Identifying and implementing targeted carp control options for the Lower Lachlan Catchment

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NON-TECHNICAL SUMMARY

Identifying and implementing targeted carp control options for the Lower Lachlan Catchment.

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NON TECHNICAL SUMMARY:

Common carp (*Cyprinus carpio*) is one of the world's eight most invasive fish species and is perceived as a significant ecological pest in many of the countries where they have been introduced. They are generally considered the worst aquatic pests present in Australia, being implicated in the degradation of many Australian river systems. As a result, there is a strong desire shared amongst the community, government, natural resource managers and researchers to develop and apply carp control programs to manage their impacts. The Invasive Animals Cooperative Research Centre (IA CRC) called for proposals for demonstration site projects where carp control strategies could be applied to show-case invasive animal control techniques. Concurrently, the Lachlan Catchment Management Authority (LCMA) had identified the control and management of carp as a high priority management outcome for the catchment within the Lachlan Catchment Action Plan. Based on the combined needs of the IA CRC and LCMA, the large carp population in the catchment, the isolation of the Lachlan River from other catchments in the Murray-Darling Basin and the presence of a supportive community in the Lachlan valley, the lower Lachlan catchment was established as a 'demonstration site' for carp control. The project was badged the *River Revival – Lachlan River Carp Cleanup* and consists of two phases: An initial benchmarking phase and a subsequent implementation phase. This report presents the results of the benchmarking phase of the project.

The objectives of the benchmarking phase included the collection of baseline data on the status of the local carp population and of those aquatic ecosystem variables which carp have been implicated as having a negative impact on. A social dimension was also incorporated into the benchmark assessment by undertaking a survey of the Lachlan Valley community's attitudes towards carp and

their impacts and the health of the Lachlan River. At the same time, a number of auxiliary assessments and pilot exercises were undertaken, and plans were developed for the infrastructure that would facilitate rapid implementation and adoption of control tools and strategies as they became available.

We collected a large amount of scientifically robust and standardised data which can be used to assess performance of delivery of carp control tools and strategies within the demonstration reach (see Chapter 2). Commencing in January 2007, water quality variables were recorded quarterly and the species richness, abundance and biomass of native fish, diversity of macro-invertebrate families, cover of aquatic macrophyte beds and the length of eroded bank were recorded annually at sites throughout the Lachlan River demonstration reach, as well as in neighbouring catchments. The abundance, biomass and recruitment of carp at each site were also recorded. Carp were the most widespread fish species collected, the second most abundant, and made up 78% of the total fish biomass within the lower Lachlan River. There were three principal recruitment areas between 2007 and 2009; (i) the lower Lachlan River and Great Cumbung Swamp, (ii) the upper Lachlan River around Cowra – Goologong; and (iii) Lake Cargelligo, Lake Brewster and riverine sites immediately downstream. However, like several other studies that have studied the environmental impacts of carp, we did not detect significant relationships between carp biomass and turbidity, nutrient concentrations within the water column, stream bank erosion, macrophyte cover, macro-invertebrate diversity, native fish diversity or total native fish biomass. We did detected a significant relationship between the biomass of carp and the biomass of algae, but algal biomass was highest at sites with low carp biomass, which is the opposite relationship to that expected if carp did in fact have negative impacts on the ecosystem. Given the weak relationships between carp biomass and the condition of the ecosystem, a rapid response in ecosystem health may be an unrealistic expectation even if a carp control plan for the lower Lachlan is extremely successful.

In order to determine the likely responses of aquatic macrophyte cover, benthic macro-invertebrates, zooplankton and small fish assemblages to effective carp control, we constructed carp-proof exclusion plots at three locations within the demonstration reach (see Chapter 3). Like the data above, preliminary exploration of data from the exclusion plots provides little support for the hypothesis that carp impact upon the diversity and abundance or biomass of small native fish species, emergent or submerged macrophytes or zooplankton density. However, the abundance of benthic macro-invertebrates does appear to show that carp are exerting pressure on benthic macro-invertebrate populations. The exclusion plots will be monitored for a further 12 months to assess the longer-term ecosystem response to carp exclusion.

In order to prepare for the subsequent implementation phase of the project we installed a Williams Carp Separation Cage (WCSC) within the demonstration reach at Island Creek Weir (Chapter 4), undertook a feasibility study for a carp eradication exercise for the Lake Cowal – Bland Creek sub-catchment (Chapter 5), developed a research plan to study the dynamics of carp recruitment within the Great Cumbung Swamp (Chapter 6) and established a pool of over 3,000 tagged carp within the demonstration reach that will be used to gauge the relative cost-effectiveness of those carp removal strategies utilised during the subsequent implementation phase of the project (Chapter 7).

The intention of the upcoming implementation phase of the project is that IA CRC developed carp control tools and strategies can be applied within the lower Lachlan River demonstration reach to reduce carp biomass relatively quickly and to an extent that reduced impacts of carp on the aquatic environment can be demonstrated by measurable recovery of aquatic ecosystem variables – particularly water quality. Emphasis will also be on engaging the community of the Lachlan catchment and encouraging them to become involved with implementing aspects of the carp control plan wherever possible.

KEYWORDS:
Common carp, pest control, Lachlan River.

1. INTRODUCTION

Common carp (*Cyprinus carpio*) has been identified by the IUCN as one of the world's eight most invasive fish species (Lowe *et al.* 2000). Although they are an important food source for humans and are also a common target species for recreational anglers across their native range (Panek 1987; Lin and Peter 1991; Splitler 1987), carp are perceived as a significant ecological pest in many of the countries where they have been introduced (Lamarra 1975; Cooper 1987; Koehn *et al.* 2000) and are generally considered the worst aquatic pest fish present in Australia and New Zealand (Chadderton *et al.* 2003). Carp have been implicated in the degradation of many Australian river systems, particularly those in the Murray-Darling Basin (Koehn *et al*. 2000), and have been declared a noxious species in most states and territories. In NSW, the introduction of carp (and other fish species) into new catchments is recognised as a key threatening process to threatened fish and aquatic ecosystems under the *Fisheries Management Act* (1994).

In Australia, the impacts of carp are estimated to cost ~$15.8 million dollars annually (McLeod 2004), $2 million of which is spent on carp management, $2 million on research and $11.8 million on remediation of environmental impacts. Increased sediment re-suspension and turbidity, increased concentrations of dissolved nutrients within the water column, negative impacts on the development of autotrophic biofilms, increased intensity or incidence of phytoplankton blooms, damage to stream banks, loss of aquatic vegetation, changes in zooplankton and benthic invertebrate community composition and biomass, declining native fish populations, declining waterfowl populations and predation on endangered amphibians have all been attributed to carp populations (see Table 1.1 for references). Further, it has been proposed that impacts of common carp result in the establishment of a positive feedback mechanism where the impacts escalate as the affected ecosystem deteriorates and the natural mechanism of predatory control by piscivorous fish declines (Zambrano and Hinojosa 1999, Penne and Pierce 2008). As a result, there is a strong desire shared amongst the community, government, natural resource managers and researchers to develop and apply carp control programs to manage the perceived impacts (Roberts *et al.* 1997; Roberts and Ebner 1998; Koehn *et al.* 2000).

Numerous workshops and working groups have been convened in order to develop and progress potential options for the control of carp in Australia. These include:

1. Forum on European carp (Nannestad *et al*. 1994).
2. National Carp Summit (Broster 1996).
3. Controlling carp – Exploring options in Australia (Roberts and Tilzey 1997).
4. Carp Control Reference Group
    a. National Management Strategy for carp control (2000 – 2005) (Murray-Darling Basin Commission 2000*a*).
    b. Future directions for research into carp (Murray-Darling Basin Commission 2000*b*).
    c. Ranking areas for action: A guide for carp management groups (Braysher and Barrett 2000).
5. National Carp Workshop (Lapidge 2003).

In 2004, the Commonwealth Government funded the Invasive Animals Cooperative Research Centre (IA CRC) to build upon the strong foundation provided by the previous Pest Animal Control CRC (PAC CRC). The IA CRC's aim is to counteract the impact of invasive animals through the development and application of new technologies and by integrating approaches across agencies and jurisdictions. The IA CRC draws research, industry, environmental, commercial

Table 1.1. Publications providing either experimental data or expert opinion that carp impact upon components of aquatic ecosystems.

Ecological impact	**Citations to reviews and experimental studies**
Increase sediment re-suspension and turbidity.	Crivelli (1981), Fletcher *et al.* (1985), Newcome and Macdonald (1991), Roberts *et al.* (1995), Driver *et al.* (1997), King *et al.* (1997), Robertson *et al.* (1997), Lougheed *et al.* (1998), Sidorkewicj *et al.* (1998), Zambrano *et al.* (1999), Schiller and Harris (2001), Parkos *et al.* (2003), Driver *et al.* (2005*b*), Pinto *et al.* (2005) and Matsuzaki *et al.* (2009).
Increase concentrations of dissolved nutrients within the water column.	Lamarra (1975), Meredith (1996), Lougheed *et al.* (1998), Williams *et al.* (2002); Parkos *et al.* (2003), Chumchal *et al.* (2005) and Driver *et al.* (2005*b*).
Impact on the development of autotrophic biofilms.	Robertson *et al.* (1997)
Increase the intensity or incidence of phytoplankton blooms.	Breukelaar *et al.* (1994), Gehrke and Harris (1994), King *et al.* (1997), Williams *et al.* (2002), Parkos *et al.* (2003), Driver *et al.* (2005*b*), Pinto *et al*. (2005) and Matsuzaki *et al.* (2009).
Damage to stream banks.	McCrimmon (1968) and Wilcox and Hornbach (1991).
Loss of aquatic vegetation.	Cahn (1929), Ricker and Gottschalk (1940), Black (1946), Chamberlain (1948), Anderson (1950), Cahoon (1953), Threinen and Helm (1954), Tryon (1954), Robel (1961), King and Hunt (1967), McCrimmon (1968), Crivelli (1983), Hume *et al.* (1983), Fletcher *et al.* (1985), Panek (1987), Engel (1995), Roberts *et al.* (1995), Lougheed *et al.* (1998), Sidorkewicj *et al.* (1998), Zambrano *et al.* (1999), Williams *et al.* (2002), Parkos *et al.* (2003), Bajer *et al.* (2009) and Matsuzaki *et al.* (2009).
Changes in zooplankton and benthic invertebrate community composition and biomass.	Stein and Kitchell (1975), Wilcox and Hornbach (1991), Diehl (1993), Roberts and Ebner (1997), Lougheed *et al*. (1998), Zambrano *et al.* (1999), Lougheed and Chow-Fraser (2001), Parkos *et al.* (2003), Hinojosa-Garro and Zambrano (2004), Schrage and Downing (2004), Miller and Crowl (2006) and Matsuzaki *et al.* (2009).
Impact upon native fish populations.	Lachner *et al.* (1970), Page and Burr (1991), Hindmarsh (1994), Koehn *et al.* (2000) and Bernstein and Olson (2001).
Impact upon waterfowl populations.	Chamberlain (1948), Robel (1961), King and Hunt (1967), Scott and Crossman (1973), Haas *et al.* (2007) and Bajer *et al*. (2009).
Prey upon endangered amphibians.	Hunter (2007).

and government agencies together to create and apply solutions for invasive animal threats. The Invasive Animals CRC is structured around six central programs, including a Freshwater Products and Strategies Program, which is aimed directly at the development and delivery of tools and techniques for managing Australia's freshwater invasive fish. Several of the projects under the freshwater program will provide significant information and tools necessary for targeted carp control. In 2005 the IA CRC called for proposals for the establishment of demonstration site projects (Barrett 2004, Barrett and Ansell 2005), where Freshwater Program outputs could be applied in a strategic manner for the purpose of trialling and show-casing invasive animal control techniques. Demonstration reaches usually occupy large reaches of river (20 – 100 km), are treated over a sufficient time scale (7 – 10 years) to be effective (Barrett 2004, Barrett and Ansell 2005, Watson 2009) and are often located close to large population centres so the benefits of the integrated management approach are readily observed by and engage the community.

Concurrently, the Lachlan Catchment Management Authority (CMA) had identified the control and management of pest species as a high priority management outcome for the catchment within the Lachlan Catchment Action Plan (Lachlan Catchment Management Authority 2006). The Lachlan valley community had identified carp control as a key issue in a survey conducted in 2003 (Byron *et al.* 2006) and the Lachlan CMA are committed to developing a carp control plan for the catchment.

Based on the combined needs of the IA CRC and Lachlan CMA, the Lachlan catchment in central-west New South Wale (85,532 km^2) was proposed as a potentially suitable 'demonstration site' for carp control. The Lachlan River flows in a westerly direction, from its headwaters in the foothills of the Great Dividing Range near Gunning and terminates in the Great Cumbung Swamp near Oxley in south-western New South Wales (Figure 1.1). The Lachlan River has an overall length of 1,450 km (Department of Land and Water Conservation. 1997) and its flow is regulated by numerous weirs and off-takes along its length. Wyangala Dam (1,218 GL capacity), located upstream of Cowra near the confluence of the Lachlan and Abercrombie rivers is the major regulatory structure on the Lachlan. For the purpose of the demonstration reach, the Wyangala Dam wall was used to delineate the Lower Lachlan region from its upper catchment headwaters. The waterways of the lower Lachlan River have been formally recognised as an Endangered Ecological Community (EEC) under the *Fisheries Management Act* 1994 and the current health of the lowland zone of the Lachlan River system has been classified as very poor (Davies *et al.* 2008), being the fifth worst of 23 valleys in the Murray-Darling Basin. The *Fisheries Management Act* 1994 identifies the introduction of invasive fish species to freshwater environments, including common carp, as one of six key threatening processes that has contributed to this situation.

There are several reasons why the lower Lachlan catchment provides a unique opportunity for implementation of a carp control demonstration program in the Murray-Darling Basin.

Firstly, the Murray-Darling Basin Authority's *Sustainable Rivers Audit* program recorded that the lowland zone of the Lachlan catchment has both the second highest abundance (Davies *et al.* 2008) and biomass (MDBA, unpublished SRA data) of carp of any of the catchment zones within the Murray-Darling Basin. This abundant carp population provides a large number of animals upon which field trails of available carp control tools can be tested.

Secondly, sufficient pre-existing data exist within the catchment to allow the identification of at least four primary carp recruitment areas, or 'hotspots' (Gilligan, in prep) within the lower Lachlan catchment: Great Cumbung Swamp, Lake Brewster, Lake Cargelligo and Lake Cowal. Downstream dispersal of carp from Lake Wyangala into the lower Lachlan catchment also occurs, although Lake Wyangala itself is outside the boundaries of the proposed demonstration reach. Significant flooding events would also result in the connection and subsequent inundation of a number of potential secondary 'hotspots', including: Lake Ita, Lake Waljeers, Booligal Swamp, Booligal Wetland, Murrumbidgil Swamp, Lake Merrimajeel, Bogandillon Swamp, Comayjong Swamp and Baconian Swamp, some of which are wetlands of national significance. Pre-existing

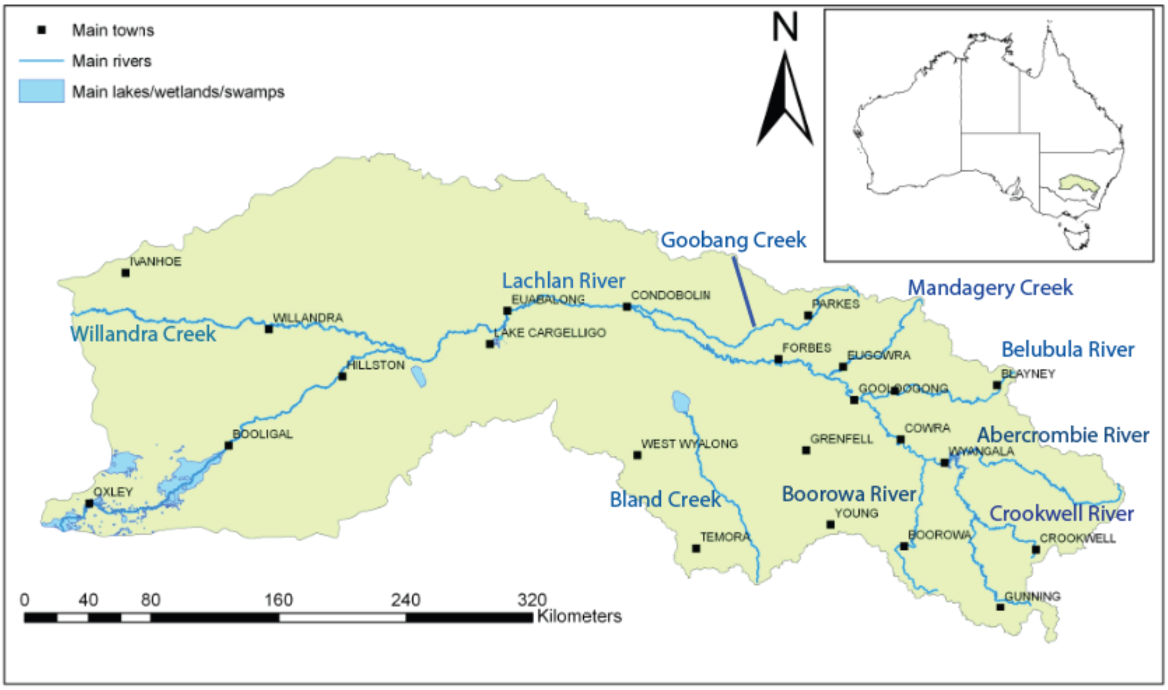


Figure 1.1. The major waterways and towns within the Lachlan catchment.

knowledge of known and likely carp recruitment 'hotspots' within the catchment means that we have a finite number of locations within the demonstration reach upon which control actions can be targeted. It is anticipated that by targeting control actions at primary 'hotspot' locations, the chances of achieving catchment-wide carp control can be maximised. Persistent drought since 2001 has resulted in the drying out of most of the lakes and wetlands within the system. This presents opportunities to achieve early gains in carp control within the system, as resident carp populations within potential hotspot locations have been eliminated and installation of exclusion devices may prevent carp from accessing these important recruitment areas when flows recommence. Within those hotspot locations that have retained water, such as the Lake Cargelligo system and Lake Wyangala, the reduced water levels have concentrated carp into smaller areas and may have excluded them from potential spawning sites.

Thirdly, the Lachlan system is typically endorheic and is largely isolated from the remainder of the Murray-Darling Basin. The terminus of the lower Lachlan River, the Great Cumbung Swamp only spills into the adjacent Murrumbidgee River during periods of exceptionally high flow (15 – 20% of years) (O'Brien and Burne 1994), the two most recent being in 1974 (the year carp entered the Lachlan catchment (Roberts and Sainty 1996)) and in 1990 (Patrick Driver, pers. comm.). As a result, the carp population within the lower Lachlan catchment is not exposed to continual immigration from the Murrumbidgee carp population, effectively isolating the Lachlan catchment as a single management unit and an ideal demonstration reach within the Murray-Darling Basin.

Lastly, the Lachlan valley community is supportive of and willing to assist with implementation of a carp control program for the catchment.

The proposal for a carp control demonstration reach in the lower Lachlan catchment was adopted by the IA CRC and funds were provided by the Lachlan CMA, IA CRC and the NSW Department of Environment, Climate Change and Water (DECCW). The project is a collaborative program involving additional in kind commitments from Industry & Investment NSW (I&I NSW), the Lachlan Catchment Management Authority (LCMA), South Australia Research and Development Institute (SARDI), Victorian Department of Sustainability and the Environment (DSE Vic), K. & C. Fisheries Global Pty. Ltd., Kingfisher Research Pty. Ltd., NSW State Water Corporation and the Lachlan Valley community (e.g., shire councils, indigenous groups, recreational fishing clubs, community groups etc.). The project addresses four of the IA CRCs goals:

- CRC objective 4. A capacity to deliver improved quality and availability of inland water through reduced impacts and rates of spread of carp and other pest fish species.
- CRC objective 9. Growth in Australian invasive animal pest control industries by supporting industry in registration, marketing, export and community uptake of products.
- CRC objective 10. Increased professional and practical skills base in invasive animal management through education, training and community awareness.
- CRC objective 11. Established national and local benchmarks for invasive animal impact, density and distribution from which performance on delivery of all outcomes can be assessed.

The project was badged the *River Revival – Lachlan River Carp Cleanup* and consists of two phases. An initial benchmarking phase and a subsequent implementation phase. The benchmarking phase commenced in January 2007 and concluded in February 2009 when the implementation phase commenced with the removal of the first carp from the system at the Island Bend fishway Williams Carp Separation Cage. The objectives of the benchmarking phase were to collect baseline data on the status of the local carp population and of those aquatic ecosystem variables which carp have been implicated as having a negative impact on prior to the implementation of control options. A social dimension was also incorporated into the benchmark assessment by undertaking a survey of the Lachlan Valley community's attitudes towards carp, their impacts and the health of the Lachlan River. Concurrent with the detailed benchmarking exercise, a number of auxiliary assessments and pilot exercises were undertaken and plans were developed for the infrastructure that would facilitate rapid implementation and adoption of control tools and strategies as they became available through the implementation phase.

Project activities of the benchmarking phase included:

1. Benchmark the status of the local carp population and the status of those aquatic ecosystem variables carp have been implicated in impacting on (undertaken by I&I NSW).
    - Carp abundance and biomass
    - Carp recruitment
    - Native fish community composition (species richness, abundance and biomass)
    - Aquatic macrophyte cover
    - Bank stability
    - Aquatic macroinvertebrate diversity
    - Water quality (turbidity, chlorophyll *a* concentrations and nutrients)
2. Benchmark social attitudes towards carp and their impacts (Deakin University, I&I NSW and the Lachlan CMA).
3. Use otolith micro-chemical analysis as a means of determining the relative contribution of hotspots within the system to the overall carp population within the lower Lachlan (SARDI and DSE Vic).
4. Field trials of carp trapping tools at Lake Brewster, Lake Cargelligo and the Great Cumbung Swamp (SARDI).
5. Established a series of replicate carp exclusion plots to help quantify the expected response of a sub-set of aquatic ecosystem variables to carp exclusion (to represent the expected nil impact condition) (I&I NSW).

6. Installation of a fishway William's Carp Separation Cage at existing vertical-slot fishways within the catchment (I&I NSW and Kingfisher Research).
7. Four weeks of commercial fishing in order to establish familiarity with the system and refine harvest technologies to maximise catch rates during the implementation phase (K. & C. Fisheries).
8. Development of a carp management plan for Lake Brewster in concert with current water resource development within the storage (Lachlan CMA, SARDI and Kingfisher Research).
9. Undertake a feasibility study for a carp eradication program within the drought affected Lake Cowal – Bland Creek subcatchment (I&I NSW).
10. Assess the recruitment biology of carp within the Great Cumbung Swamp (I&I NSW).
11. Establish a pool of tagged carp within the demonstration reach as a tool to assess the relative cost-efficiency of the range of carp removal tools during the implementation phase (I&I NSW and K. & C. Fisheries).
12. Development of a formal communications plan for the project (Lachlan CMA).
13. Facilitate community engagement by attendance at and sponsorship of community carp-muster events (Lachlan CMA, I&I NSW, SARDI and K. & C. Fisheries).

Each of these project activities was undertaken or contracted by one of more of the projects collaborative partners. Those components managed by I&I NSW (1, 5, 6, 9, 10, and 11) are presented as chapters in this report. Executive summaries and citations to those reports produced for project components managed by other collaborators or sub-contractors are provided in the appendices.

2. BENCHMARKING THE STATUS OF CARP POPULATIONS AND THE CONDITION OF NATIVE FISH COMMUNITIES AND OTHER AQUATIC ECOSYSTEM FEATURES PRIOR TO THE IMPLEMENTATION OF CARP CONTROL ACTIVITIES IN THE LACHLAN

2.1. Introduction

Common carp (*Cyprinus carpio*) are considered 'ecosystem engineers' (Matsuzaki *et al.* 2009) and have been implicated in the degradation of many Australian river systems, particularly those in the Murray-Darling Basin (Koehn *et al*. 2000). They are generally considered the worst aquatic pest species present in Australia and New Zealand (Chadderton *et al.* 2003) as well as in many of the countries where they have been introduced (Lamarra 1975; Cooper 1987; Koehn *et al.* 2000).

