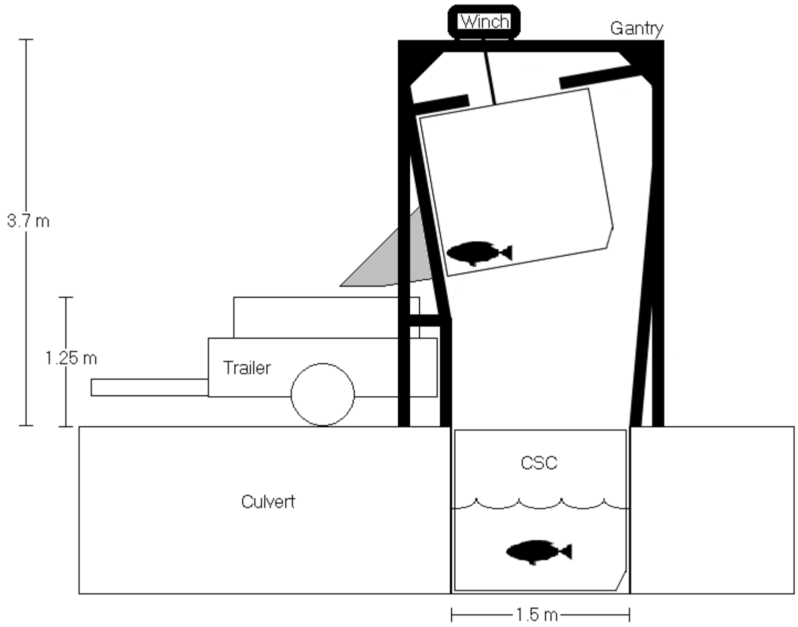


Figure 32: Schematic of the wetland carp cage at Lake Bonney SA (picture: Leigh Thwaites, SARDI Aquatic Sciences).

3.6 Decision Support Package

In late 2009, SARDI produced a decision support package for the Invasive Animals Cooperative Research Centre aimed at providing managers with information and direction regarding carp management options in wetland habitats (Smith *et al*. 2009).

The document outlines the benefits and limitations of various carp control actions and provides a framework for assessing options and selecting the most appropriate approach based on the intent and objectives of a given project. It also outlines some of the considerations that should be addressed in the development of carp control programs to assist community and local management groups in initiating control programs.

It is recommended that this document be considered at the time of project planning for any carp control activity that targets wetland sites such as those in the Lower Lachlan River. Inevitably, a combination of methods will be ideal to provide maximal outcomes from carp control works and this decision support package will be a useful tool in developing a sensible strategic approach to planning carp control investment tailored to individual target sites.

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