Increased sediment re-suspension and turbidity, increased concentrations of dissolved nutrients within the water column, negative impacts on the development of autotrophic biofilms, increased intensity or incidence of phytoplankton blooms, damage to stream banks, loss of aquatic vegetation, changes in zooplankton and benthic invertebrate community composition and biomass, declining native fish populations, declining waterfowl populations and predation on endangered amphibians have all been attributed to carp populations (see Table 1.1). Further, it has been proposed that impacts of common carp result in the establishment of a feedback mechanism where the impacts escalate as the affected ecosystem deteriorates. This eventuates as the natural mechanism of predatory control by native piscivorous fish declines (Zambrano and Hinojosa 1999, Penne and Pierce 2008), or, because of the collapse of the trophic structure in carp affected ecosystems, carp are forced to forage more actively, further exacerbating sediment re-suspension and turbidity and their flow-on effects (Zambrano *et al.* 2001).

The establishment of national and local benchmarks for invasive animal impact, density and distribution is one of the 13 goals of the Invasive Animals CRC and is particularly relevant for demonstration site projects. The quantification of the current status of the carp population within the demonstration reach and of those aquatic ecosystem variables most likely to respond as a result of carp control is therefore a central component of the initial benchmarking phase of the *River Revival – Lachlan River Carp Cleanup*. The intent of the benchmarking exercise and subsequent monitoring program is to provide scientifically robust and standardised data which can be used to assess performance of delivery of carp control tools and strategies within the demonstration reach (Braysher 2007). This can be achieved both by assessing change in the status of carp populations within the catchment directly (abundance, biomass and recruitment) as well as by assessing the responses in those environmental parameters that carp have a perceived impact upon.

We established an ecological monitoring program based on the recommendations of Downes *et al.* (2002). This included the establishment of monitoring sites within the main channel of the Lachlan River (the treatment system) with control sites in the two neighbouring drainages to the north and south of the Lachlan: the Macquarie River and Murrumbidgee River (Figure 2.1). These monitoring sites were sampled during the benchmarking phase, before carp control actions were applied, and will continue to be sampled after carp control actions commence in the Lachlan River (during the implementation phase). Graphical summaries of the benchmark data and power analyses describing the minimum effect size (change in parameter values) detectable based on variance in the data collected during the benchmarking phase are provided here.

2.2. Methods

2.2.1. Study sites

Riverine monitoring sites within the Lachlan were selected systematically rather than randomly. Given the 'demonstration reach' nature of the project (Barrett 2004, Barrett and Ansell 2005), it was important in the context of the communications strategy to foster community familiarity with the outputs and to ensure that sites were dispersed throughout the entire study area. Therefore 12 sites were established in the Lachlan River to represent each town or other major river access point along the river, dispersed roughly equi-distantly from Cowra (292 m ASL, the most upstream riverine site) downstream to Braebuck Woolshed (79 m ASL, the most downstream) (Figure and Table 2.1). The selection of suitable control sites was necessary to allow inference that any changes observed within the Lachlan were a result of the management interventions, as opposed to broader processes occurring across the region (Downes *et al.* 2002). However, as is typical for monitoring programs within lotic aquatic ecosystems, the identification and selection of suitable control sites was problematical (Downes *et al.* 2002). The Lachlan catchment has a unique character resulting from its particular geography, climate, geology, river regulation and its linkages within the nested hierarchy of catchments within the Murray-Darling Basin. Based on their proximity to the Lachlan, the neighbouring Macquarie and Murrumbidgee Rivers were the only reasonable candidates for controls. Although neither drainage is entirely analogous to the Lachlan, they represent the best available and most similar systems. However, because of inflows into the Murrumbidgee from the Snowy Mountains Hydro Scheme, and the alpine drainage of the Murrumbidgee catchment, the Macquarie is hydrologically the more similar of the two control systems. Five sites were established within each control river (Figure and Table 2.1). We are not aware that the Murrumbidgee or Central-West Catchment Management Authorities are planning any carp control programs that are likely to confound our assessment in the Lachlan.

Additional sites were established within areas believed to be primary carp recruitment areas, or 'hotspots' (Gilligan, in prep) that contribute recruits to the lower Lachlan catchment. These were the Great Cumbung Swamp, Lake Brewster, Lake Cargelligo, Lake Cowal and Wyangala Dam (Figure 2.1 and Table 2.1). The Great Cumbung Swamp, Lake Brewster and Lake Cargelligo in particular will be targeted under the carp control plan commencing during the implementation phase. For analyses, data from these sites were not pooled with riverine monitoring sites within the Lachlan, but represent a fourth 'location' category within the data set.

2.2.2. Fish sampling

Fish communities (including carp) were sampled using a standardised electrofishing/bait trap protocol as established by the Sustainable Rivers Audit for the Murray-Darling Basin (Murray-Darling Basin Commission 2006). The SRA procedure is based on electrofishing (either boat, back-pack, bank-mounted, or a combination of each depending on local conditions) with additional use of un-baited shrimp traps. This provides a consistent quantitative assessment of fish communities. Data collected include species identity, catch-per-unit-effort, and the length of individual fish. Biomass and the proportion of new recruits in the population are derived from the length data.

Either large 4.5 m boat (Smith-Root GPP 7.5 H/L) or small 3.7 m boat (Smith-Root GPP 2.5H/L) mounted electrofishing was undertaken depending on the site conditions. Large boat electrofishing was undertaken at most sites, with a small boat electrofisher used at smaller less navigable sites. All navigable habitats were sampled with the boat electrofishers. Boat electrofishing sampling effort consisted of twelve 90 second (power on) boat electrofishing operations. Each operation was undertaken using intermittent electrofishing, with a ~15 second application of power followed by a pause and advance of the boat to new habitat. This protocol was adopted to minimise 'herding' of fish. Two of the twelve operations were undertaken 'mid-stream' to sample potential pelagic fish. Each operation took an average of four minutes to complete. Backpack electrofishing (NIWA EFM300) was undertaken where a boat could not be launched, but where wading was possible. Backpack operations consisted of 150 seconds of electrofishing (power on). Each operation was undertaken using intermittent electrofishing, with the backpack used to fish all areas accessible to the stationary operators (1.5 – 2 metre radius). Following electrofishing of that area, the operators moved ~3 m and repeated the process. Each backpack operation took an average of seven minutes to complete. Where the River channel was less than 10 m wide, the stream was fished in a 'zig-zag' pattern. In areas where the river channel was wider, shots were alternated between banks.

During each operation, dip-netters removed all electrofished individuals and placed them in an aerated live-well (boat fishing) or bucket (backpack fishing). All individuals that could not be dip-netted but could be positively identified were recorded as 'observed'. All electrofishing was undertaken during daylight hours.

Ten commercially available collapsible shrimp traps were set (un-baited) in an attempt to sample small benthic fish species typically under-represented in electrofishing samples. Traps were set for a minimum period of two hours whilst electrofishing was being undertaken. Bait traps were set in water less than 1 m deep.

At the completion of each operation (electrofishing and shrimp traps), captured individuals were identified, counted, measured and observed for health conditions such as externally visible parasites, wounds, diseases etc. before being released. All taxa were recorded to species level except for carp-gudgeons, which were recorded as *Hypseleotris* spp. In the case of difficult identifications, specimens were preserved in ethanol for laboratory identification. Length measurements to the nearest millimetre were taken as fork length for species with forked tails and total length for other species. Where large catches of a species occurred, only a sub-sample of individuals were measured and examined for each gear type. The sub-sampling procedure consisted of measuring all individuals in each operation until a total of at least 50 individuals had been measured. Only 20 individuals of that species from subsequent operations of that gear type were measured. All additional individuals were only counted. Sub-sampling for health status involved careful observation of one side (usually the left) of every fish that was measured.

Sampling was conducted annually between 5 March and 3 April 2007, 26 March and 27 May 2008 and 12 January and 24 March 2009.

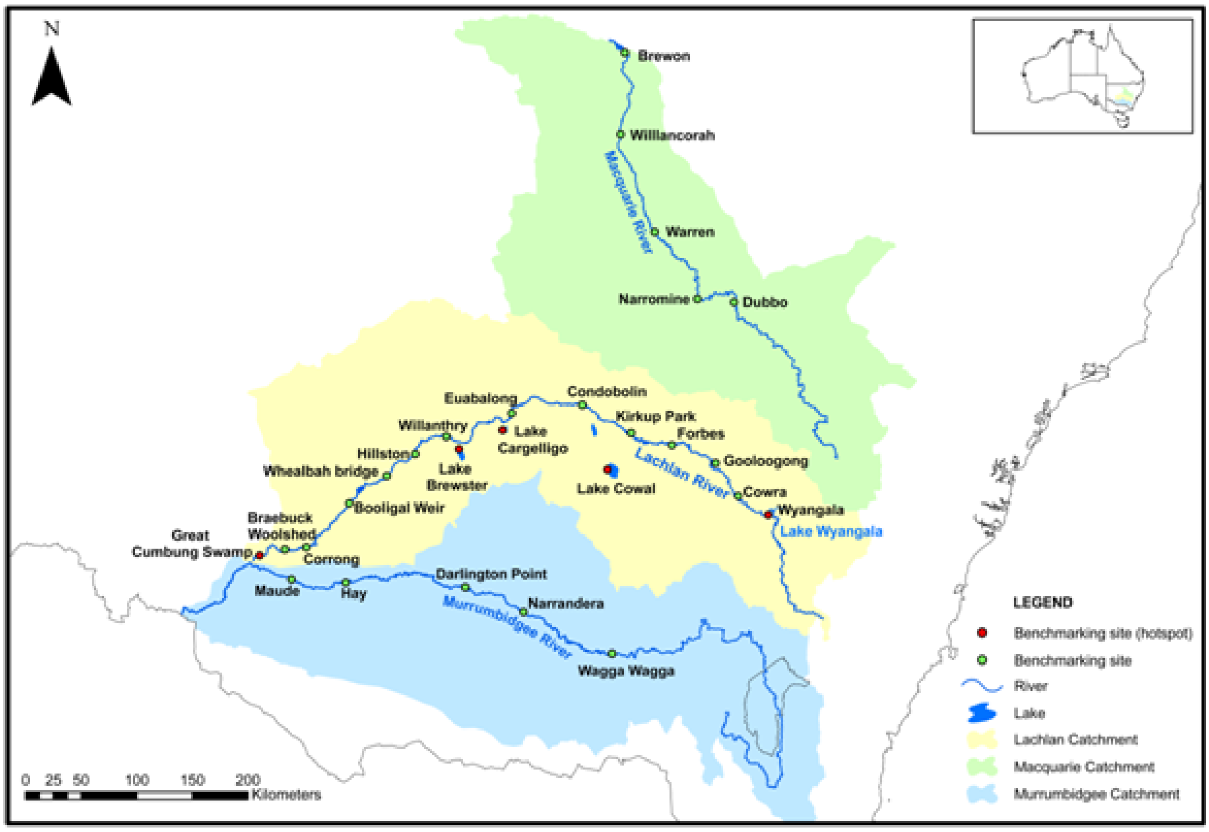


Figure 2.1. Map of Lachlan treatment sites, Macquarie and Murrumbidgee control sites and Lachlan hotspots sites established to monitor the performance of carp control tools and strategies applied in the lower Lachlan carp control demonstration project.

Table 2.1. Sites sampled for benchmarking within each catchment. Hotspot locations are shaded in grey.

Site Name	I&I NSW Site No.	Waterbody	Latitude	Longitude	Altitude (m)
Lachlan River					
Wyangala Dam	15510	Lake Wyangala	-33.95783	148.96776	377
Cowra	15502	Lachlan River	-33.494344	148.405011	292
Gooloogong	15504	Lachlan River	-33.60724	148.43471	267
Forbes	15500	Lachlan River	-33.240434	148.010459	245
Lake Cowal	N/A	Lake Cowal	-33.383806	147.274314	202
Kirkup Park	95	Lachlan River	-33.31707	147.61935	254
Condobolin	186	Lachlan River	-33.09092	147.15091	212
Euabalong	707	Lachlan River	-33.11143	146.47568	165
Lake Cargelligo	15501	Lake Cargelligo	-33.29939	146.37819	152
Willanthry	15512	Lachlan River	-33.34404	145.83894	140
Lake Brewster	15511	Lake Brewster	-33.252810	145.575134	133
Hillston	185	Lachlan River	-33.47926	145.53165	123
Whealbah Bridge	36	Lachlan River	-33.65090	145.25529	104
Booligal Weir	60658	Lachlan River	-33.87386	144.87866	98
Corrong	721	Lachlan River	-33.22451	144.45802	80
Braebuck Woolshed	722	Lachlan River	-34.19706	144.11160	79
Great Cumbung Swamp	15513	Lachlan River	-34.27632	143.99796	75
Murrumbidgee River					
Wagga Wagga	3610	Murrumbidgee River	-35.10891	147.44566	180
Narrandera	3602	Murrumbidgee River	-34.76995	146.57395	145
Darlington Point	15508	Murrumbidgee River	-34.34025	146.00181	126
Hay	15507	Murrumbidgee River	-34.51561	144.83476	96
Maude	15509	Murrumbidgee River	-34.47500	144.29404	78
Macquarie River					
Dubbo	15503	Macquarie River	-32.25008	148.59605	258
Narromine	15506	Macquarie River	-32.22634	148.24678	236
Warren	15505	Macquarie River	-31.68598	147.83374	199
Willancorah	12945	Macquarie River	-30.90017	147.50742	135
Brewon	20	Macquarie River	-30.23379	147.54160	128

2.2.3. Macro-invertebrate sampling

Macro-invertebrates were sampled using the standard methods described in the Australian River Assessment System protocol (AUSRIVAS) (Turak *et al.* 2004). A 0.25 mm mesh kick-net was used to sample two 10 m edge transects along the river bank. All available sub-habitat types within the edge habitat were represented. Riffle samples were not collected as no riffle habitats exist at any monitoring site. Immediately after collection, samples were live-picked in the field. A minimum sorting time of 40 minutes was spent on each sample. If any new taxa were discovered after 30 minutes of picking, picking continued for a further 10 minutes from the time of discovery of the new taxa. Picking was discontinued after a maximum sorting time of 60 minutes. Collected macro-invertebrates were identified to family level using available identification keys (Hawking 2000). However, oligochaete worms could not be identified to family level and these were only identified to the level of order.

Although we followed the AUSRIVAS sampling protocols, data were not analysed using the AUSRIVAS models to assess macro-invertebrate community ‘health’ due to its apparent poor power to distinguish macro-invertebrate condition at reference and assessment sites in the Lachlan catchment (Chessman *et al.* 2006). Instead, only the number of macro-invertebrate families collected at sites is reported.

Only a single round of macro-invertebrate sampling was conducted between 18 – 21 September 2007. No macro-invertebrate sampling was undertaken in 2008 due to uncertainty regarding the utility of the data. However, despite the reported poor performance of the AUSRIVAS outputs, the macro-invertebrate results can still be legitimately interpreted using a basic taxa richness value – the number of macro-invertebrate families collected.

2.2.4. Macrophyte and bank erosion mapping

Aquatic macrophyte cover and bank erosion were mapped using handheld Trimble Nomad™ 800LC units with Terrasync™ mapping software installed. These units utilise GPS technology to enable accurate field digitisation of the aquatic habitat features. At each site, a ~ 1.2 km section of river was mapped with the co-ordinates in Table 2.1 indicating the middle of each reach. Hotspot (lake and wetland) sites were mapped in a wedge shape which extended 500 m either side of the site co-ordinates and up to 1 km into the wetland. As a digitisation template, each unit used a 1:50,000 topographical map (GDA 94_MGA Zone 55) for that region in addition to a manually digitised outline of the stream or lake bed for each site derived from SPOT 5 imagery. Each reach was divided laterally along the thalweg and two staff simultaneously mapped aquatic habitat features from opposing banks to this mid-line.

The size, shape, and area of macrophyte beds were mapped as position-independent features by drawing the outline of the macrophyte bed as a polygon onto the screen of the PDA. The identity of macrophytes was recorded to genus level using Sainty and Jacobs (2003).

Actively eroding banks were defined as areas of stream bank where removal of material by surface wash, undercutting or slope failure was evident and unchecked by plant growth or showing signs of stabilisation. The start and end point of each actively eroding bank feature were recorded as position-dependent features. A digital photo of each erosion feature was taken in the field to aid classification of the nature of the erosion. The location and length of each erosion feature was then digitised by manually drawing a polyline that linked each erosion start and end point along the contour of the stream bank.

Mapping was conducted twice at sites in the Lachlan River between 3 September and 25 September 2007 and 1 September and 19 September 2008. Sites in the Murrumbidgee and Macquarie Rivers, and Lachlan Hotspot locations were only mapped once in 2008. The Lake Cowal site was not mapped in either year as the site has remained dry since December 2005 and no aquatic vegetation or erosion was likely to be present.

2.2.5. *Water quality sampling (turbidity, nutrients and chlorophyll* a*)*

A Palintest® interface photometer 7500 was used to record the concentrations of four nutrients in the field: nitrite (NO_2), nitrate (NO_3), sulphate (SO_4) and phosphate (PO_4). Concentrations were recorded to the third decimal place in milligrams per litre (mg L^{-1}). The Palintest® photometer is self calibrating and was cleaned as per the manufacturer's instructions. Chlorophyll *a* was measured in micrograms per litre (µg L^{-1}) to the third decimal place using a Turner Designs *Aqua*fluor™ handheld fluorometer. This unit was calibrated prior to each sampling event as per the manufacturer's specifications. A Model U10 Horiba® water quality meter was used at each site to record temperature (^{o}C), pH, turbidity (NTU), dissolved oxygen (mg L^{-1}), and conductivity (µS cm^{-1}). Probes were calibrated prior to each sampling event. All samples were collected mid-stream at a depth of 20 cm, after washing the test vials *in-situ*. A second turbidity reading was recorded using a secchi disk (cm).

Water quality parameters were measured at each site four times per annum (mid summer, autumn, winter, spring) commencing in summer 2007. However, chlorophyll *a* data is not available from the first two sampling occasions as data collection for that variable commenced in winter 2007. The last round of data collected that is incorporated into this benchmarking report was collected in Spring 2008.

2.2.6. *Data analysis*

2.2.6.1. *Biomass estimation*

Biomass of carp and other native and alien species was estimated from length-weight relationships presented in Table 8 of the SRA fish theme pilot report (Murray-Darling Basin Commission 2004).

2.2.6.2. *Carp recruitment*

Recruits are young juvenile fish that represent the recent breeding activity of the population. For this study, we assumed recruits to be fish less than one year old. Brown *et al.* (2005) reports the size of carp at one year of age as approximately 150 mm (95% CI of ~90 – 210 mm). Therefore, for this study we defined carp recruits as those individuals with a fork length < 150 mm. This size limit was used as a guideline to distinguish fish which were spawned during the preceding breeding season.

2.2.6.3. *Analysis of benchmark data – Fish assemblage variables*

The sampling frame is structured by three catchment classifications (Lachlan, Macquarie and Murrumbidgee) with the Lachlan catchment further sub-divided into Lachlan River and Lachlan hotspots categories. The four catchment/hotspot classifications will be termed 'regions'. Each site was sampled for three years (2007, 2008 and 2009). Data for carp biomass, total abundance and young of year abundance (recruitment), native species richness and total native biomass were analysed using linear mixed models with sampling structure fitted as random effects and year as a fixed effect. The linear mixed model is given by:

y ~ μ + year + **site** + **catchment** + **catchment.recruitment** + **catchment.year** + **catchment.recruitment.year** + **site.year**

The terms in bold are the random effects and the underlined term is the residual error.

Carp biomass was square root transformed and carp abundance, carp recruitment, native biomass and native abundance were $\log_n$ transformed to satisfy the assumptions of normality and constant variance. For carp recruitment and native species richness, an autoregressive correlation of order 1 associated with year and unequal variances for years was used due to a significant change in the log-likelihood. The analysis was conducted using the statistical software package ASReml-R (Butler *et al.* 2007). The significance of the random terms was tested using the change in log likelihood for the removal of each random term from the full model. The likelihood ratio test with Stram and Lee (1994) adjustment was used to test whether the variance component associated with each random effect is zero.

2.2.6.4. Analysis of benchmark data – Water quality variables

Analysis of water quality data differ because there is an additional 'season' factor. Year and site remain as random effects, but season, catchment and recruitment zone nested with catchment are fixed (because they were specifically chosen and they can therefore be re-used in any future study). The lack of replication means that interactions with year are not testable. The fitted model was:

y ~ μ + **year** + **site** + catchment + recruitment(catchment) + season.recruitment(catchment) + season + **site.year**

The terms in bold are the random effects and the underlined term is the residual error.

Chlorophyll *a* was $\log_{10}$ transformed to satisfy normality assumptions. Analysis was performed using the mixed procedure in SAS® version 9.2 (SAS 2009) and fixed effects are tested using Restricted Maximum Likelihood (REML).

2.2.6.5. Estimation of power for post-control analyses – fish assemblage variables

Using estimates of model parameters from section 2.2.6.3 above, and target treatment effects for the implementation phase, data were simulated for 5 years (3 years benchmarking phase and 2 years implementation phase). Initially, data were simulated using a 25% reduction from benchmarking level as the treatment effect in year 4 and a 70% reduction from benchmarking level as the treatment effect in year 5 at Lachlan sites. The effect size of a 70% reduction in year 5 aligns with the project objective for carp biomass. The simulated data were analysed using the following linear mixed model:

y ~ μ + year + treatment in year 4 + treatment in year 5 + **site** + **catchment** + **catchment.recruitment** + **catchment.year** + **catchment.recruitment.year** + **site.year**

The terms in bold are the random effects and the underlined term is the residual error.

An F-value was calculated for the treatment effect in year 5 and the probability level determined using the Kenward and Roger (1997) approximation for the Wald statistic. The simulation was repeated 5,000 times. The power was calculated as the proportion of simulations when the p-value was less than 0.05. The simulation was then repeated for a range of treatment effect sizes (10, 20, 30, 40, 50 percent reduction from benchmarking levels in year 4 and 50, 60, 70, 80, 90 percent reduction from benchmarking levels in year 5). The simulation was repeated 5,000 times for each of the 25 combinations of treatment effect sizes.

2.2.6.6. Estimation of power for post-control analyses – Water quality variables

Bootstrap re-sampling of benchmarking phase data was used to create simulated implementation phase data for each water quality variable. Five hundred bootstrapped data sets were each run through the mixed model analysis for water quality variables from section 2.2.6.4. The proportion of significant interaction effects for recruitment zone.treatment is the probability of declaring a significant effect if the response variable doesn't change (Type I error). Each of the simulated implementation phase samples was then manually impaired (reduced) by an effect size of 10, 20, 30, 40, 50, 60, 70 and 80 percent and the analysis was repeated. The power of the test at each effect size is the proportion of the 500 tests that declare a significant recruitment zone x before/after interaction.

2.2.7. Correlation of carp biomass with ecosystem parameters

We tested for relationships between carp biomass and each of the ecosystem parameters recorded from the 12 Lachlan River treatment sites (pre-treatment) using non-parametric Spearman's rank correlation. Data used were the average for each parameter across years and seasons so that each site represented a single point in each correlation.

2.3. Results

2.3.1. Carp biomass, abundance and recruitment

Carp were the most widespread species collected during the study, being found at all 26 sites that were sampled. They also constituted the highest fish biomass of any species and made up 78% of the total fish biomass. They were the second most abundant species after carp-gudgeons.

A majority of the variance in carp biomass was unexplained by factors in the ANOVA model (59%). No significant differences in the biomass of carp within the four regions (Lachlan, Murrumbidgee, Macquarie and Lachlan hotspots) were detected ($p = 0.499$). Although Figure 2.2 suggests that carp biomass declined between 2007 and 2009 in both the Lachlan and Macquarie Rivers, but not within the Murrumbidgee River or Lachlan Hotspot locations, the ANOVA interaction term was not statistically significant ($p = 0.500$). The only significant factor detected was 'site' ($p = 0.001$) indicating that carp biomass varied among sites within and across regions.

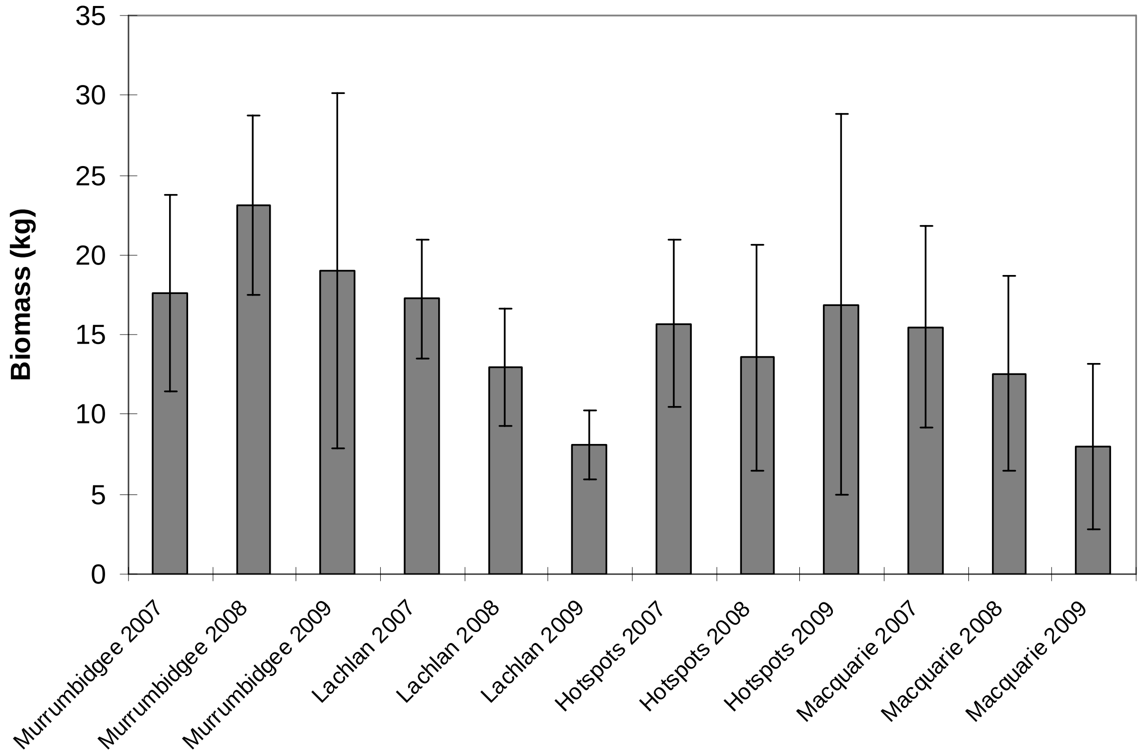


Figure 2.2. Average (±SE) biomass of carp per sample in the four regional groups over the three rounds of benchmark sampling (2007, 2008, 2009).

Within the Lachlan demonstration reach there were substantial and significant differences in carp biomass between sites (Figure 2.3). Carp biomass was high at the two upper-most sites within the demonstration reach, Cowra and Goologong. The second region of high carp biomass was within Lake Cargelligo and riverine sites downstream (Willanthry, Hillston and Whealbah Bridge). The lower most riverine site, Braebuck Woolshed at Oxley also had a high carp biomass. Variance in carp biomass across the three years of sampling was not equal at all sites, being greater at Willanthry, Goologong, Whealbah Bridge, Braebuck Woolshed and Hillston (Figure 2.3). The increased variance at these sites is likely to be a result of the substantial declines in carp biomass at these five sites in particular between 2007 and 2009.

A vast majority of the variance in the abundance of carp recruits (90%) is unexplained by factors in the ANOVA model. There were no significant differences in the abundance of carp recruits within the four regions (p = 0.469). Of the three years sampled, the average abundance of carp recruits was slightly higher in the Macquarie River than the other three regions due to the collection of a high number of small juvenile carp at Brewon (downstream of the Macquarie Marshes) in 2007 (Figure 2.4). There was substantial variability in the abundance of carp recruits observed across years, with generally more carp recruits collected in 2008 than in either 2007 or 2009. In the Murrumbidgee River, carp recruitment was large in both 2007 and 2008 but very low in 2009 (Figure 2.4). However, the interaction term between region and year was not statistically significant (p = 0.500).

Within the lower Lachlan demonstration reach, new carp recruits were most abundant in the lower reaches between Corrong and the Great Cumbung Swamp, the upper reaches of the Lachlan (Cowra and Goologong), and the mid reaches in and adjacent to Lake Cargelligo and Lake Brewster (Figure 2.5).

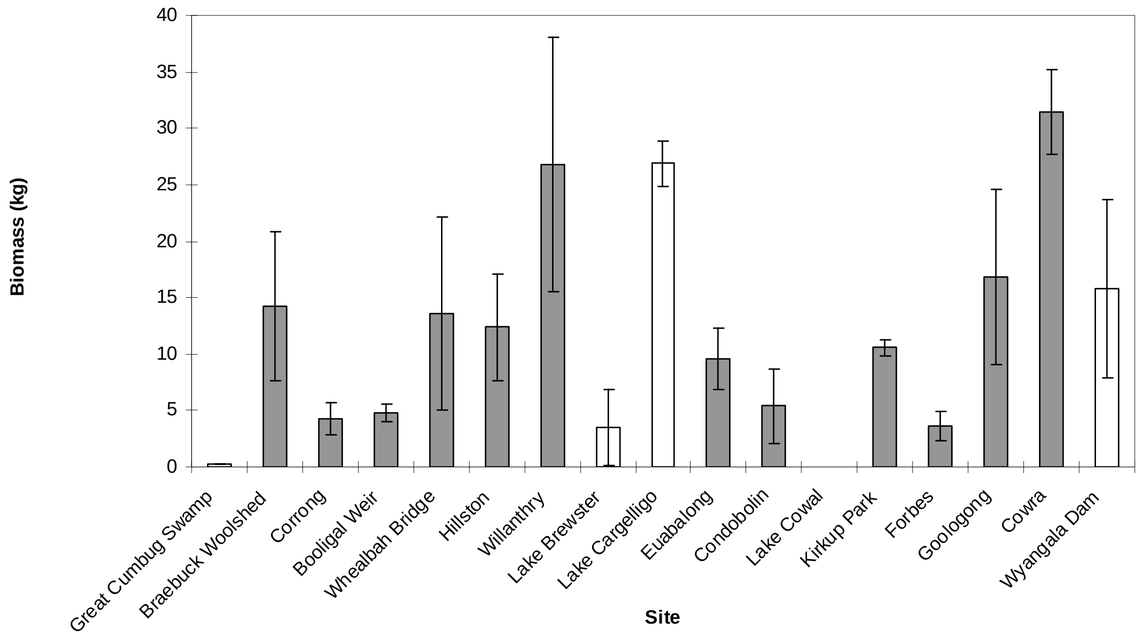


Figure 2.3. Average (±SE) biomass of carp per sample at sites within the lower Lachlan demonstration reach over the three rounds of benchmark sampling (2007, 2008, 2009). Riverine sites are presented as grey bars and hotspots sites as white bars.

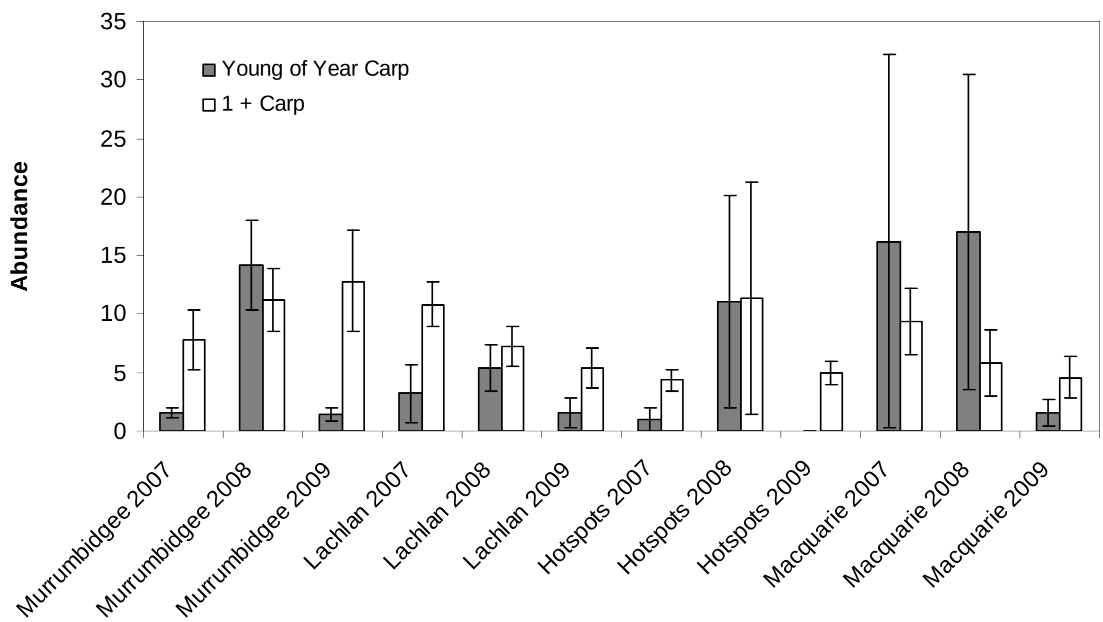


Figure 2.4. Average (±SE) abundance of young of year carp (YOY) and carp older than one year (1+) in the four regional groups over the three rounds of benchmark sampling (2007, 2008, 2009).

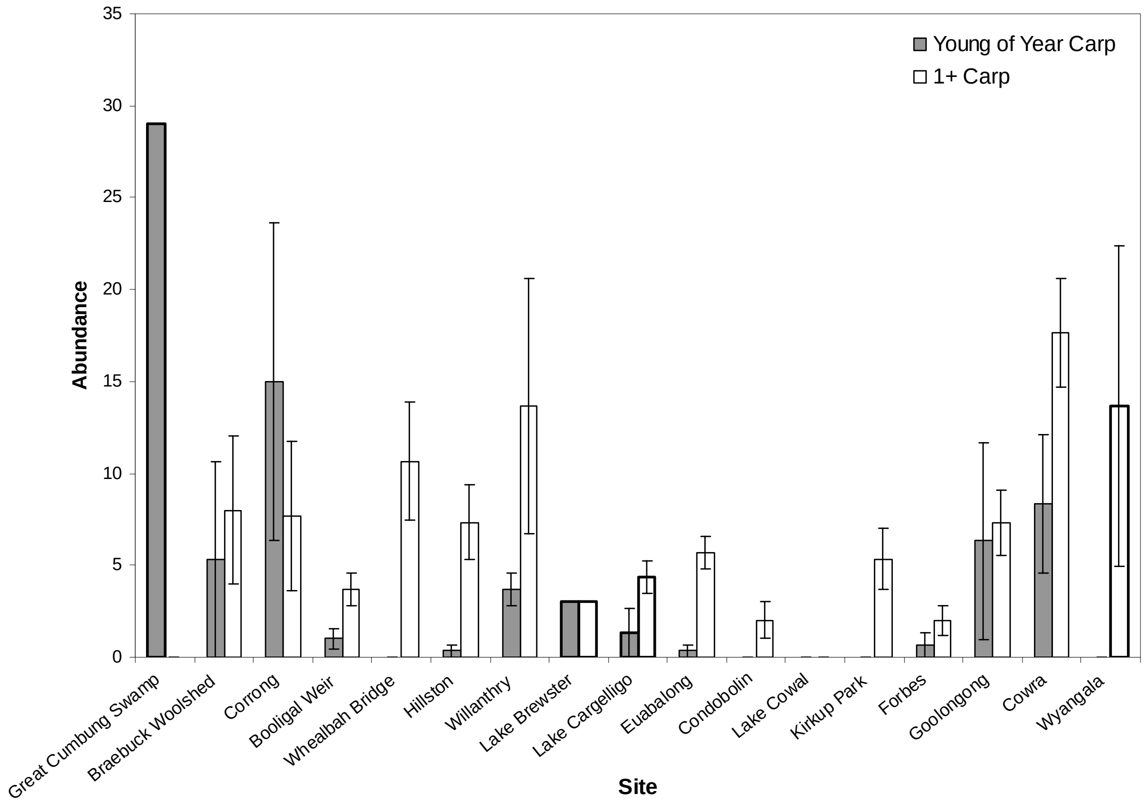


Figure 2.5. Average (±SE) abundance of young of year carp and carp older than one year at sites within the Lachlan over the three rounds of benchmark sampling (2007, 2008, 2009). Hotspot locations are outlined in bold lines.

Power analyses suggest that the established experimental design only has moderate power to detect change in carp biomass within the Lachlan River demonstration reach. A 70% reduction in carp biomass can only be detected at $\alpha = 0.175 - 0.183$ ($\beta < 0.381$) and a 90% reduction can only be detected at $\alpha = 0.050 - 0.053$ ($\beta < 0.738$). Therefore, a reduction of carp biomass of more than 90% would be required in order to confirm significant change at the conventional 5% significance level. In contrast, the experimental design does have the statistical power to detect similar proportional changes in total carp abundance and the abundance of carp recruits. For total abundance, although a 70% reduction in carp abundance can only be demonstrated at $\alpha = 0.121 - 0.127$ ($\beta < 0.506$), a 90% reduction can be demonstrated at $\alpha = 0.011 - 0.013$ ($\beta < 0.934$). Reductions of carp abundance in the Lachlan River of more than around 80% can be demonstrated as statistically significant change at the conventional 5% significance level. For the abundance of new recruits, both a 70% and 90% reduction can be detected at the conventional 5% significance level. A 70% reduction in recruit abundance can be demonstrated at $\alpha = 0.040 - 0.041$ ($\beta < 0.778$), and a 90% reduction can be demonstrated at $\alpha = 0.006 - 0.008$ ($\beta < 0.976$).

2.3.2. Water quality

2.3.2.1. Turbidity

Turbidity varied significantly across the four regions (p = 0.008) (Figure 2.6). The Murrumbidgee was the least turbid river, followed by the Lachlan River, Macquarie River and finally the Lachlan hotspot locations, but the only significant paired comparison was between the Murrumbidgee and Lachlan hotspots regions (Figure 2.6). Season had a significant effect on turbidity (p = 0.04), with turbidity in spring being significantly greater than all other seasons, but this was not significant after Scheffe correction for Type 1 error. There was no significant region by season interaction (p = 0.376).

Within riverine sites within the Lachlan demonstration reach, there was a non-significant correlation between the average biomass of carp and the average turbidity (r_s = -0.497, n = 12, p = 0.100) (Figure 2.7). However, the relationship suggested a negative association, with turbidity being lower at sites with higher carp biomass. Among the other water quality parameters, turbidity was also significantly positively correlated with nitrite (r_s = 0.860, n = 12, $p < 0.001$), and sulphate (r_s = 0.587, n = 12, p = 0.045) concentrations.

2.3.2.2. Phytoplankton biomass (Chlorophyll a)

There were no statistically significant differences in the chlorophyll *a* concentrations across the four regions, although the differences did approach significance (p = 0.084) (Figure 2.8). There was a significant season effect on chlorophyll *a* concentration (p = 0.007) and a significant region by season interaction term (p = 0.042).

ANZECC (2000) recommended limits for chlorophyll *a* of 5 µg L^{-1} were exceeded in the Macquarie River at Dubbo and Narromine in July 2007, at Brewon in April 2007 and July 2008, and at Willancorah in January 2007, September 2007, January 2009 and April 2009. In the Lachlan hotspots, recommended limits were exceeded at Lake Brewster in January 2007 and 2008, Lake Cargelligo in January, April and July 2007 and at the Great Cumbung Swamp in every sample collected. In the Lachlan River, recommended limits were exceeded at Braebuck Woolshed, Corrong, Condobolin, Kirkup Park and Forbes in January 2007, Corrong in April 2007 and Kirkup Park in September 2008. In the Murrumbidgee River, recommended limits were exceeded at Maude in January 2007 and Hay in April 2007. However, a concentration of chlorophyll *a* of ≥ 20 µg L^{-1} has been proposed as representing algal bloom conditions (Cullen *et al.* 1993). This concentration was not exceeded at any site during any round of sampling.

Within riverine sites within the Lachlan demonstration reach, there was a strong negative correlation between the average biomass of carp and the average chlorophyll *a* concentrations (r_s = -0.727, n = 12, p = 0.007) (Figure 2.9). Chlorophyll *a* concentrations were lowest at sites with higher carp biomass. Among the other water quality parameters, chlorophyll *a* was also significantly correlated with sulphate concentration (r_s = 0.615, n = 12, p = 0.033).

2.3.2.3. Nutrient concentrations

The concentration of nitrite varied significantly across the four regions (p = 0.01) (Figure 2.10). The Murrumbidgee had the lowest nitrite concentration, followed by the Lachlan River, Macquarie River and finally the Lachlan hotspot locations (Figure 2.10). There was no significant season effect (p = 0.149). The ANZECC (2000) recommended limit for nitrite of 1mg L^{-1} was not exceeded at any of the sites tested. Within riverine sites within the Lachlan demonstration reach, there was no correlation between the average biomass of carp and the concentration of nitrite (r_s = -0.259, n = 12, p = 0.416) (Figure 11). Among the other water quality parameters, nitrite concentration was significantly correlated to turbidity (r_s = 0.860, n = 12, p <0.001) and sulphate concentration (r_s = 0.762, n = 12, p = 0.004).

The concentration of nitrate varied significantly across the four regions (p = 0.029) (Figure 2.12). The Murrumbidgee had the lowest nitrate concentration, followed by the Macquarie River, Lachlan River and finally the Lachlan hotspot locations (Figure 2.12). There was no significant season effect (p = 0.212). The ANZECC (2000) recommended limit for nitrate of 10 mg L^{-1} was not exceeded at any site tested. Within riverine sites within the Lachlan demonstration reach, there was no correlation between the average biomass of carp and the concentration of nitrate (r_s = 0.308, n = 12, p = 0.330) (Figure 13). However, among the other water quality parameters, the concentration of nitrate was significantly correlated with the concentration of sulphate (r_s = -0.594, n = 12, p = 0.042).

There was no significant difference in the concentration of phosphate across the four regions (p = 0.071) (Figure 2.14) and there was no significant season effect (p = 0.077). The ANZECC (2000) recommended limit for phosphate of 0.05 mg L^{-1} was exceeded at all sites on most sampling occasions. Within riverine sites within the Lachlan demonstration reach, there was no correlation between the average biomass of carp and the concentration of phosphate (r_s = -0.203, n = 12, p = 0.527) (Figure 2.15). The concentration of phosphate was not related to any of the water quality parameters.

The concentration of sulphate varied significantly across the four regions (p = 0.050) (Figure 2.16). The Murrumbidgee had a lower concentration of sulphate than the Macquarie River, Lachlan River and Lachlan hotspot locations (Figure 2.16). There was a significant season effect (p = 0.025) but there was no significant region x season interaction term (p = 0.705). The ANZECC (2000) recommended limit for sulphate of 400 mg L^{-1} was only exceeded in the Great Cumbung Swamp in January 2008. Within riverine sites within the Lachlan demonstration reach, there was no correlation between the average biomass of carp and the concentration of sulphate (r_s = -0.161, n = 12, p = 0.617) (Figure 2.17). However, among the other water quality parameters, the concentration of sulphate was significantly correlated with the concentrations of nitrite (r_s = 0.762, n = 12, p = 0.004), chlorophyll *a* (r_s = 0.615, n = 12, p = 0.0.033), nitrate (r_s = -0.594, n = 12, p = 0.042) and turbidity (r_s = 0.587, n = 12, p = 0.045).

2.3.2.4. Statistical power to detect change in water quality variables

Power analyses suggest that the established experimental design has the statistical power to detect a 40% decline in the concentration of nitrate (β = 0.912), 50% declines in the concentrations of phosphate (β = 0.956) and sulphate (β = 0.986), a 60% decrease in turbidity (β = 0.954), 70% decrease in the chlorophyll *a* concentration (β = 0.918) and an 80% decline in the concentration of nitrite (β = 0.820) within the Lachlan River demonstration reach at the conventional α = 0.05 significance level.

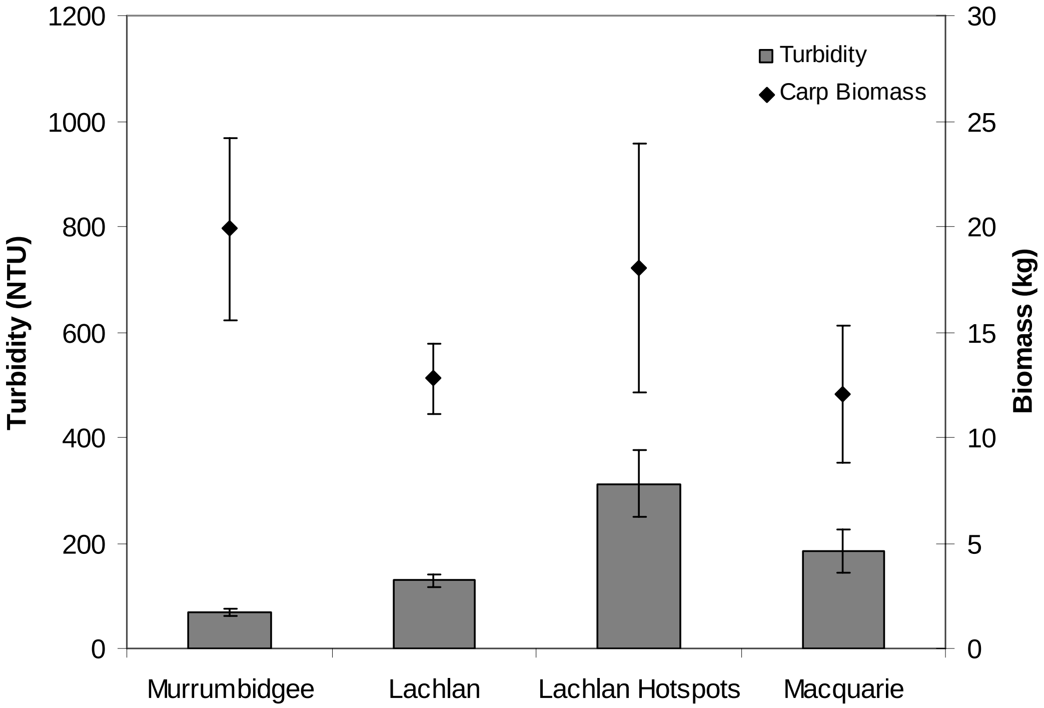


Figure 2.6. Average (±SE) turbidity and carp biomass recorded in each region during the benchmark sampling.

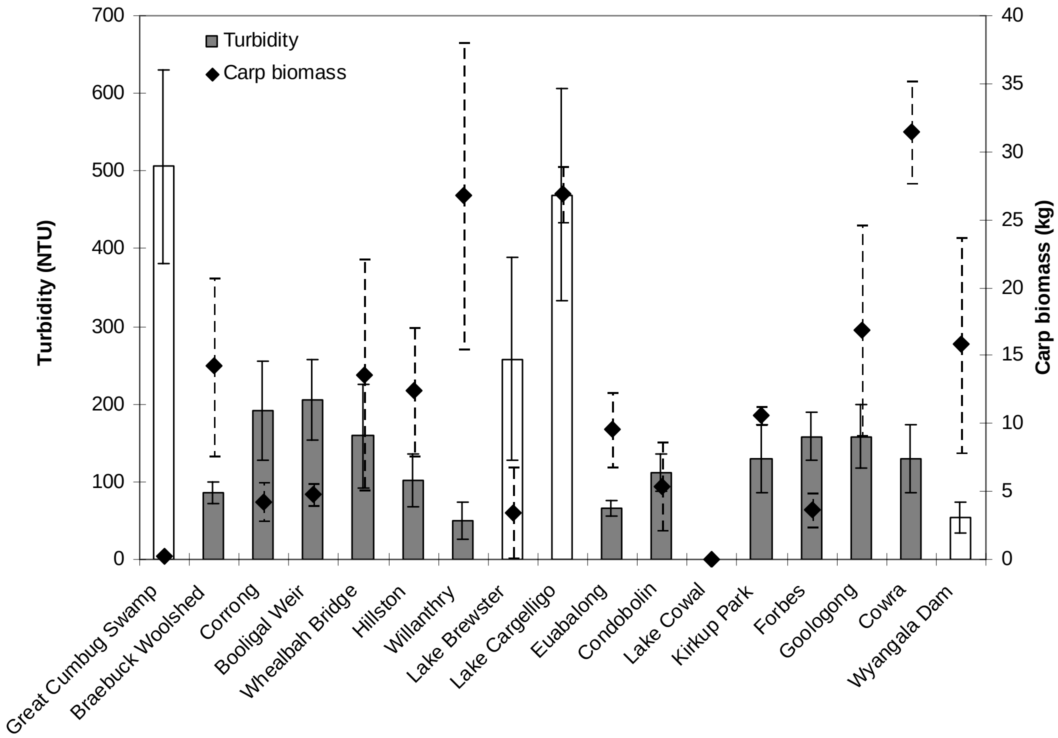


Figure 2.7. Average (±SE) turbidity and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for turbidity and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

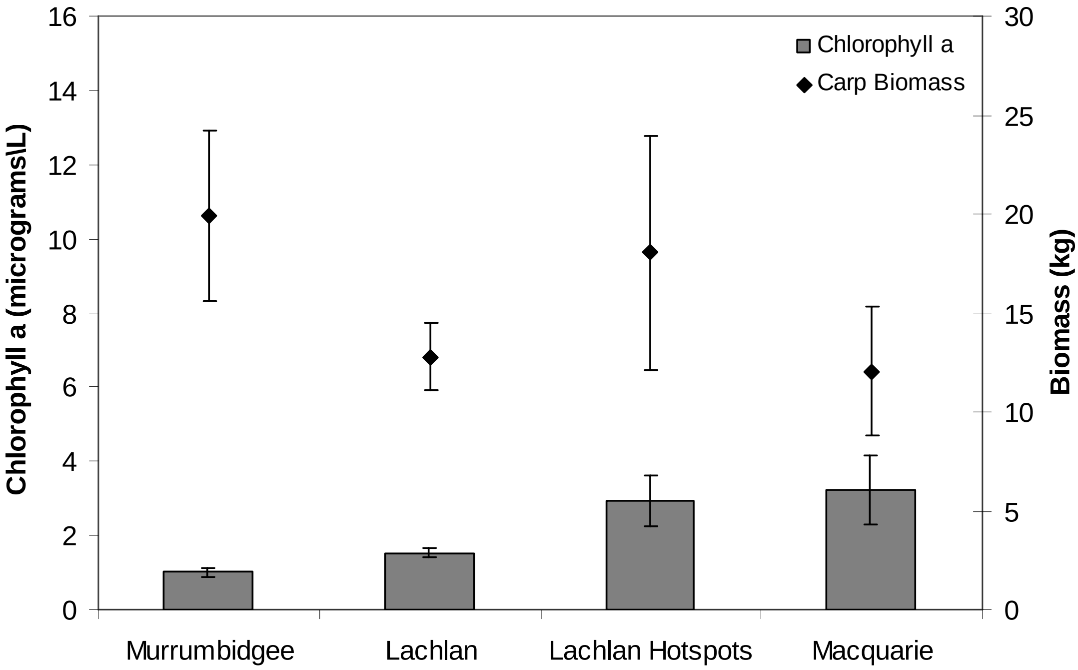


Figure 2.8. Average (±SE) chlorophyll *a* concentrations and carp biomass recorded in each region during the benchmark sampling.

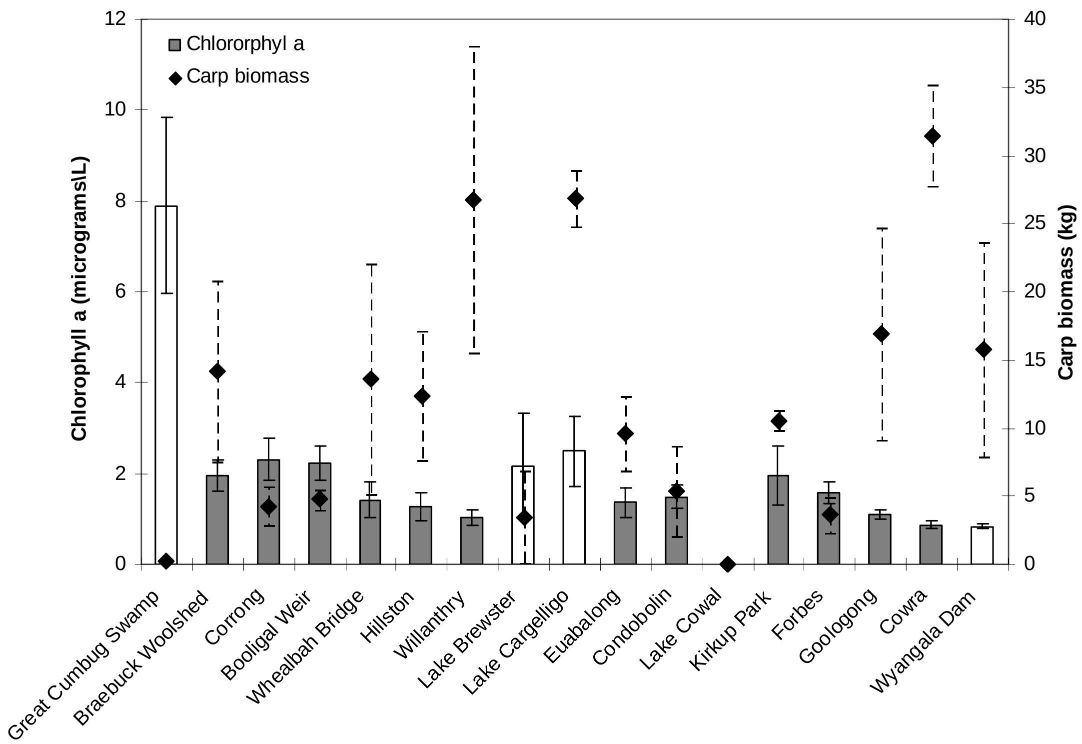


Figure 2.9. Average (±SE) chlorophyll *a* concentrations and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for chlorophyll *a* concentration and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

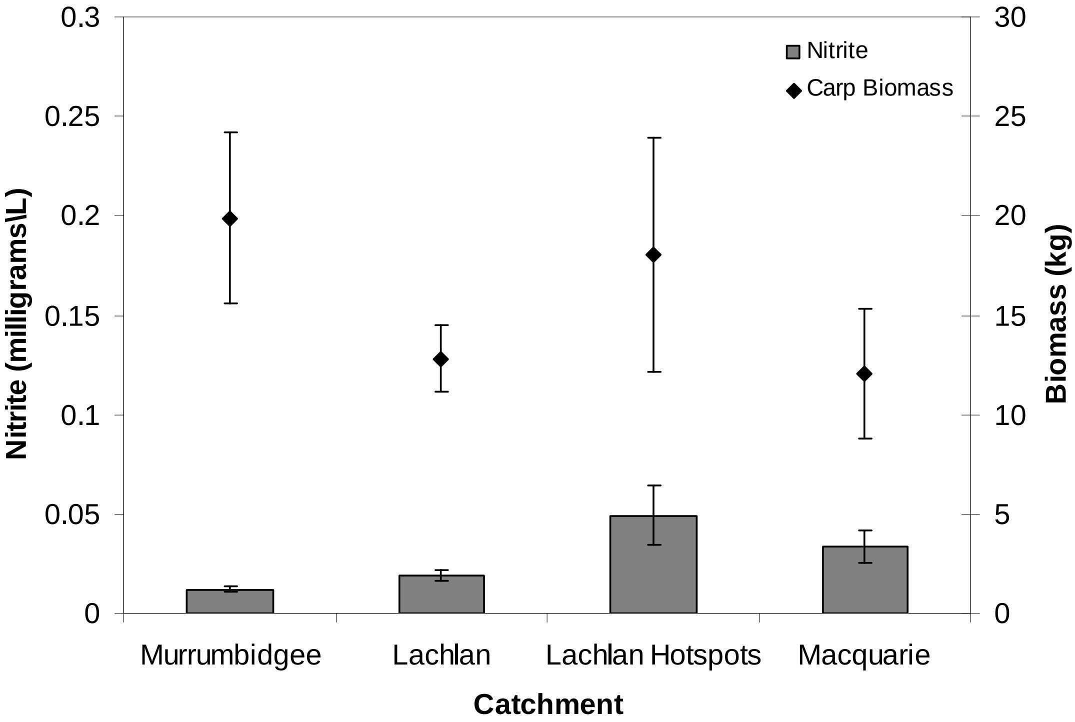


Figure 2.10. Average (±SE) nitrite levels and carp biomass recorded in each region during the benchmark sampling.

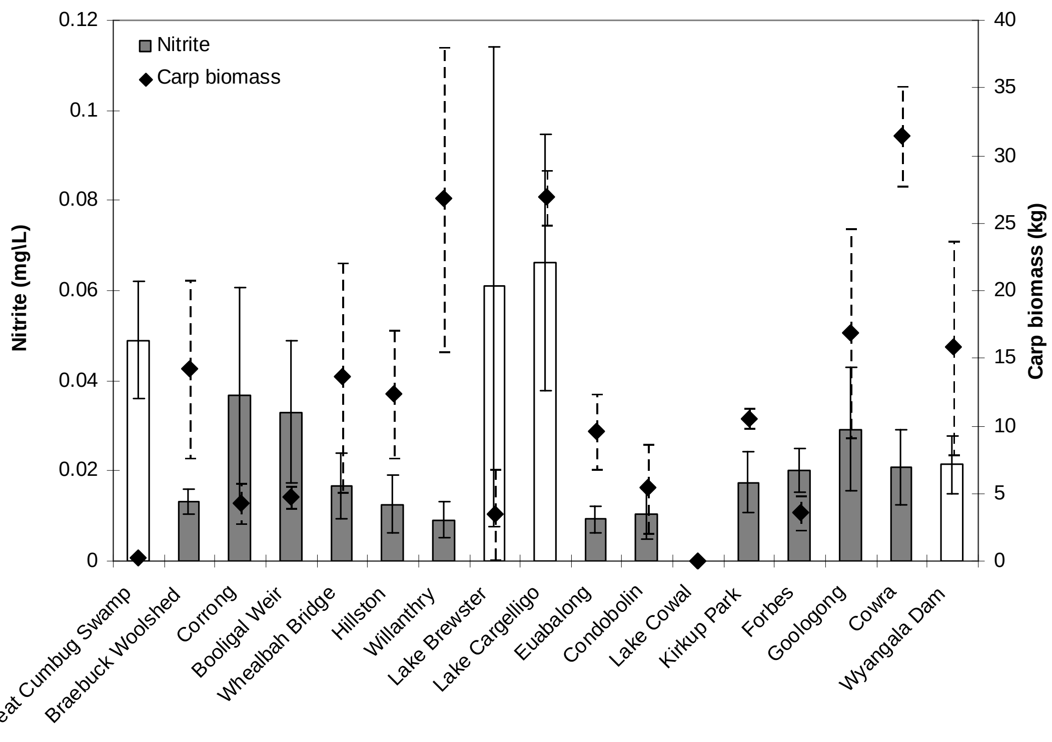


Figure 2.11. Average (±SE) nitrite concentrations and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for nitrite concentration and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

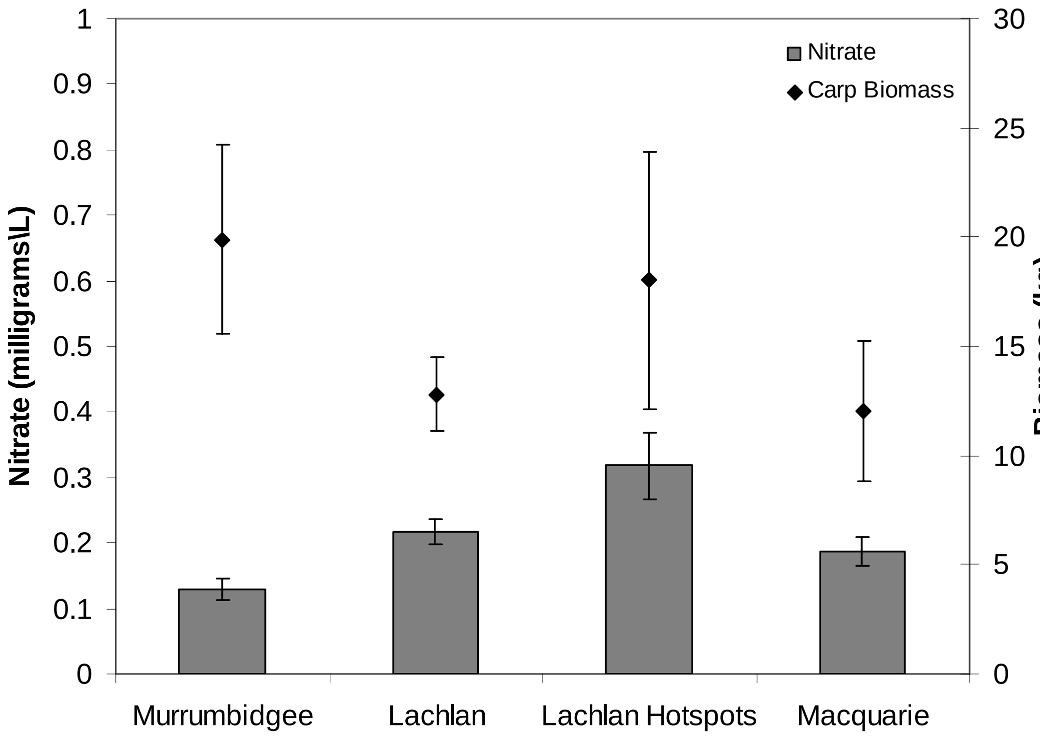


Figure 2.12. Average (±SE) nitrate levels and carp biomass recorded in each region during the benchmark sampling.

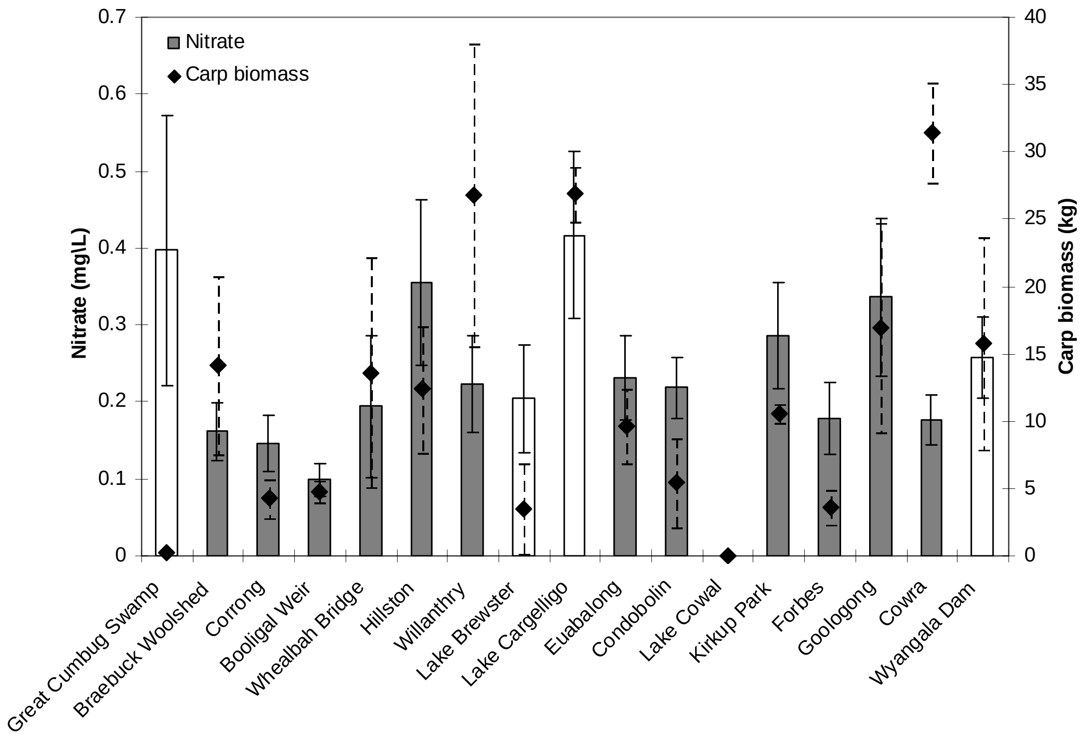


Figure 2.13. Average (±SE) nitrate concentrations and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for nitrate concentration and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

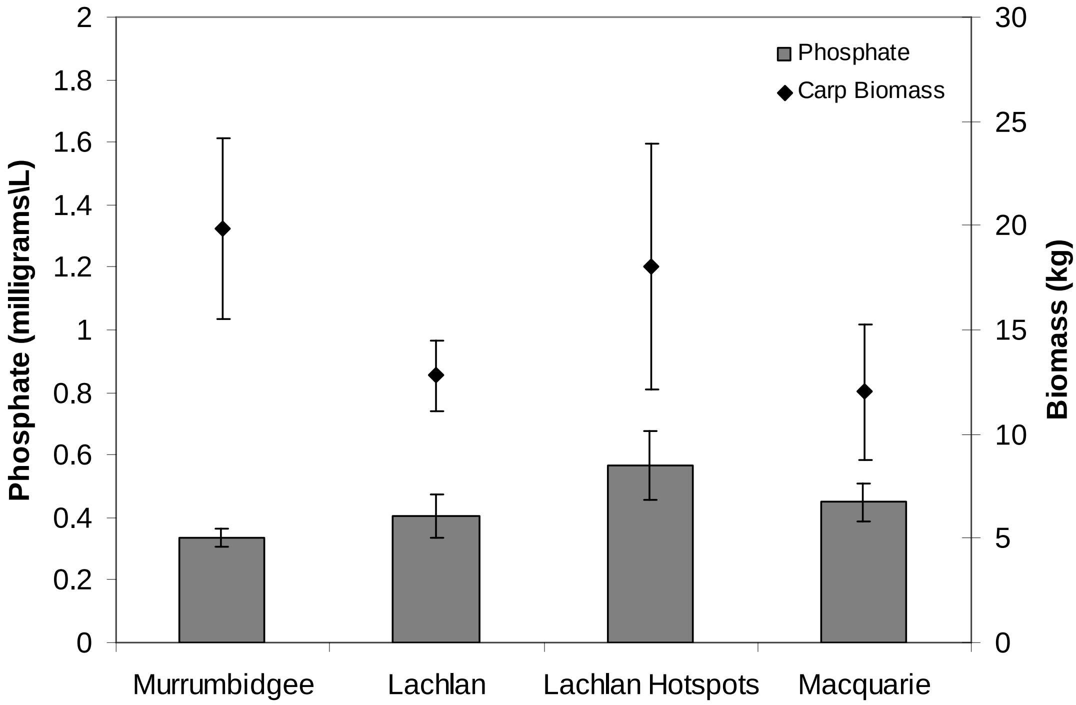


Figure 2.14. Average (±SE) phosphate levels and carp biomass recorded in each region during the benchmark sampling.

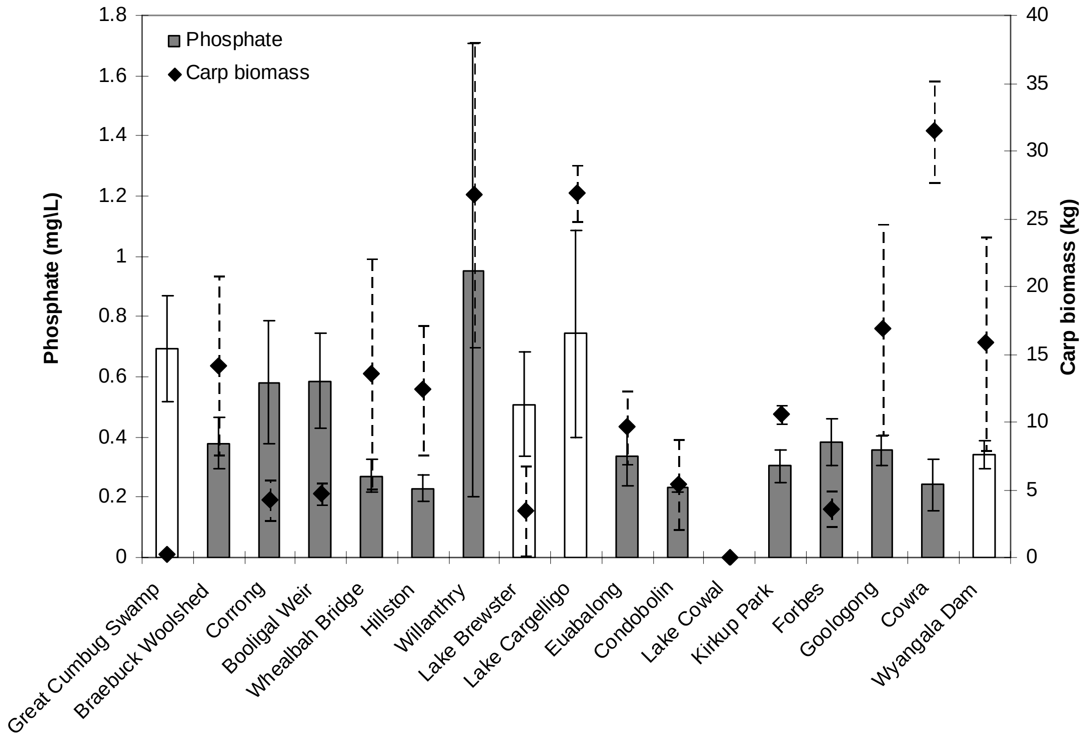


Figure 2.15. Average (±SE) phosphate concentrations and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for phosphate concentration and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

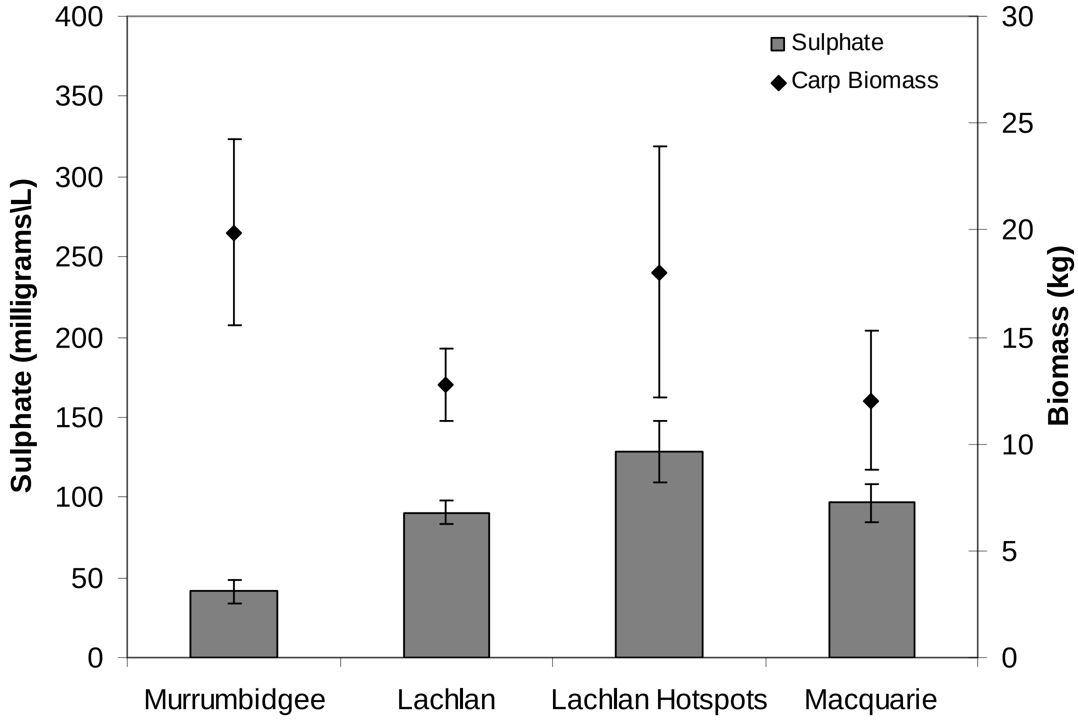


Figure 2.16. Average (±SE) sulphate levels and carp biomass recorded in each region during the benchmark sampling.

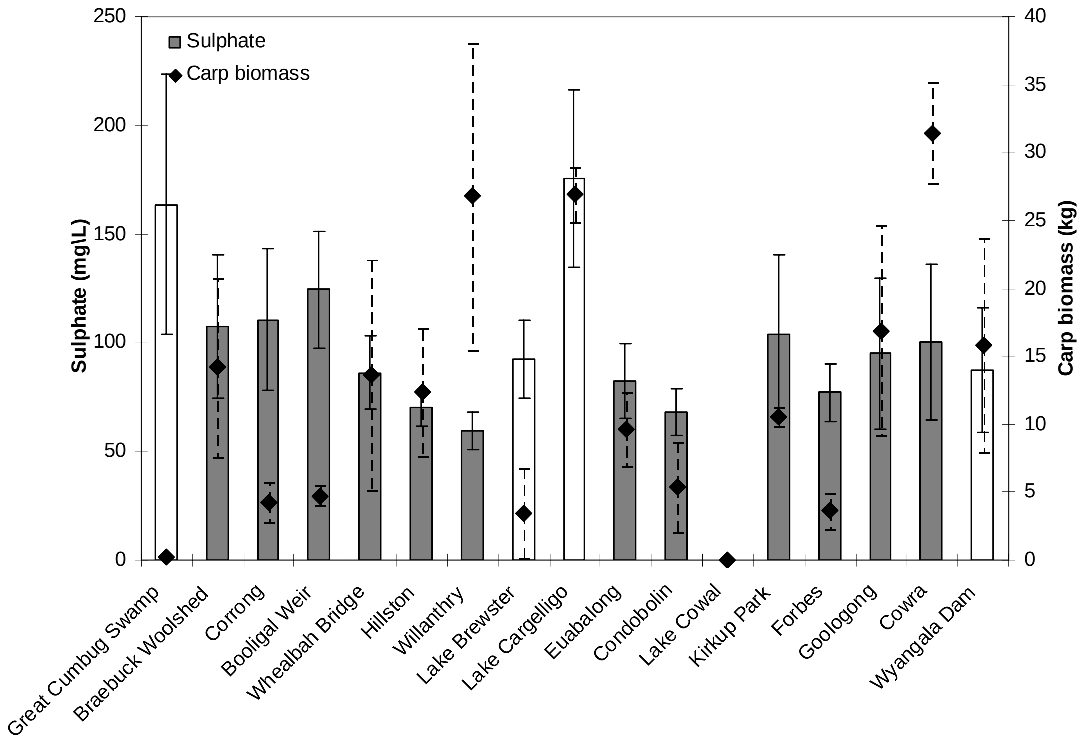


Figure 2.17. Average (±SE) sulphate concentrations and carp biomass (diamonds) at sites within the Lachlan catchment. SE bars are solid lines for native biomass and dashed for carp biomass. Riverine sites are presented as grey bars and hotspots sites as white bars.

2.3.3. Bank stability

Bank erosion was only present at one of the 26 mapped monitoring sites – Narrandera (Murrumbidgee River), where 108 m (5.4% of total) of eroded bank was recorded. This consisted of three lengths of eroded bank, all within an outside bend. Visual assessment of the nature of the erosion suggests bank collapse as a result of undermining and/or scouring (Figure 2.18). However, the cause of the erosion is unclear.

As a consequence of the scarcity of bank erosion at the established monitoring sites, our experimental design does not have the capacity to either allow an assessment of the relationship between carp density and bank erosion or to enable a test of the hypothesis of a reduction in bank erosion that would result from effective carp control if carp are in fact a cause of bank erosion.

Figure 2.18. One of three sections of eroded bank at Narrandera on the Murrumbidgee River, the only site within the monitoring program where bank erosion was recorded.

2.3.4. Aquatic macrophyte cover

Beds of eight species of aquatic macrophyte were recorded at the 26 monitoring sites mapped. The emergent common reed (*Phragmites australis*) and cumbungi (*Typha* spp.) were the most widespread, being found at 44% and 41% of sites respectively. The next two most widespread species were the submerged water milfoil (*Myriophyllum* spp.) and ribbonweed (*Vallisneria* spp.), being found at 26% and 18% of sites respectively. The remaining four species; umbrella sedge (*Cyperus eragrostis*), tall spikerush (*Eleocharis sphacelata*), common rush (*Juncus usitatus*) and slender knotweed (*Persicaria decipiens*) were only recorded at a single site each.

There was no obvious differences in the cover of emergent or submerged macrophytes within the four regions in 2008 apart from a lack of submerged macrophyte beds in the Lachlan hotspot sites in 2008 (Figure 2.19). Within the Lachlan demonstration reach, there was substantial variability among sites (Figure 2.20). There was no correlation between the biomass of carp present and the cover of emergent macrophytes (r_s = -0.341, n = 12, p = 0.278) or submerged macrophytes (r_s = 0.424, n = 12, p = 0.170). The cover of emergent macrophytes was not correlated with any other aquatic ecosystem parameter measured. However, the cover of submerged macrophytes is significantly negatively correlated to turbidity (r_s = -0.743, n = 12, p = 0.006) and the concentration of nitrite (r_s = -0.715, n = 12, p = 0.009).

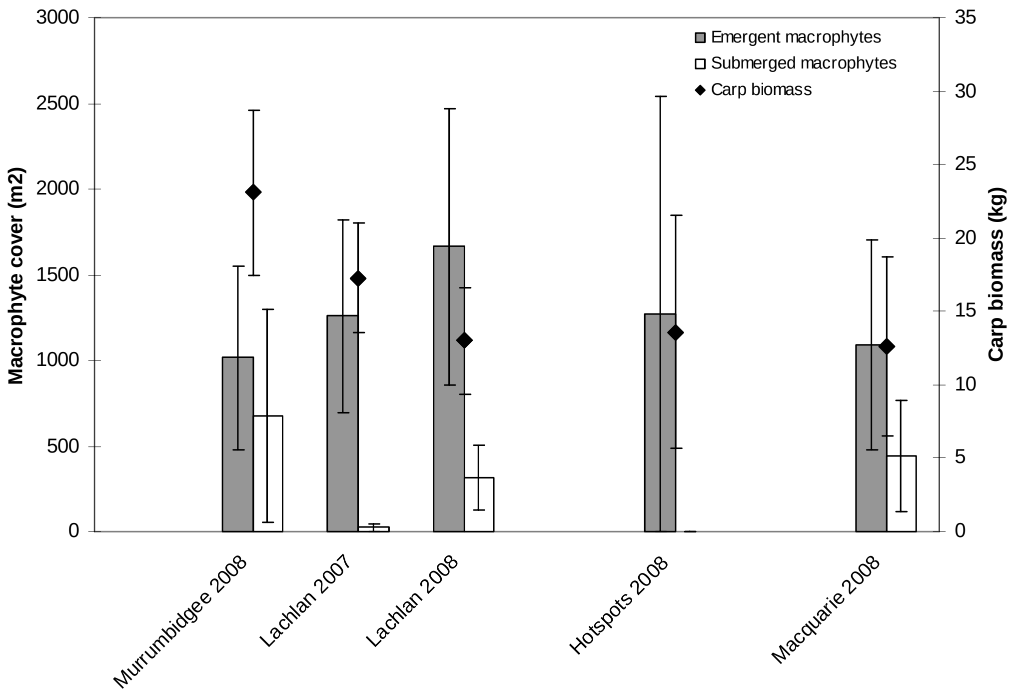


Figure 2.19. Average (±SE) cover of emergent (grey bars) and submerged (white bars) macrophyte beds (m^2) and the carp biomass (diamonds) across the four regions during the 2007 and 2008 benchmark sampling seasons. No macrophtye data are available from the Murrumbidgee, Macquarie or Lachlan hotspot treatment groups for 2007.

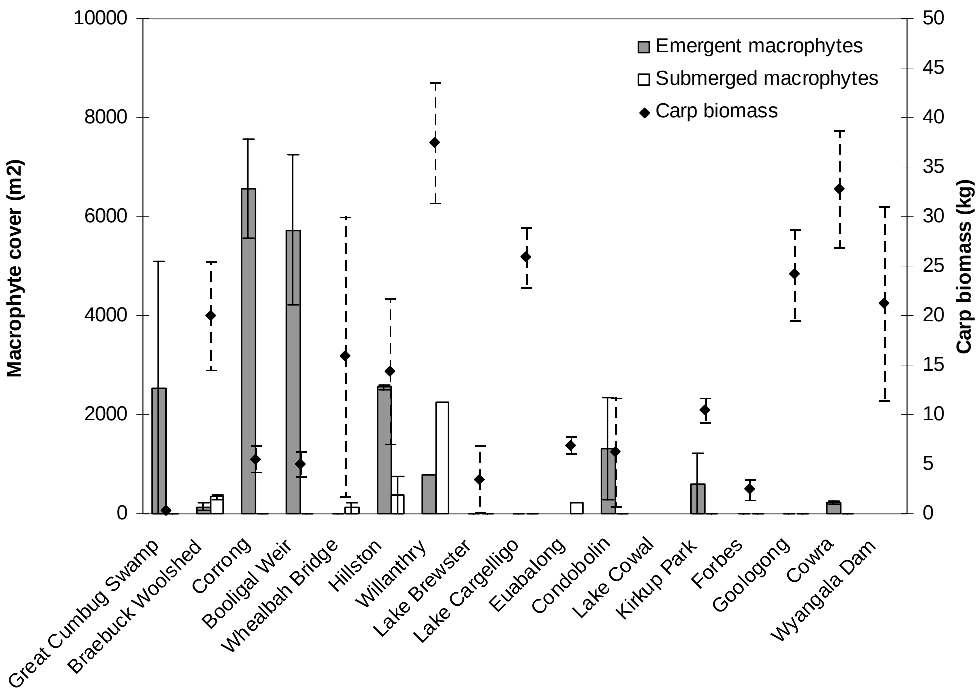


Figure 2.20. Average (±SE) cover of emergent (grey bars) and submerged (white bars) macrophyte beds (m^2) and the carp biomass (diamonds) at sites within the Lachlan over the two rounds of benchmark sampling (2007, 2008). SE bars are solid lines for native biomass and dashed for carp biomass.

2.3.5. Macro-invertebrate diversity

Twenty macro-invertebrate families were collected from the 25 sites sampled in 2007.

There was very little difference in the number of macro-invertebrate families collected from each region (Figure 2.21). Further, the proportion of sites each macro-invertebrate taxa was collected from within each treatment group was similar (Table 2.2). Within the Lachlan demonstration site, there was no obvious spatial pattern in the distribution of macro-invertebrate family richness (Figure 2.22). Further, there was no correlation between the number of macro-invertebrate families present at each site and the biomass of carp (r_s = -0.222, n = 12, p = 0.488). Macroinvertebrate diversity was not correlated with any of the other aquatic ecosystem parameters recorded.

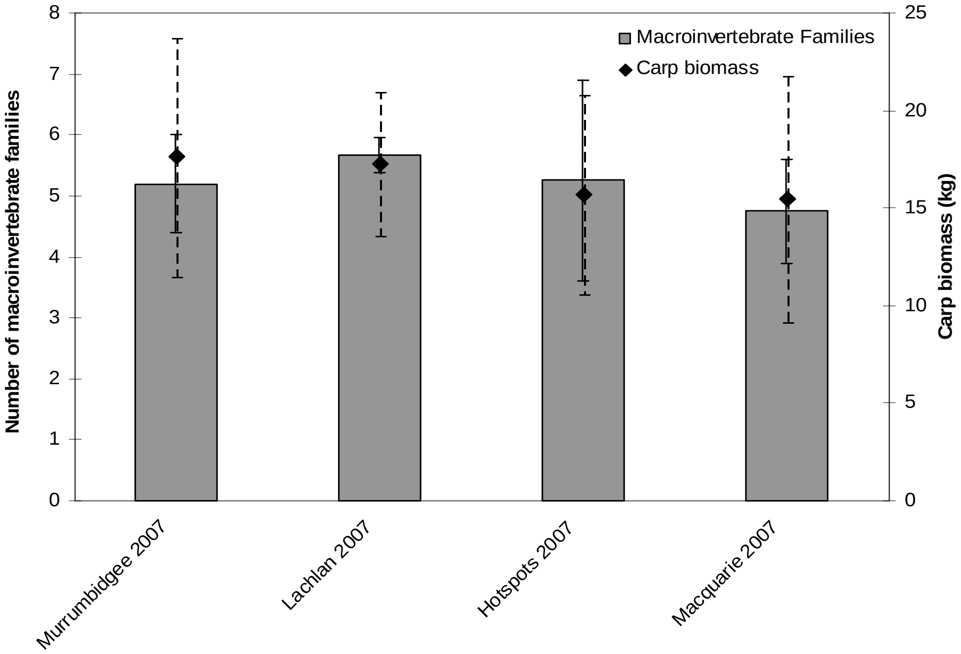


Figure 2.21. Average (±SE) number of macro-invertebrate families (bars) and the carp biomass (diamonds) across the four regions during the first rounds of benchmark sampling (2007). The SE bars are solid for macro-invertebrate family richness and dashed for carp biomass.

Table 2.2. The proportion of sites within each region at which macro-invertebrate families were collected (2007 sampling round only).

Order	**Family**	**Lachlan** (*n* = 12 sites)	**Murrumbidge e** (*n* = 5 sites)	**Macquarie** (*n* = 4 sites)	**Lachlan hotspots** (*n* = 4 sites)
Decapoda	Atyidae	0.83	1	0.75	0.75
Hemiptera	Corixidae	0.83	1	0.75	1
Hemiptera	Notonectidae	0.83	0.6	0.75	0.75
Trichoptera	Leptoceridae	0.58	0.4	0.75	0.25
Ephemeroptera	Leptophlebiidae	0.58	0.4	0	0.25
Diptera	Chironomidae	0.50	0.6	0	0.75
Ephemeroptera	Caenidae	0.33	0	0	0
Decapoda	Palaemonidae	0.33	0.4	0.5	0
Odonata	Lestidae	0.17	0	0	0.25
Decapoda	Parastacidae	0.17	0	0.5	0.25
Ephemeroptera	Baetidae	0.08	0.6	0	0
Coleoptera	Carabidae	0.08	0	0	0
Coleoptera	Dytiscidae	0.08	0	0	0
Coleoptera	Hydrophilidae	0.08	0	0	0
Oligochaeta		0.08	0	0	0.25
Diptera	Tipulidae	0.08	0	0	0
Isopoda	Corallanidae	0	0	0.25	0
Trichoptera	Ecnomidae	0	0.2	0	0
Coleoptera	Elmidae	0	0	0	0.25
Gastropoda	Physidae	0	0	0.5	0.5

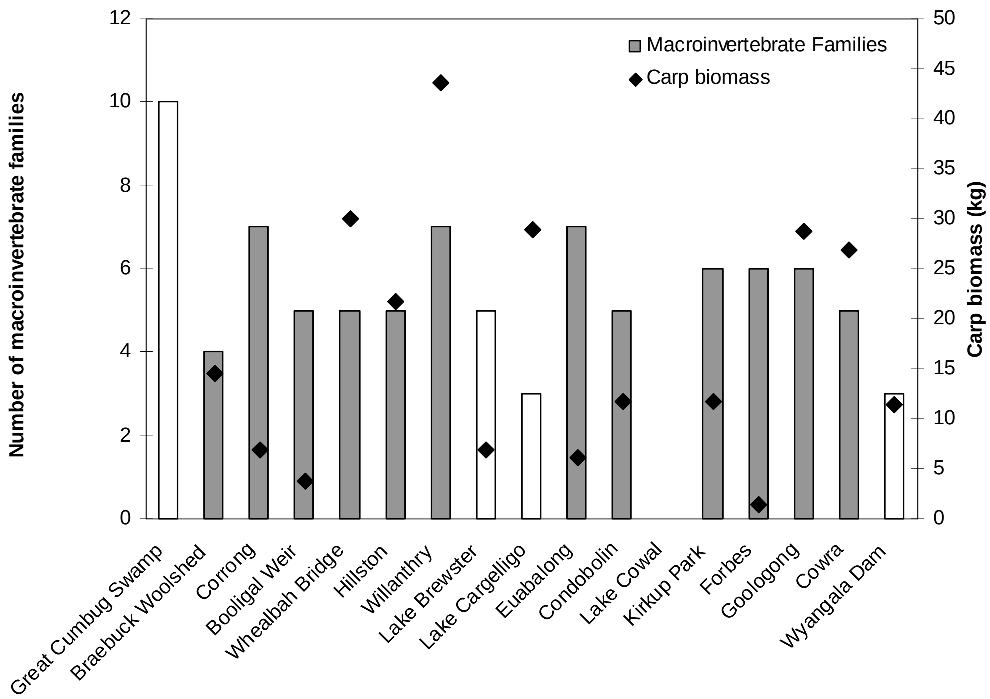


Figure 2.22. Number of macro-invertebrate families (bars) and the biomass of carp (diamonds) at sites within the Lachlan in the first round of benchmark sampling (2007). Riverine sites are presented as grey bars and hotspots sites as white bars.

2.3.6. Native fish diversity and biomass

Thirteen species of native fish were collected from the 26 monitoring sites sampled. Ten species were collected from sites within the lower Lachlan demonstration site. Those three species not collected in the Lachlan were spangled perch (*Leiopotherapon unicolor*) which was only collected from the two most downstream sites in the Macquarie River (Brewon and Willancorah), trout cod (*Maccullochella macquariensis*) which was only collected from the two most upstream sites in the Murrumbidgee River (Wagga Wagga and Narrandera) and Murray-Darling rainbowfish (*Melanotaenia fluviatilis*) which was collected from both the Macquarie and Murrumbidgee Rivers, but not from the Lachlan.

The most widespread native species were Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua*) and carp-gudgeons (*Hypseleotris* spp.) (Figure 2.23). Murray cod and golden perch were the two native species that constituted the highest proportion of the native fish biomass. All other native species made only a minor contribution (Figure 2.23).

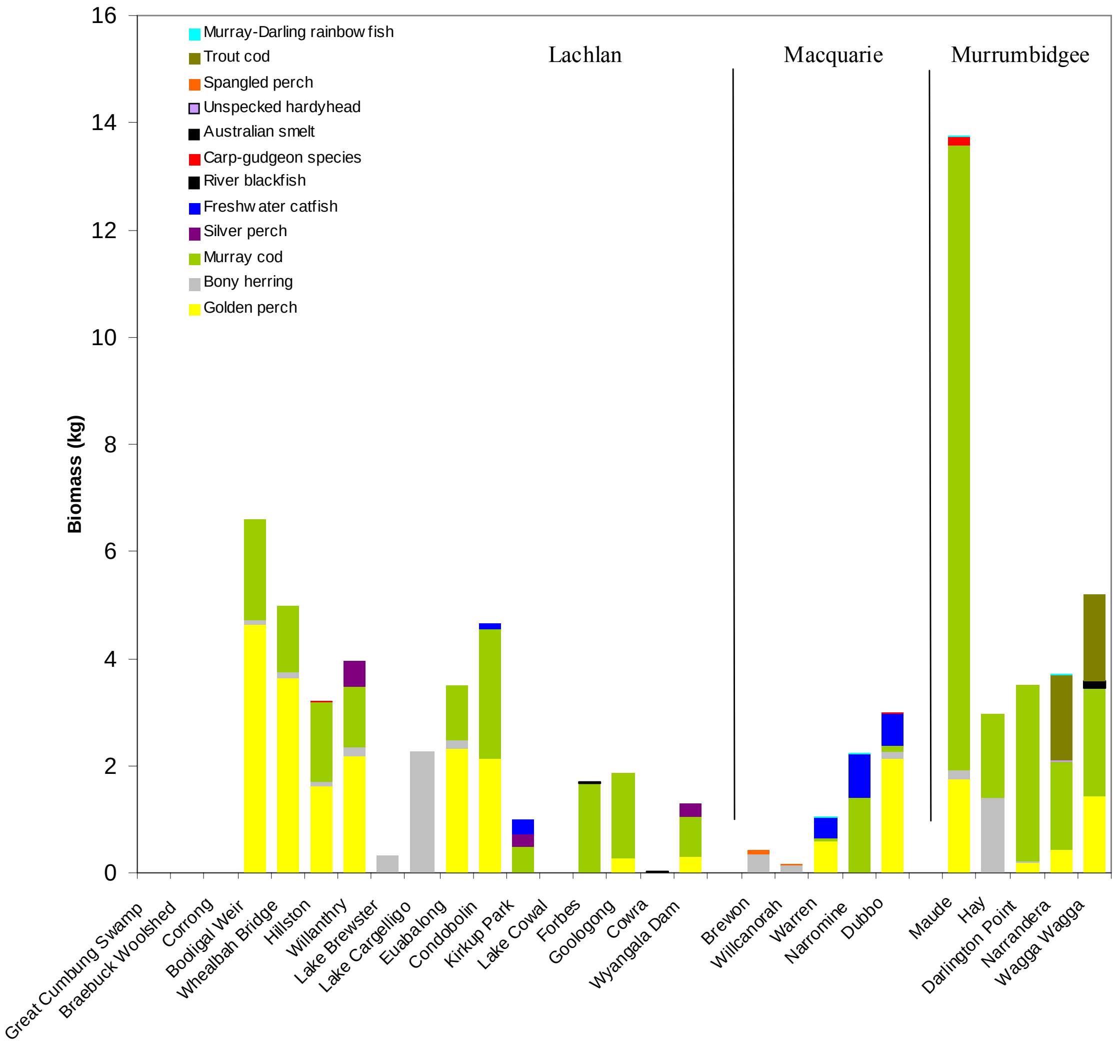


Figure 2.23. The average biomass of individual native fish species collected from each monitoring sites over the 2007, 2008 and 2009 sampling seasons.

Factors used within the ANOVA model explained 79% of the variance in native species richness. Although the Murrumbidgee River appeared to support more species per site than either the Lachlan or Macquarie rivers, and sites in the Lachlan River appeared to have the lowest average number of native species per site of the three catchments (Figure 2.24), the differences between regions were not statistically significant at the 5% significance level (p = 0.146).

Within the Lachlan demonstration site there were substantial and significant differences in the species richness of native species between sites (Figure 2.25). In particular, the Cowra, Corrong and Braebuck Woolshed sites had a particularly low diversity of native fishes (Figure 2.25). The riverine sites between Condobolin and Booligal had the highest native species diversity (Figure 2.25). Across riverine sites within the Lachlan demonstration reach, there was no correlation between the biomass of carp and the number of native species present at a site (r_s = 0.039, n = 12, p = 0.904). However, the number of native fish species present at a site was correlated with the concentrations of sulphate (r_s = -0.701, n = 12, p = 0.011), nitrate (r_s = 0.644, n = 12, p = 0.024) and nitrite (r = -0.629, n = 12, p = 0.028). There was also a significant positive correlation between the number of native fish species present and the total biomass of native fish at a site (r_s = 0.729, n = 12, p = 0.007).

A large proportion of the variance in native fish biomass (48%) was not explained by the factors within the ANOVA model. As for carp biomass, site was the only significant factor within the model ($p = 0.002$). No significant differences in the biomass of native fish within the four locations was detected ($p = 0.312$) although the Murrumbidgee River had a slightly higher native fish biomass than the other three treatment groups, particularly in 2008 and 2009 (Figure 2.26).

There was a particularly low biomass of native fish collected from within Lachlan hotspot locations in 2008 (Figure 2.26).

Within the Lachlan demonstration site there was less variability in native fish biomass than carp biomass, but there were still substantial and significant differences in the biomass of native fish between sites (Figure 2.27). In particular, the Cowra, Lake Brewster, Corrong, Braebuck Woolshed and Great Cumbung Swamp sites had a particularly low biomass of native fishes (Figure 2.27). The riverine sites between Condobolin and Booligal had the highest biomass of native fishes (Figure 2.27). Within riverine sites within the Lachlan demonstration reach, there was no correlation between the biomass of carp and the biomass of native fishes ($r_s = -0.070$, $n = 12$, $p = 0.829$).

Power analyses suggest that the established experimental design only has very low power to detect change in total native fish biomass within the Lachlan River demonstration site. A 90% increase in total native fish biomass can only be detected at $\alpha = 0.219 – 0.228$ ($\beta < 0.317$). In contrast, the experimental design does have the statistical power to detect increases in the number of native fish species. An increase of just two native fish species per site can be detected at $\alpha = 0.063 – 0.064$ ($\beta < 0.689$). Increases of three or more species per site can be detected at $\alpha < 0.016$ ($\beta > 0.904$).

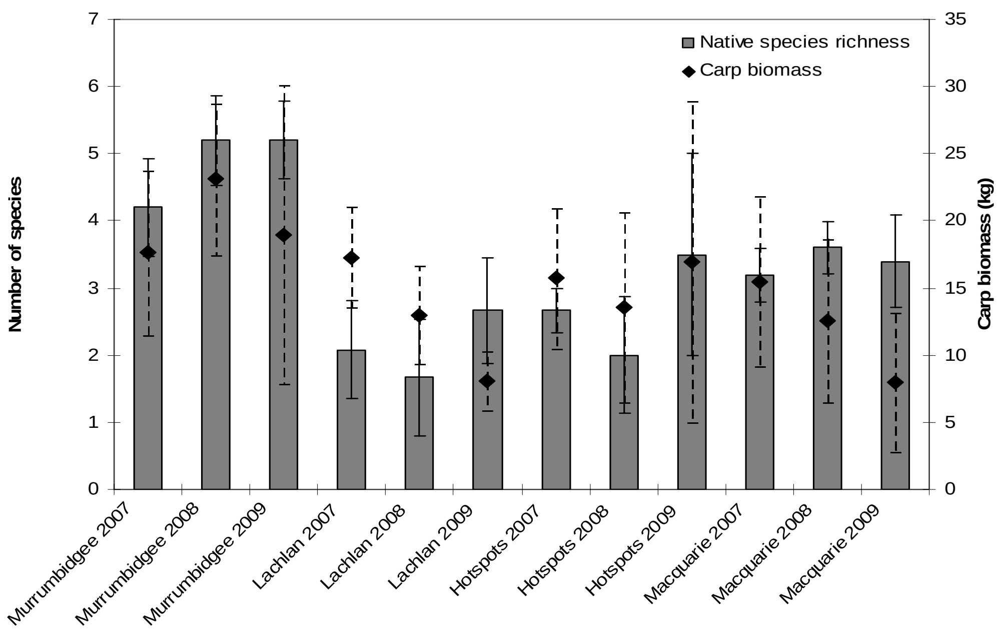


Figure 2.24. Average (± SE) number of native fish species (bars) and the carp biomass (diamonds) across the four regions over the three rounds of benchmark sampling (2007, 2008, 2009). SE bars are solid lines for native species richness and dashed for carp biomass.

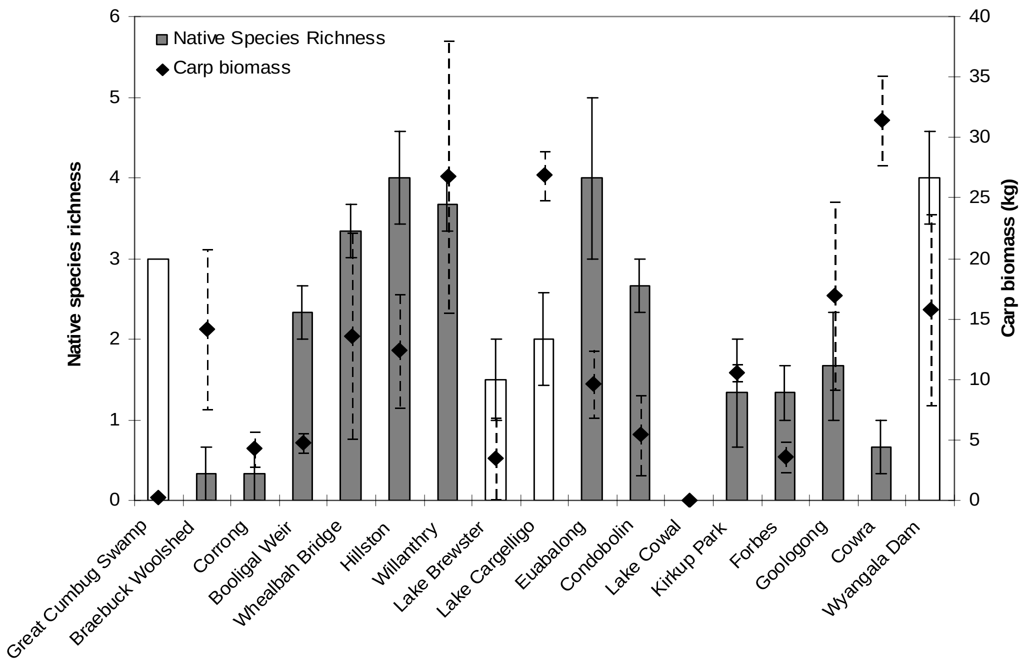


Figure 2.25. Average (± SE) number of native species at sites (bars) and the carp biomass (diamonds) within the Lachlan over the three rounds of benchmark sampling (2007, 2008, 2009). Riverine sites are presented as grey bars and hotspots sites as white bars. SE bars are solid lines for native species richness and dashed for carp biomass.

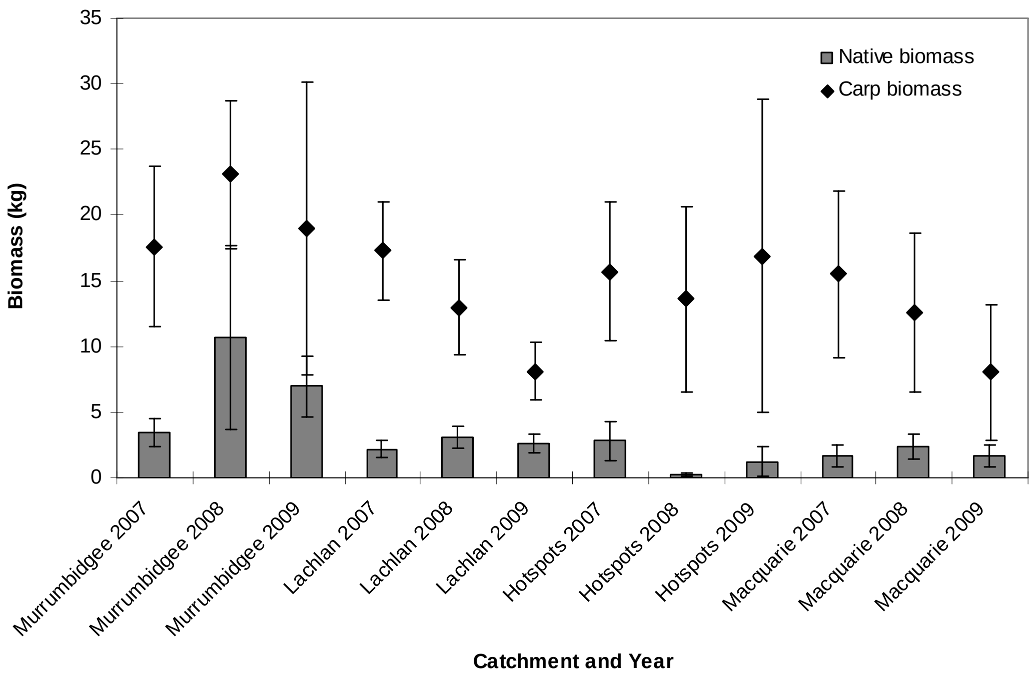


Figure 2.26. Average (±SE) biomass of native fishes (bars) and the carp (diamonds) across the four regions over the three rounds of benchmark sampling (2007, 2008, 2009).

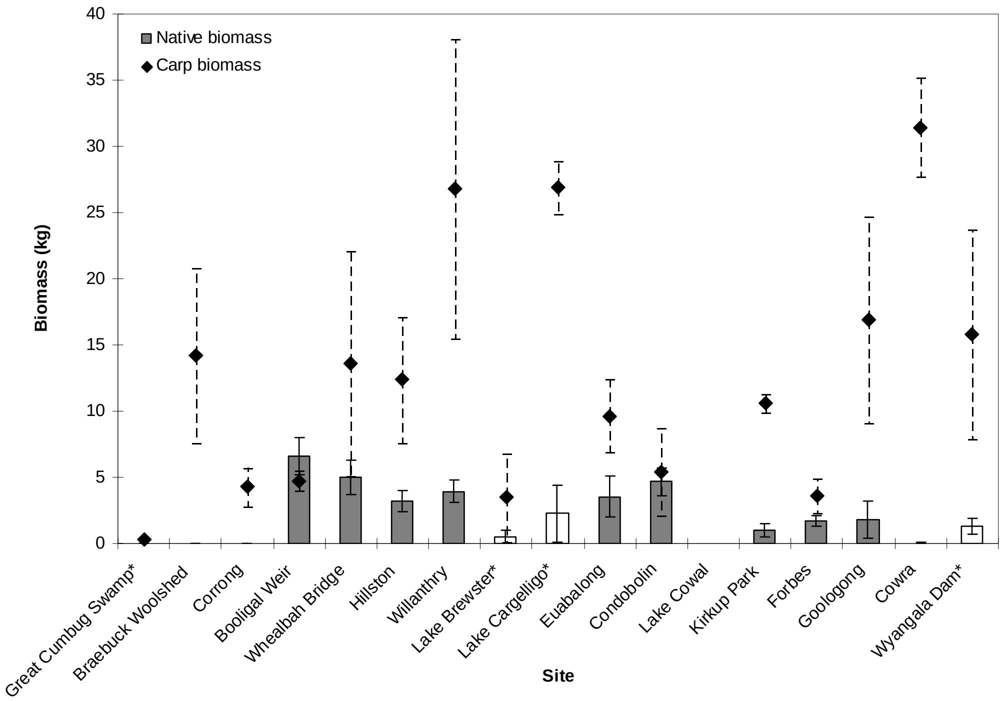


Figure 2.27. Average (±SE) biomass of native fishes (bars) and the carp (diamonds) at sites within the Lachlan over the three rounds of benchmark sampling (2007, 2008, 2009). Riverine sites are presented as grey bars and hotspots sites as white bars. SE bars are solid lines for native biomass and dashed for carp biomass.

2.4. Discussion

2.4.1. The carp population of the lower Lachlan River

Within the three year period over which we benchmarked the status of fish communities and ecosystem components in the lower Lachlan River (2007 – 2009), common carp were the most widespread fish species collected, being the only species that occurred at every site sampled. Carp were the second most abundant species and constituted the highest fish biomass of any species, making up 78% of the total fish biomass within the lower Lachlan River. We found substantial and significant differences in carp biomass, abundance and recruitment between sites (Figures 2.3 and 2.5).

Our data are standardised by the level of fishing effort defined by the SRA sampling protocol and not as kilograms per hectare, as is often reported in carp impact assessment and population dynamics literature. A rough approximation based on an assumed electrofishing efficiency of 25% and an average area fished of approximately 0.3 ha per sample, equates to a rough calibration factor of 13.33. Therefore the average carp biomass density recorded among our monitoring sites between 2007 and 2009 ranged from a minimum of 0.002 kg ha^{-1} to a maximum of 826 kg ha^{-1} (mean 49 ± 15 kg ha^{-1}).

Carp recruited within the Lachlan River in all three years. There were three principal areas where young of year carp were collected; (i) the lower Lachlan River and Great Cumbung Swamp, (ii) the upper Lachlan River around Cowra – Goologong, and (iii) Lake Cargelligo, Lake Brewster and riverine sites immediately downstream. The greatest abundance of recruits was collected from the lower Lachlan region in 2007 and 2008. In 2007, young of year carp were only collected at Corrong, suggesting that a recruitment site exists somewhere in that region. However, in 2008, carp recruits were also collected at Braebuck Woolshed and the Great Cumbung Swamp, indicating that carp recruitment was more widespread within the lower Lachlan under the hydrological conditions that occurred in the spring of 2007 than it had been under the conditions in the springs of 2006 and 2008. In fact, no carp recruits at all were detected in the lower river in 2009.

Although carp recruits were collected in the two uppermost Lachlan River sites in all three years sampled, none were collected from Wyangala Dam in any year. Based on the collection of large numbers of carp recruits in the upper Lachlan and Abercrombie Rivers in recent years (I&I NSW, unpublished data), it was presumed *a priori* that Wyangala Dam was a carp hotspot and the source of large numbers of carp recruits. However, these new results cast doubt on that assumption and suggest instead that a carp recruitment area must exist somewhere between Goologong and the Wyangala Dam wall. Since we only recorded young of year carp at Cowra and not Goologong in 2009, it is likely that the recruitment area is perhaps closer to, or upstream of Cowra. It is important that the location of this recruitment area is identified and managed as part of the *River Revival – Lachlan River Carp Cleanup*.

Much lower abundances of carp recruits were detected from the third carp recruitment area in the mid-Lachlan. Carp recruitment was only detected in Lake Cargelligo in 2008 and this was only a small number of young of year fish. Previous samples of carp from Lake Cargelligo (I&I NSW, unpublished data) suggest that when conditions are favourable, the level of carp recruitment in the lake system can be orders of magnitude greater than that observed between 2007 and 2009. Carp recruits were only collected from within Lake Brewster in 2007. There were no carp of any size collected from the Lake Brewster site in 2008 and the site was dry in autumn 2009. Small numbers of carp recruits were collected from the riverine sampling site immediately downstream of both of these wetland systems (Willanthry) in all three years. However, given that little or no water had been released from either wetland since sampling commenced, it is likely that these were spawned locally in the Lachlan River channel.

Only one or two carp recruits were detected at Forbes, Euabalong, Hillston and Booligal in either 2008 or 2009 and these could have migrated up or downstream from one of the other recruitment areas. No carp recruits were collected at Whealbah Bridge, Condobolin, Kirkup Park or Wyangala Dam during any sampling event between 2007 and 2009. Lake Cowal, a site known to be a carp recruitment hotspot based on previous sampling (I&I NSW, unpublished data), has remained dry throughout the study period and so no carp recruitment was recorded at this site.

Overall, the relative abundance of new recruits over the three years sampled was low relative to recruitment events observed within the Macquarie and Murrumbidgee River during the same period and across the broader Murray-Darling Basin over the past 15 years (I&I NSW, unpublished data). The generally poor recruitment of carp populations in the Lachlan within the study period is likely to be a result of the current drought. Carp recruitment is greatest when high spring flows inundate floodplains and floodplain lakes (Swee and McCrimmon 1966; McCrimmon 1968; Crivelli 1981; King *et al.* 2003; Sommer *et al.* 2004; Brown *et al.* 2005; Stuart and Jones 2006*b*). The average annual discharge of the Lachlan River at Cowra is 900 GL per annum, but is naturally very variable (Chessman *et al.* 2006). During the period of this study, annual discharge at Cowra was 178.4 GL in 2007, 140.2 GL in 2008 and was 125.3 GL in 2009. As a result, a majority of spawning sites in the Lachlan catchment remained dry throughout the period of data collection. The locations of carp recruitment, and the distribution and abundance of young of year carp may change considerably from that observed during this study under average or particularly under high spring flow conditions.

The data we provide on the biomass, abundance and recruitment of the Lachlan River carp population serve two purposes. They provide benchmarks upon which assessment of the ecosystem effects of carp control can be gauged, and the spatial variability in carp biomass at sites provides a broad range in carp density values across which correlations between current carp density and condition of a range of ecosystem variables could be investigated in a riverine environment. This is important and unique in that all published assessments of carp impacts have been assessed in lentic systems or in experimental ponds (references in Chapter 3).

2.4.2. Statistical power to detect change and the design of an ongoing monitoring program

Several authors have suggested that a threshold density of carp exists above which lake environments switch between alternative clear water and macrophyte dominated and turbid phytoplankton dominated stable states (Meijer *et al.* 1990; Zambrano *et al.* 2001). These studies suggest that at least 70% of cyprinid biomass must be removed to achieve rehabilitation of water clarity. Further, Thresher (1997) and Brown and Walker (2004), using independent carp population dynamics models, have suggested that control programs would need to achieve greater than 90% or 75% control in order to reduce carp populations to a relatively stable low population growth rate.

However, having accepted a 70 – 90% reduction in carp biomass as a best-estimate target, we must first define the pre-control biomass in order to be able to gauge progress towards achieving it. Zambrano *et al.* (2001) defined the equilibrium carrying capacity as the original condition. However, this remains problematic, as even if an equilibrium carrying capacity existed (as opposed to a dynamic system in constant flux driven by climatic cycles), the invasion of carp in the Murray-Darling Basin has been so recent that we do not yet know whether carp populations have stabilised at an equilibrium density. Commercial fishery records from NSW (Reid *et al.* 1997) suggest that following the post-invasion proliferation during the 1970s, carp biomass has remained relatively stable since the mid to late 1980s. However, Nicol *et al.* (2004) reported a significant 40 ± 27 % decline in the abundance of carp in the Murray River between 1995 and 2002 and our data from the Lachlan River suggest a significant 53 % decline in biomass since 2007. These more recent figures may suggest that carp population densities in the Murray-Darling Basin may still exceed the environment's carrying capacity and carp densities may continue to fall. Alternatively, if drought is the principle factor driving the recent declines, it may be prudent to assume that potential exists for carp populations to increase again if climatic conditions improve.

Regardless of the long-term stability or otherwise of the existing carp density, the earliest available standardised data from the lower Lachlan catchment were collected at a single site; Whealbah Bridge, between 1994 and 1995 (Harris and Gehrke 1997). A second site, Kirkup Park was included in 1998 and 1999 (I&I NSW, Freshwater Fish Research Database). From 2000 onwards, ~12 ± 2 sites have been sampled per annum (I&I NSW, Freshwater Fish Research Database). These data suggest that the average carp biomass within the demonstration reach has been 20.8 ± 2.5 kg per standard SRA-style sampling event (or approximately 277 kg/ha^{-1}) over the last 15 year period, with the 2009 density having the lowest average biomass on record (8.12 ± 2.2 kg) and 1999 having the highest (26.6 ± 8.2 kg). Setting a 70 or 90% carp biomass reduction target based on the maximum average density recorded since 1994 equates to a target carp biomass of 7.98 kg and 2.66 kg per sample respectively. These estimates equate to densities of around 106 kg/ha^{-1} and 35 kg/ha^{-1}, which are below those reported by other authors as the threshold densities below which carp begin to impact on the environment (~100 kg/ha^{-1} (Bajer *et al*. 2009), <161 kg/ha^{-1} (Matsuzaki *et al.* 2009), 174 kg/ha^{-1} (Parkos *et al.* 2003), 450 kg/ha^{-1} (Fletcher *et al.* 1985) and 500 kg/ha^{-1} (Miller and Crowl 2006).

Power analysis of our benchmark data indicates that the current experimental design only has the statistical power to detect a > 90% reduction in the carp biomass at sites within the Lachlan River demonstration site. However the experimental design has greater power to detect changes in total carp abundance (an ~80% reduction) and particularly the abundance of carp recruits (a 70% reduction). These effect-sizes are in the order of those suggested as necessary to result in minimising carps impacts and leading to potential ecological recovery.

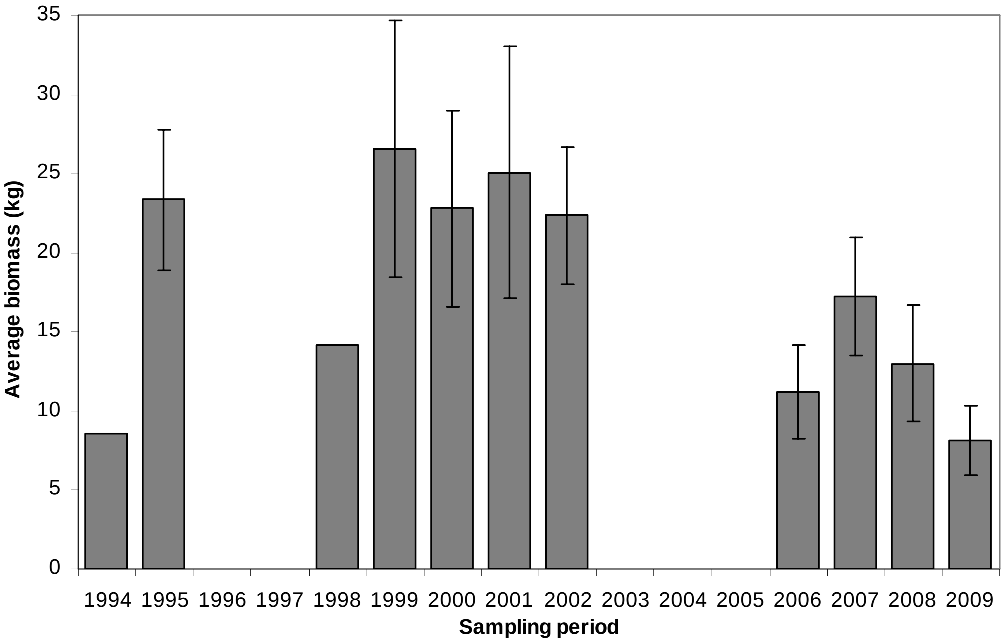


Figure 2.28. Change in the average (±SE) biomass of common carp from sites within the Lower Lachlan Demonstration Reach since standardised data collection commenced in 1994 (I&I NSW, Freshwater Fish Research Database).

Given that we have reasonable statistical power to detect 80 – 90% reductions in carp abundance and biomass, effect sizes that are consistent with published estimates of the carp control required to effect ecological recovery, we would anticipate that at least some responses in those aquatic variables purported to be affected by carp should become evident within the demonstration reach. The outputs of power analyses based on each of the benchmarked aquatic ecosystem variables suggest that the established experimental design provides sufficient statistical power to detect an increase in 2 – 3 native fish species per site, a 40% decline in the concentration of nitrate, 50% declines in the concentrations of phosphate and sulphate, 60% decrease in turbidity, 70% decrease in the phytoplankton biomass and an 80% decrease in the concentration of nitrite. However, due to poor statistical power, at least a doubling in total native fish biomass is required before we would be able to detect a statistically significant response at the conventional 5% significance level.

Limited statistical power to detect meaningful changes in phytoplankton biomass, nitrite concentration and total biomass of native fish under the current experimental design warrants consideration of whether ongoing monitoring of these variables should be enhanced by additional sampling, or alternatively, whether they should be omitted from the ongoing monitoring program. Given that subsequent BACI style assessment of these variables will always be restricted by limitations of the data already collected, additional data collected during the subsequent implementation phase is unlikely to improve power to detect change. However, if the assessment switches from a BACI comparison to trend analysis after several years of carp reduction, additional replication of sampling for these parameters could enhance our ability to detect a response. Because the power analyses were undertaken assuming only a BACI assessment, we don't know what the implications for statistical power are, and the current sampling intensity may already provide sufficient power to detect trends as the temporal scale of the dataset increases through time. For these reasons, enhanced sampling for phytoplankton biomass, nitrite or total native fish biomass are not proposed. Because total native fish biomass is only one of five fish assemblage parameters derived from fish community sampling, no reduction in sampling costs would result from excluding it from ongoing analysis. Similarly, nitrite concentration and phytoplankton biomass are only two of six water quality parameters measured during water quality field sampling, so omission of these two variables does not result in any significant cost savings. Given that their inclusion does not significantly increase the cost of the field sampling activities, we propose that data collection for all three of the low-power parameters be continued in the hope that either a substantial response is detected if carp impacts are controlled, or that we may be able to detect changes through trend analysis as opposed to the planned short-term BACI comparison.

2.4.3. Observed relationships between carp and aquatic ecosystem condition in the Lachlan River

2.4.3.1. Impacts of carp on sediment re-suspension, turbidity, nutrient concentrations and algal blooms

Increasing turbidity is potentially one of the most significant over-arching impacts of carp on aquatic systems (Schiller and Harris 2001). The benthic foraging behaviour of adult carp re-suspends sediments and disrupts the physical condition of the substratum (King and Hunt 1967; Crivelli 1981; Wilcox and Hornbach 1991). The resulting increased turbidity can suppress biofilm production, disrupt zooplankton grazing, limit the growth of macrophytes and algae by reducing light penetration, reduce survival of eggs and larvae of various fish species, alter breeding behaviour and limit the foraging behaviour of visually-cued fish (Lougheed *et al.* 1998; Schiller and Harris 2001; Zambrano *et al.* 2001; Newcome and Macdonald 1991). Carp biomass explained 76% of variation in turbidity in an enclosure experiment (Lougheed *et al.* 1998) and turbidity was significantly greater in wetlands or ponds where carp were present at higher densities (Lougheed *et al.* 1998; Zambrano and Hinojosa 1999; Zambrano *et al.* 1999; Parkos *et al.* 2003; Schrage and Downing 2004; Pinto *et al.* 2005; Matsuzaki *et al.* 2009). The exclusion of carp from marsh habitats led to a 45% improvement in clarity (Lougheed *et al.* 1998). The introduction of carp to experimental plots has increased turbidity by 10 times (Sidorkewicj *et al.* 1998). The effects of benthic foraging also influence phytoplankton density (Breukelaar *et al.* 1994; Gehrke and Harris 1994; King *et al.* 1997; Williams *et al.* 2002; Parkos *et al.* 2003; Driver *et al.* 2005*b*; Pinto *et al.* 2005; Matsuzaki *et al.* 2009) by the release of nutrients through re-suspension of nutrient laden sediments or through excretion (Lamarra 1975; Breukelaar *et al.* 1994; Gehrke and Harris 1994; Meredith 1996; Lougheed *et al.* 1998; Williams *et al.* 2002; Parkos *et al.* 2003; Schrage and Downing 2004; Chumchal *et al.* 2005; Driver *et al.* 2005*b*). Juvenile carp may promote algal blooms by reducing zooplankton biomass directly through predation (Gehrke and Harris, 1994; Lougheed *et al.* 1998; Parkos *et al.* 2003).

In contrast to these published examples demonstrating a significant positive relationship between carp and turbidity, we found no significant correlation between the biomass of carp and the local turbidity within the Lachlan River demonstration reach. If the carp-turbidity relationship is a threshold response rather than a linear trend (Meijer *et al.* 1990; Zambrano *et al.* 2001; Parkos *et al.* 2003; Miller and Crowl 2006; Bajer *et al.* 2009; Matsuzaki *et al.* 2009), either the carp densities that currently occur at all sites in the Lachlan are below the threshold at which carp impact upon turbidity in riverine systems, or conversely that the minimum carp density observed exceeds the threshold for impact at all sites. Given that the carp densities observed during this study ranged from as low as 0.002 kg ha^{-1} to a maximum of 826 kg ha^{-1} we doubt either of these hypotheses and suggest that factors other than carp biomass drive the spatial pattern of turbidity within the Lachlan. However, the relationship between carp biomass and turbidity may not be detectable by comparing carp biomass and turbidity at individual sites as it may be the cumulative carp biomass in the catchment upstream rather than the carp biomass at the specific location that drives the relationship. Explorer John Oxley, the first European to see the Lachlan River in 1817, described the lower Lachlan River as "extremely muddy" (Oxley 1820) and in 1836, a second explorer, Sir Thomas Mitchell observed that the lower Lachlan was "very green and muddy" (Mitchell 1839). Therefore, even before any European influence on the catchment, and over a century before carp became established, the waters of the lower Lachlan River were turbid and therefore natural factors other than carp biomass may drive the spatial pattern of turbidity within riverine habitats.

In contrast to turbidity, we identified a significant correlation between the average biomass of carp and the average phytoplankton biomass at a site. However, the negative correlation observed is actually the inverse of that most often referred to in the literature (Matsuzaki *et al.* 2009), with phytoplankton biomass being greatest at sites with low carp biomass and a relatively low threshold of impact. The observed negative relationship cannot be explained by predation of zooplanktivorous juvenile carp on zooplankton grazers, as sites with the highest phytoplankton biomass were those where few young of year carp were collected. Given that we found no significant relationships between the biomass of carp and the concentrations of dissolved nutrients within the water column (r_s ranging from -0.259 to 0.308, $n = 12$), there is little evidence to suggest that carp influence phytoplankton biomass in the Lachlan River via re-suspension of nutrient laden sediments, particularly given that the relationship between carp and phytoplankton biomass was negative.

The absence of significant positive correlations between carp biomass and turbidity, phytoplankton biomass or nutrient concentrations was unexpected but not altogether surprising. Although several studies have reported significant relationships, not all studies have been able to document impacts of carp biomass on turbidity, nutrient concentration or phytoplankton biomass at large catchment scales (Fletcher *et al.* 1985; Driver *et al.* 1997) or in ponds or enclosures (Robel 1961; Lougheed *et al.* 1998; Chumchal *et al.* 2005; Driver *et al.* 2005*b*). Fletcher *et al.* (1985) reported no increases in turbidity at carp densities of 140 – 1,500 kg ha^{-1}. Robel (1961) also failed to detect significant differences in turbidity in ponds enclosing carp densities of up to 670 kg ha^{-1}. Driver *et al.* (2005*b*) found that turbidity was significantly but weakly related to carp abundance, but not biomass within an experimental pond system. Overall, the relationship between carp and turbidity is complex, with sediment type, water depth, presence of water plants, and variation in wind velocity and water temperature all being important factors (Fletcher *et al.* 1985; Dieter 1990; Robertson *et al.* 1997; Lougheed *et al.* 2004). Although, our experimental design has the statistical power to detect change in these ecosystem parameters, we may not see any responses after a reduction in carp biomass simply because extrinsic confounding factors affect turbidity, phytoplankton biomass and dissolved nutrient concentrations more than carp do. For example, Lougheed and Chow-Fraser (2001) attributed higher than expected reductions in turbidity in a North American marsh following the exclusion of adult carp to zooplankton grazing as opposed to reduced impacts of carp themselves.

Overall, the expectation that water clarity will improve, algal blooms will be less prevalent and suspended nutrient concentrations in the Lachlan River will decline following carp control may be an unreasonable expectation.

Importantly, the concentrations of nitrite, nitrate and sulphate did not exceed the ANZECC (2000) recommended limits at most sampling locations. Therefore, there are supposedly no water quality problems associated with these three nutrients that need to be rectified. However, although the concentrations were within acceptable limits, we were still able to detect significant relationships with the important parameters of submerged macrophyte cover and native fish species richness. Further surveillance and assessment of these relationships may help in identifying the true ecological drivers of these relationships.

2.4.3.2. Impacts of carp on bank stability

Although it has been suggested that carp damage stream banks (McCrimmon 1968; Wilcox and Hornbach 1991), the role of carp in bank collapse or bank instability has not yet been quantified. Roberts *et al.* (1995), Brown (1996), Schiller and Harris (2001) highlight that factors such as river regulation, sediment type and flow regime also contribute to bank slumping. Further, the role of stock access (trampling) (Kauffman and Krueger1984; Fleischner 1994; Trimble and Mendel 1995, Roberts and Ebner 1997; Robertson 1997; Robertson 1998; Humphrey and Patterson 2000; Robertson and Rowling 2000; Jansen and Robertson 2001) along with destruction of bankside vegetation by tree removal and over cultivation (Brown 1996) should also be acknowledged as primary causes or contributing factors towards bank instability. Among our 27 monitoring sites, bank erosion was only present at one, Narrandera (Murrumbidgee River) and this was likely a result of factors other than carp. Therefore, it must be concluded that either the carp densities that currently exist in the Lachlan, Macquarie and Murrumbidgee Rivers are below the threshold at which carp impact upon bank stability in riverine systems, or that factors other than carp biomass are the primary cause of bank erosion.

2.4.3.3. Impacts of carp on macrophytes

There are many accounts of carp destroying aquatic macrophyte beds either directly through uprooting (e.g., during benthic foraging) or indirectly by increasing turbidity, altering nutrient concentrations or reducing photosynthesis by sediment smothering (Cahn 1929; Ricker and Gottschalk 1940; Black 1946; Chamberlain 1948; Anderson 1950; Cahoon 1953; Threinen and Helm 1954; Tryon 1954; Robel 1961; King and Hunt 1967; McCrimmon 1968; Crivelli 1983; Hume *et al.* 1983; Fletcher *et al.* 1985; Panek 1987; Engel 1995; Roberts *et al.* 1995; Lougheed *et al.* 1998; Sidorkewicj *et al.* 1998; Zambrano *et al.* 1999; Williams *et al.* 2002; Parkos *et al.* 2003; Miller and Crowl 2006; Bajer *et al.* 2009). In most studies, herbivory by carp was considered rare and only occurred when preferred food items are unavailable (Hume *et al.* 1983; Crivelli 1983; Fletcher *et al.* 1985; Roberts *et al.* 1995; Parkos *et al.* 2003). It is thought that damage to macrophytes occurs as a by-product of benthic feeding, with soft leaved and shallow rooted plants such as *Potamogeton*, *Vallisneria* and *Chara* species reportedly being most susceptible to damage. However, in other studies, direct herbivory has been reported (Sidorkewicj *et al.* 1998; Zambrano and Hinjosa 1999; Hinojosa-Garro and Zambrano 2004; Miller and Provenza 2007).

The implications of macrophyte loss for aquatic ecosystems are potentially large, as macrophytes perform several important ecosystem functions. Macrophytes contribute to the aquatic carbon cycle, modify flow and create velocity shelters (Newell 1995), provide habitat for bacteria, fungi and algal epiphytes (Burns *et al.* 1994), aid sedimentation, stabilise the substratum (Lougheed and Chow-Fraser 2001), suppress phytoplankton growth by competing for nutrients (Grimm and Backx 1990; Lougheed and Chow-Fraser 2001), provide habitat and shelter for invertebrates (Diehl, 1993; Lougheed and Chow-Fraser 2001), act as nursery areas for small and juvenile fish (Petering and Johnson 1991) and provide food and habitat for waterfowl (Chamberlain 1948; Robel 1961; King and Hunt 1967; Scott and Crossman 1973; Haas *et al.* 2007; Bajer *et al*. 2009).

Case studies of the impact of carp biomass on aquatic vegetation indicated that macrophyte cover declined by 14% at a carp density of 30 kg ha^{-1}, 32% at 110 kg ha^{-1} and 77% at 255 kg ha^{-1} and species richness of macrophytes declined as carp biomass increased (Bajer *et al*. 2009), that low densities of juvenile carp (18 – 210 kg ha^{-1}) reduced the re-establishment of macrophytes by 14 – 60% and higher densities of adults (138 – 535 kg ha^{-1}) completely destroyed all submerged weeds within 4 months (Sidorkewicj *et al.* 1998) and that a carp density of 800 kg ha^{-1} reduced macrophyte diversity and reduced cover by 83% (Lougheed *et al*. 2004).

However, within the lower Lachlan demonstration reach, we found no significant correlation between the biomass of carp and the cover of emergent or submerged macrophytes. As for turbidity, the absence of significant negative correlations between carp biomass and emergent and submerged macrophyte cover was unexpected, but not altogether surprising. Although many studies have reported significant impact of carp on aquatic macrophytes, others have found no significant relationships (Chumchal *et al.* 2005). Further, several of those studies that have reported impacts on macrophyte cover or growth have reported species-specific effects, with some macrophyte species heavily affected, but others not. Although, our experimental design has the ability to detect change in these ecosystem parameters, we may not see any responses after a reduction in carp biomass simply because extrinsic confounding factors affect the growth of macrophyte beds within river channels more than carp do. Our data suggest that the cover of submerged macrophtyes is negatively related to turbidity and nitrite concentration within the Lachlan. Turbidity obviously affects submerged macrophyte growth through shading, but the linkage with nitrite concentration is less clear. Given that we found no significant relationship between carp biomass and turbidity, it appears that other factors that contribute to turbidity, rather than carp biomass are the key processes driving submerged macrophyte cover.

2.4.3.4. Impacts of carp on macroinvertebrates

Carp potentially impact upon invertebrates in two main ways; through direct predation and by habitat alteration. Larval and juvenile carp consume zooplankton (Hume *et al.* 1983; Khan 2003; Parkos *et al.* 2003) and, as they mature, adult carp switch to benthic foraging (Khan 2003). Therefore, abundant populations of juvenile carp should directly affect zooplankton communities and abundant populations of adult carp should directly affect benthic macroinvertebrate communities. The reported impacts of carp on macrophyte beds and substrate disturbance can indirectly impact on macroinvertebrate communities as macrophyte beds provide habitat and shelter for invertebrates (Diehl, 1993; Roberts and Ebner 1997; Lougheed *et al.* 1998; Lougheed and Chow-Fraser 2001) and substrate disturbance can negatively affect the benthic community structure (Wilcox and Hornbach 1991; Zambrano *et al.* 1999). For example, Lougheed *et al.* (1998) showed that carp impact on populations of large zooplankton such as *Daphnia* by increasing turbidity and reducing cover provided by macrophytes. Similarly, Hinojosa-Garro and Zambrano (2004) found that crayfish abundance declined even at low densities of carp, with the relationship driven by the preference of crayfish for submerged macrophyte beds. Carp abundance has been shown to be inversely related to benthic macroinvertebrate abundance, especially gastropods (Stein and Kitchell 1975, Zambrano *et al.* 1999) and chironomids (Matsuzaki *et al.* 2009). In the lower Lachlan catchment, historical evidence and ethnographic accounts suggest that diverse macroinvertebrate communities were present up until the 1970s, when carp invaded the system (Roberts and Sainty 1996, Chessman *et al.* 2006). However, other studies have reported mixed responses. Miller and Crowl (2006) found that carp significantly affected invertebrate communities in small exclosures but not in larger ones. Schrage and Downing (2004) observed large changes in the composition of zooplankton and the biomass, but not the composition of benthos. Other studies report no impacts of carp on zooplankton communities at all (Chumchal *et al.* 2005). Not all indirect impacts are necessarily negative, as Parkos *et al.* (2003) found that as carp reduced the abundance of macroinvertebrate predators (small fish), the presence of carp actually led to increased abundance of zooplankton grazers. Further, a meta-analysis of carp impact studies by Matsuzaki *et al.* (2009) found that, in general, carp increased the densities of some zooplankton groups.

Within the lower Lachlan River demonstration site we did not detect any correlation between the biomass of carp and the number of macroinvertebrate families present in edge habitats. Re-directing the macroinvertebrate sampling effort to focus on benthic macroinvertebrates and zooplankton may be a more appropriate strategy for future monitoring.

2.4.3.5. *Impacts of carp on native fish*

Populations of Australian native freshwater fish species have declined markedly in distribution and abundance during the last 100 years. While the causes of these declines have been discussed at length (Cadwallader 1978; Cadwallader 1986; Cadwallader and Lawrence 1990; Faragher and Harris 1994; Harris and Gehrke 1997), it is still not clear what impacts carp have had on native fish when compared to other environmental impacts such as the modification of flow regimes, overfishing, habitat loss, habitat degradation, and the impact of other exotic fish and their diseases. Diet studies of Australian carp populations suggested limited predation on native fishes (Khan 2003). However, some accounts from America suggest that carp may feed on fish eggs and larvae (Lachner *et al*. 1970; Page and Burr 1991). There is no information on the significance of competition between carp and native fish and it has been suggested that benthivorous carp do not compete with native fish for food, except when food is limited (Brown 1996; Roberts and Ebner 1997). However, like adult carp, plotosid catfish such as the freshwater catfish (*Tandanus tandanus*) are primarily benthic foragers and the similarities of the mouth structure and foraging behaviour suggest that at least catfish species may be in direct resource competition with adult carp. Further, larval and juvenile carp feed almost exclusively on zooplankton and insect larvae (Hume *et al*. 1983; Khan 2003) and therefore high densities of young carp compete directly with all species of native zooplantivorous fish and the larvae and juveniles of virtually all species (Schiller and Harris 2001). This is particularly likely in ‘hotspot’ locations (Gilligan, in prep.) where the density of juvenile carp can be extremely high (Jones and Stuart 2007). When and if they occur, habitat changes caused by carp (e.g., increased turbidity and loss of macrophytes) may influence small native species, such as southern pygmy perch (*Nannoperca australis*), olive perchlet (*Ambassis agassizii*) and flat-headed galaxias (*Galaxias rostratus)*, which are reliant on aquatic macrophytes for spawning and cover (Llewellyn 1974; Humphries 1992; Llewellyn 2005). Lastly, carp have been implicated in the spread of fish diseases, such as the exotic bacteria *Aeromonas salmonicida* (Hindmarsh, 1994) and parasites such as *Lerneae* spp. (Rowland and Ingram 1991).

Within the lower Lachlan demonstration reach, we did not detect any correlation between the diversity or biomass of native fishes and the biomass of carp. In addition to the possible explanations for the lack of observed relationship between turbidity and macrophyte cover discussed above, a further hypothesis specifically relevant to native fish populations is that each species may respond differently to the presence of carp. Those species capable of surviving through the invasion boom of the 1970 – 80s (Reid *et al.* 1997), when carp biomass was at its highest, have demonstrated their ability to co-exist with carp and are still present in the Lachlan system. It is those species that have declined substantially, such as freshwater catfish, Murray-Darling rainbowfish, unspecked hardyhead (*Craterocephalus stercusmuscarum fulvus*), olive perchlet, southern pygmy perch and flat headed galaxias that could be predicted to respond most to a reduction in carp biomass. The fact that these species remain at very low abundances suggests that they may be substantially affected by carp at current carp densities and that a recovery in these species may be dependent on reducing carp biomass within the lower Lachlan River. However, their potential for response may be compromised if the species are now locally extinct in the lower Lachlan catchment. This is likely to be true for both southern pygmy perch and flat-headed galaxias. For these two species, even total carp eradication will not result in a detectable response.

2.5. Conclusions

We quantified the status of the common carp population in the lower Lachlan River between 2007 and 2009. Carp were the most widespread fish species collected, the second most abundant, and made up 78% of the total fish biomass within the lower Lachlan River. The three principal recruitment areas between 2007 and 2009 were; (i) the lower Lachlan River and Great Cumbung

Swamp, (ii) the upper Lachlan River around Cowra – Goologong, and (iii) Lake Cargelligo, Lake Brewster and riverine sites immediately downstream.

Despite demonstrating that our monitoring program provides adequate statistical power to detect meaningful changes in many of those ecosystem parameters reported to be impacted upon by common carp, we were unable to detect significant correlations between turbidity, nutrient concentrations within the water column, stream bank erosion, macrophyte cover, macroinvertebrate diversity, native fish diversity or total native fish biomass. Further, we detected a significant negative relationship between the biomass of carp and the biomass of phytoplankton, which is the opposite relationship to that expected if carp did have negative impacts on the ecosystem. We propose several potential reasons why we did not demonstrate that carp impact on ecosystem parameters in the Lachlan, whereas numerous publications have convincingly demonstrated impacts on the same parameters in other experimental systems. Firstly, the impacts of carp in river systems may not be as extreme as those reported in lentic ecosystems in which virtually all published carp impact assessments have been undertaken. Secondly, the relationship between carp biomass and turbidity may not be detectable at individual sites and that it is the cumulative carp biomass in the catchment upstream rather than the carp biomass at the specific location that drives the relationship. Thirdly, for native fish populations, the response to carp removal may be species specific as opposed to community-wide changes. Fourth, if the impacts of carp are a threshold response rather than a linear trend (Zambrano *et al.* 2001; Matsuzaki *et al.* 2009), either the carp densities that currently occur at all sites in the Lachlan are below the threshold at which carp impact upon riverine systems, or conversely that the minimum carp density observed exceeds the threshold for impact at all sites. Lastly, factors other than carp biomass may drive the condition of aquatic ecosystem parameters within the Lachlan.

Our results suggesting little impact of carp on aquatic ecosystems is not unique. Across the numerous studies that have attempted to quantify the effects of common carp on aquatic ecosystems, although some effects are reported consistently, other effects have been highly variable. Parkos *et al.* (2003) suggested that a simultaneous evaluation of all (or several) ecosystem components would help explain the variability of some of the effects of carp. Despite adopting this approach within our demonstration reach, we were still unable to develop a firm understanding on the relationship between carp density and ecosystem impacts.

Despite our results, very detailed ethnographic accounts of an increase in turbidity, loss of ribbonweed and a switch from a native to alien dominated fish community in the lower Lachlan catchment correspond to the invasion of the catchment by carp in the 1970s (Roberts and Sainty 1996; Roberts and Ebner 1998). Recovery studies provide an alternative to impact studies (Koehn *et al*. 2000). Instead of attempting to detect the impact of a disturbance, recovery studies remove the source of disturbance and the investigation focuses on detecting recovery (Roberts and Ebner 1997). This form of assessment is free of many of the constraints of assessing the impact of an introduced population of carp and has been applied successfully in Australia (King *et al.* 1997, Robertson *et al.* 1997) and will be the focus of the monitoring program as it progresses into the implementation phase of the project. However, Lougheed and Chow-Fraser (2001) caution that monitoring needs to be continued for over a decade in order to determine the ultimate effect of carp exclusion and other restorative efforts. Consequently, expectations that ecosystem recovery will be detectable within the funded two year implementation phase of the *River Revival – Lachlan River Carp Cleanup* may be unrealistic.

3. PRELIMINARY RESULTS: QUANTIFYING THE RATE AND EXTENT OF RECOVERY OF AQUATIC MACROPHYTES, BENTHIC MACRO-INVERTEBRATES, ZOOPLANKTON AND SMALL NATIVE FISHES IN LONG-TERM CARP EXCLUSION PLOTS

3.1. Introduction

It is acknowledged within the field of invasive species management that once invasive species have become established, the potential for successful eradication can be extremely low (Trexler *et al.* 2000; Chick and Pegg 2001: Simberloff 2003; Braysher 2007). In response, it has been recommended that pest management targets should aim to minimise the impacts of established pest populations (Bomford and Tilzey 1997; Koehn *et al*. 2000; Koehn and MacKenzie 2004; Braysher 2007). Although this seems a logical strategy, there are two obvious difficulties with applying the approach to carp management in the Murray-Darling Basin. The first is that considerable uncertainty remains about the actual extent to which carp contribute towards the degradation of the various aquatic ecosystem variables (see previous chapter). The second is that little standardised data for any of these variables were collected from the lowlands of the Murray-Darling Basin prior to the invasion of carp. As a result, we don't have the capability to produce a reasonably accurate model of the zero impact state for relevant aquatic ecosystem parameters and therefore can't define the necessary 'minimum impact' management targets.

Numerous studies have utilised manipulative experiments (either replicated enclosure/exclosure experiments, replicated pond experiments or unreplicated before-after assessments of carp eradication, control or exclusion) to quantify the impact of carp on aquatic ecosystem variables (Cahn 1929; Black 1946; Anderson 1950; Threinen and Helm 1954; Mraz and Cooper 1957; Robel 1961; King and Hunt 1967; Lamarra 1975; Forester and Lawrence 1978; Crivelli 1983; Fletcher *et al.* 1985; Qin and Threlkeld 1990; Richardson *et al.* 1990; Breukelaar *et al.* 1994; Roberts *et al.* 1995; Verrill and Berry 1995; King *et al.* 1997; Robertson *et al.* 1997; Batzer 1998; Lougheed *et al.* 1998; Zambrano and Hinojosa 1999; Zambrano *et al.* 1999; Lougheed and Chow-Fraser 2001; Kahn *et al.* 2003; Parkos *et al.* 2003; Williams and Moss 2003; Lougheed *et al.* 2004; Schrage and Downing 2004; Chumchal *et al.* 2005; Driver *et al.* 2005b; Pinto *et al.* 2005; Evelsizer and Turner 2006; Miller and Crowl 2006; Matsuzaki *et al.* 2007; Roozen *et al.* 2007; Hochhalter 2009; Matsuzaki *et al.* 2009). A meta-analysis of 16 of these studies (Matsuzaki *et al.* 2009) suggests the overall consensus is that (in order of the extent of the impact); carp significantly increase the biomass of phytoplankton, increase turbidity, increase the density of rotifers and copepods within the zooplankton community, decrease the concentration of ammonia in the water column, negatively effect submerged macrophytes, decrease the abundance of chironomids in the benthos and increase the concentration of total phosphorus in the water column. But carp had no significant effect on the concentration of total nitrogen or phosphate in the water column, the density of cladocerans within the zooplankton community, or abundance of oligochaete worms within the benthos (although the result for oligochaete worms was heavily influenced by a single study). However, for some of these parameters, particularly turbidity, phytoplankton biomass and rotifer density, the results have been highly variable across studies. Further, the consistent effects reported for aquatic macrophytes and total phosphorus have been of quite a small magnitude despite being statistically significant.

Therefore, although some ecosystem changes can be anticipated to result from carp control programs, the extent of the change may be heavily dependant on site-specific factors such as the nature of the substratum, the particular species of aquatic macrophyte assessed, or the preceding condition of the ecosystem (Lougheed and Chow-Fraser 2001). Further, all the studies reported have been undertaken in shallow lentic waterbodies such as marshes, lakes or artificial ponds and we are not aware of the existence of any equivalent manipulation experiment data from lotic (flowing water) environments. The assessment of pre-treatment data presented in the previous chapter provides only a correlative suggestion of little relationship between the biomass or carp and the condition of the range of aquatic ecosystem parameters monitored at riverine sites in the Lachlan. However, assuming that the carp control activities implemented under the *River Revival – Lachlan River Carp Cleanup* are sufficient to result in a substantial reduction in carp biomass, the existing monitoring program will subsequently enable a robust assessment of the impacts of carp in a lotic environment.

Although we will be in a position to test for recovery of the aquatic ecosystem and demonstrate the role carp control played in that change, the data available may still not allow us to define 'minimum impact' management targets. The only data available from the Lachlan which may guide establishment of outcome targets are the detailed ethnographic accounts of an increase in turbidity, loss of ribbon weed (*Vallisneria americana*) and a switch from a native to alien dominated fish community in the lower Lachlan catchment corresponding to the invasion of the catchment by carp in the 1970s (Roberts and Sainty 1996; Roberts and Ebner 1998). But even these accounts do not provide quantitative figures to utilise as targets. Carp exclusion plots are perhaps the best means by which we can rapidly obtain quantitative data on the local condition of aquatic parameters in a carp-free state. Further, exclusion plots may enable us to model the rate of recovery that can be expected once carp biomass has been reduced. Additionally, as the *River Revival – Lachlan River Carp Cleanup* is primarily a demonstration site exercise, exclusion plots installed at publicly assessable locations provide a focal point for community education and engagement in the project.

We established a series of six 40.5 m^2 paired carp exclusion plots at three locations in the lower Lachlan demonstration site in order to document the extent and rate of recovery of aquatic macrophytes, benthic macro-invertebrates, zooplankton and small fish assemblages following the exclusion of carp. The exclusion plots will be maintained as carp-free for a period of two years, which is substantially longer than the duration of the generally short-term published experiments, and monitored quarterly over that period. Thereafter, carp will be allowed access to one half of the exclusion plots and the response of the monitored parameters will be recorded in order to establish conclusive proof that carp were the factor responsible for the change. The extent of recovery of the ecosystem components within the exclusion plots over the first two years will be used to establish catchment targets for recovery of the broader Lachlan ecosystem.

3.2. Methods

3.2.1. Experimental design

Long-term carp exclusion is dependant on a carp-proof exclosure design that prevents carp from both burrowing under or leaping over exclosure walls, is robust enough to withstand storms and is resistant to vandalism (Gilligan *et al.* 2005). The relatively high cost of construction of such exclosure designs limited the amount of spatial replication possible to three study sites. Carp exclusion cages were designed to exclude all sub-adult and adult carp, while providing free access for macro-invertebrates and small fishes (including very small carp) for a period of up to four years. Each exclosure was constructed from a series of 1.5 m wide by 2.66 m high panels constructed from 25 mm galvanised RHS frames and 25 mm square galvanised weld-mesh. The base of each panel has a 500 mm apron extending outwards at 90^{o} which was covered with railway ballast to prevent carp from burrowing under and into the cage. The top 500 mm of each panel angled outwards at 15^{o} to prevent fish from jumping into the cage during times of elevated water level. Panels were assembled to form 9 x 9 m cages divided into paired 9 x 4.5 m exclusion plots (Figure 3.1). A third 9 x 4.5 m unfenced plot was pegged out adjacent to the exclusion cage to act as a control plot at each site. Therefore, each replicate (location) consisted of three treatment plots: Inside cage – no carp access for the term of the study, inside cage – no carp access for 2 years and the unfenced control plot.

Figure 3.1. Mountain Creek carp exclusion cage.

Because the sampling process within the plots was destructive, the same sampling location within each plot could not be re-used during successive sampling events. Therefore, at the commencement of the study we divided each plot into 162 0.5 x 0.5 m sampling cells. An *a priori* sampling design was generated using DiGGer (Coombes 2009) to obtain an optimal spatial allocation of cells to sample per sampling event. The design was carried out in three steps:

1. Select sampling locations – 204 sampling locations were selected for each location by allocating 204 replicates of 1 treatment and 1 replicate of 282 treatments. This step involved blocking in two directions.
2. Allocate sampling year to selected sampling locations – Each 9 quadrat x 9 quadrat block (equivalent to ¼ cage) contained 34 selected sample locations. Sampling years were distributed within each block (8 sampling locations/year/block + 2 non-destructive sampling locations/block)
3. Allocate sampling time within years within blocks – Each 9 quadrat x 9 quadrat block (equivalent to ¼ cage) contained 8 selected sample locations for each year. Sampling times (corresponding to seasons) were distributed within each year (2 sampling locations/time/year/block).

The total biomass and diversity of aquatic vegetation, macro-invertebrates, zooplankton and small fish species will be quantified four times per annum over the first 2 years of the experiment. After two years of carp exclusion, one exclusion plot at each site will be opened to allow adult carp free access. Monitoring of the cages will continue quarterly for a further two years, or until conditions have reverted to the pre-exclusion state in the treatment plot.

3.2.2. Site selection

To be eligible as a potential site for installation of a carp exclusion plot, candidate locations needed to have a relatively flat uniform substratum; be within a waterway that was unlikely to dry out over a three to four year period, but where flow velocities would not damage the cage; at least one of them must be in a publicly accessible location in order to fulfil its role as a 'demonstration'; and at least one in a less accessible location to ensure against vandalism.

Sites on the foreshores of Lake Brewster and Lake Cargelligo were obvious initial candidates for selection. However, at the commencement of the study, Lake Brewster was dry and the influence of water level fluctuations at the Lake Cargelligo foreshore meant that the cage would need to be so far offshore that it would create a boating hazard. An alternative site for the Lake Brewster cage was chosen at Benson's Drop in Mountain Creek, the outlet channel of Lake Brewster (Figure 3.2). An alternative site for the Lake Cargelligo cage was chosen in Curlew Water, another lake within the Lake Cargelligo system. Unfortunately, after installation of the cage at this site in May 2008, water levels in Curlew water declined more than was expected, and the exclusion plot was left exposed. A further alternative site was secured in Lake Forbes and the cage was dismantled and re-installed at the new site (Figure 3.2). The third site was in Yarrabandai Creek at Burrawang West Station, an eco-resort near Ootha (Figure 3.2). Local council and NSW Maritime approval was sought and granted at all three locations.

Yarrabandai Creek is a small tributary of Goobang Creek. To date, the Burrawang West cage has had a maximum water depth of 0.6 m. The substratum of the plots is a silty-clay throughout and contains a large amount of organic material such as decomposing cumbungi (*Typha* spp.) stems and root systems. Exclusion cage construction was completed in May 2008. At the time of installation, the Burrawang West plot contained a large amount of the floating macrophyte azolla (*Azolla filiculoides*) and small stands of cumbungi.

Benson's Drop is a location on Mountain Creek, the outlet flow channel from Lake Brewster into the Lachlan River. The exclusion cage site is downstream of the Benson's Drop Weir in the backed-up waters formed by Willandra Weir on the Lachlan River. To date, the Mountain Creek site has had a maximum water level of 0.9 m. The substratum within the plot is similar to that at Burrawang West but is largely free of obvious organic detritus. Exclusion cage construction was completed in October 2008. At the time of installation, the Mountain Creek plot contained a large amount of azolla as well as patches of submerged ribbon weed.

Lake Forbes is a lake approximately 4.5 km long and 100 m wide that bisects the township of Forbes. The lake backs onto Tom's Lagoon and receives water from town stormwater run-off, several unnamed tributaries and the town bore. To date, the Forbes plot has had a maximum water depth of 1.2 m. The substrate in the cages is a similar to the other two exclusion plots but is covered by a small amount of fine organic debris, a few small sticks and rocks. Exclusion cage construction was completed in October 2008 (after being moved from Curlew Water). At the time of installation, the plot contained no emergent, submerged or floating macrophytes. The exclusion cage is located in parkland close to the town centre and its high visibility provides ideal opportunities for public demonstration and project promotion. An interpretive sign detailing the

River Revival project and the exclusion cage experiment has been erected at the site to inform the community and foster their involvement in the project.

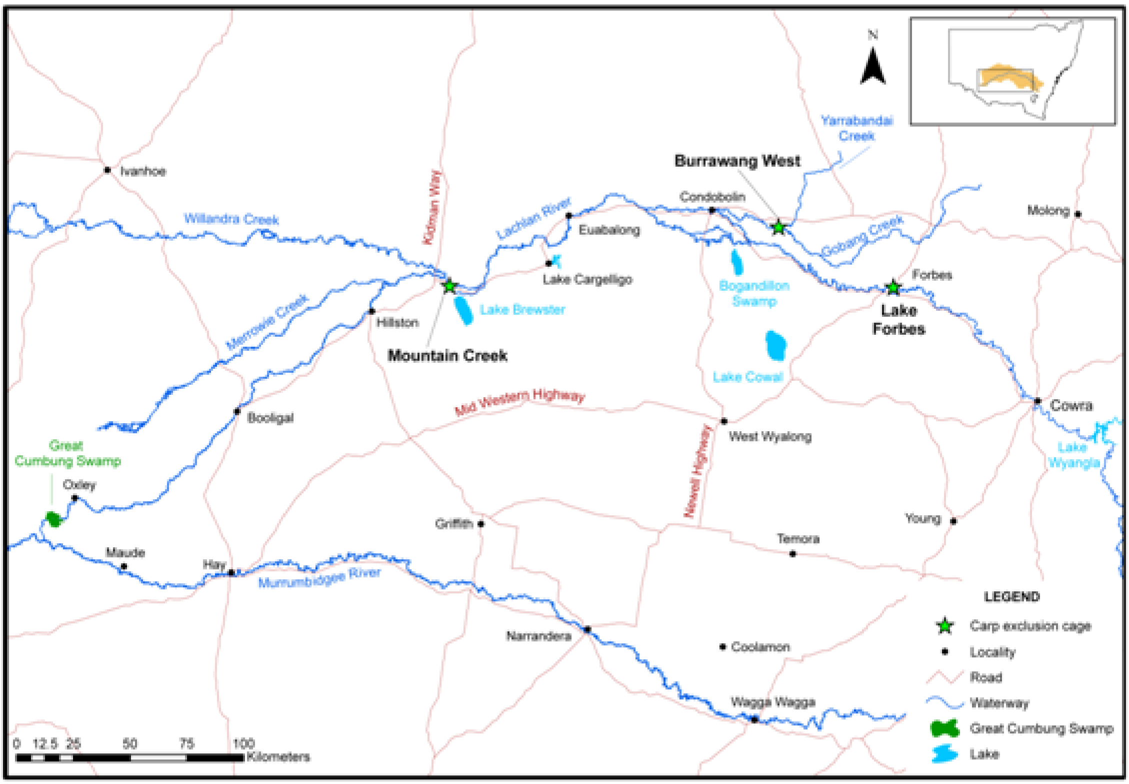


Figure 3.2. The locations of the three carp exclusion plots within the Lower Lachlan Demonstration Reach.

3.2.3. Sampling methods

Sampling commenced at all three study sites on 25 – 27 February 2009. The second and third samples where collected on 27 – 28 May and 1 – 3 September 2009. Ongoing quarterly sampling will continue until November 2010. At that time, sections of mesh will be removed from one exclusion plot and post-treatment sampling will continue up until November 2012, or will be discontinued sooner if parameters have reverted to the February 2009 condition.

3.2.3.1. Small fish

Fish were sampled from each plot using both backpack electrofishing and unbaited shrimp traps. Backpack electrofishing consisted of repeat-pass electrofishing of the entire area of each plot, with each pass consisting of approximately 220 seconds of power-on time. Ten unbaited collapsible shrimp traps were set inside each plot with a soak time of at least 30 minutes. At the completion of sampling, captured individuals were identified, counted, measured and observed for externally visible parasites, wounds and diseases before being released. All taxa were recorded to species level, except for the carp-gudgeon species complex which were recorded as *Hypseleotris* spp. Length measurements recorded to the nearest millimetre were taken as caudal fork length for fork-tailed species and total length for other species. All sampling was undertaken during daylight hours.

3.2.3.2. Aquatic macrophytes

String-lines were used to define the exact positions of each cell to be sampled for macrophytes. A 0.5 x 0.5 m box frame is placed over the sample cell and all plant material inside that quadrat was harvested. The harvested plants from each cell are identified to species before being separated into floating, submerged and emergent categories. These were dried in an oven at 60°C until completely dry and the weight was recorded to three decimal places.

3.2.3.3. Benthic macro-invertebrates

Benthic macro-invertebrate samples are collected from the same cells as the macrophyte samples. Three sediment core samples 15 cm × 19.6 cm^2 were collected per cell. Each core sample was preserved in ethanol. The preserved sediment samples were passed through 250, 500 and 1,000 µm nested sieves and then hand-picked in the laboratory. Specimens were identified to family level and counted. Samples were then placed in an oven at 60°C for 24 hours and the dry weight was recorded to three decimal places.

3.2.3.4. Zooplankton

A 390 mm diameter 250 µm mesh plankton net was hauled the length of the cage (9 m) ten times. The sample was pooled and sieved through 106, 250, 500 and 1000 µm nested sieves and the volume (ml) of each of the four size classes of zooplankton was recorded. The dominant species within each size class was identified.

3.2.3.5. Photopoints

Photo-points at each of the front left and right corners and looking diagonally across each plot were established and an image was taken during each sampling occasion.

3.3. Results

These are the preliminary results based on the first three rounds of carp-exclusion sampling.

Seven species of fish were collected during the first three rounds of sampling, including four species of native fish (one endangered) and three alien species. There has been no obvious or consistent response in the diversity or abundance of small native fish species to carp exclusion across the three study locations (Figure 3.3). No native fish at all have been collected from any plot at the Burrawang West site. Preliminary data from Mountain Creek and Lake Forbes varied as much among the two carp free treatments as these did with the unfenced control plots.

The number of benthic macro-invertebrate families was even lower than fish diversity at all sites, with only three families collected so far; Chironomidae, Belostomatidae and Lymnaeidae. However, the macro-invertebrate data appears to be reflecting carp effects more than the fish data. No benthic macro-invertebrates have been collected from any of the unfenced control plots throughout the sampling period (Figure 3.4). In contrast, they were found at a single carp exclusion plot (of six) in the first sampling round and 66% of carp exclusion plots in the second and third rounds of sampling (Figure 3.4).

Floating macrophytes were collected at both Mountain Creek and Burrawang West study sites but not at Lake Forbes (Figure 3.5). The only species collected were azolla and duckweed (*Spirodela* spp). At Burrawang West, azolla has been increasing in biomass in all three treatment plots, but the increase has been greatest in the carp exclusion treatments. This trend was similar at Mountain

Creek. However, at this site the coverage of azolla was so dense that it formed a continuous sheet that threatened to confound any response by submerged macrophytes within the exclusion plots.

Table 3.1. Fish sampled within the three plots at each study site.

Species	Total number	Location Mountain Creek	 Burrawang West	 Lake Forbes
Carp-gudgeon species complex	240	•		•
Eastern gambusia*	188	•	•	•
Flat-headed gudgeon	90	•		•
Goldfish*	25	•	•	
Olive perchlet	19	•		
Common carp*	5	•		•
Un-specked hardyhead	5	•		•

** Alien species*

Therefore, on the 11 June we harvested the azolla from within the Mountain Creek exclusion plots, leaving approximately as much azolla inside as was present on the outside. A total of 61.44 kg and 138.24 kg (wet weight) of azolla was removed from the left and right plots respectively.

Cumbungi (*Typha* spp) was the only species of emergent macrophyte collected within experimental plots but was only collected at the Burrawang West site, where it was first collected in September 2009 from all three treatment plots (Figure 3.5).

Submerged macrophytes were only collected at the Mountain Creek site (Figure 3.5). Species collected include ribbon weed and curly pondweed (*Potamogeton crispus*). The biomass of submerged macrophytes has increased between February and September 2009 within all three treatment plots at that site. However, as growth within the unfenced control plot has been equivalent to or greater than the growth recorded in the carp exclusion plots, carp cannot be implicated as a factor in the submerged macrophyte response.

No zooplankton at all have been collected from any study site throughout the sampling period presented here.

As yet, the established photo-points have not proved useful in providing a visual catalogue of change within the plots, with only one plot (Burrawang West – left exclusion plot) having obvious signs of change due to the establishment, growth and spread of cumbungi (Figure 3.6).

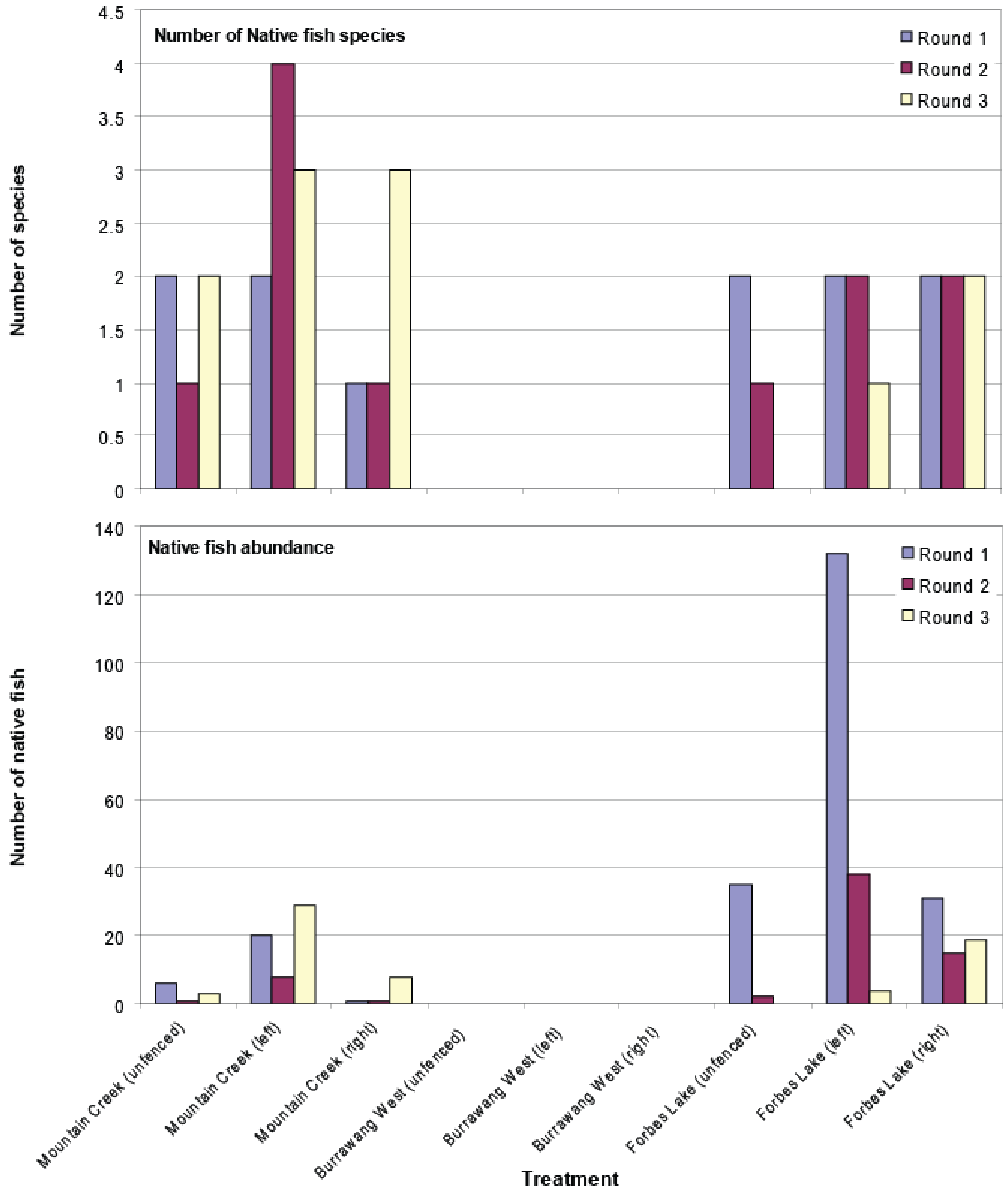


Figure 3.3. Preliminary results from the first three rounds of quarterly small fish assemblage monitoring within carp exclusion plots and unfenced (control) plots at three locations within the Lower Lachlan Demonstration site.

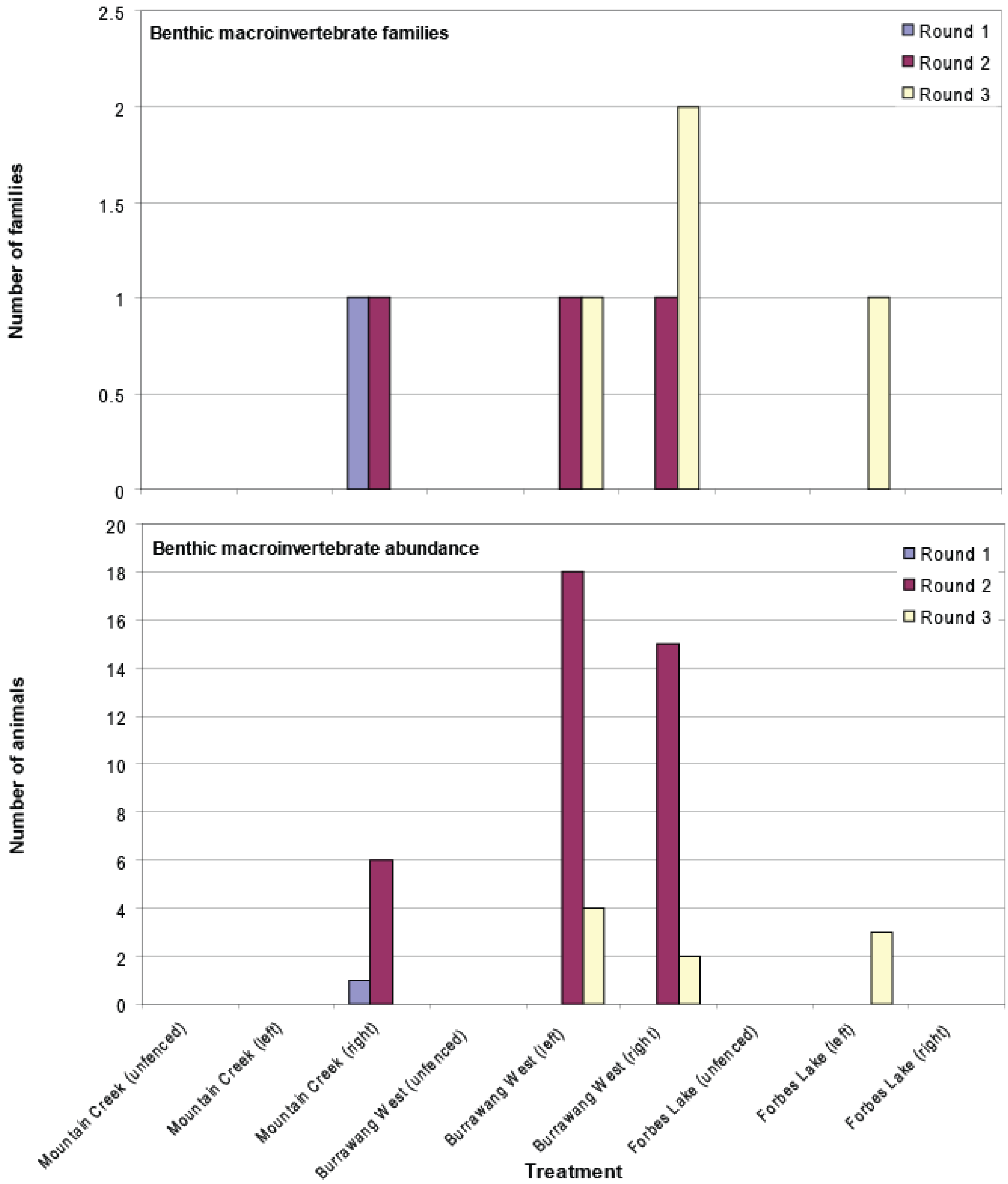


Figure 3.4. Preliminary results from the first three rounds of quarterly benthic macro-invertebrate assemblage monitoring within carp exclusion plots and unfenced (control) plots at three locations within the Lower Lachlan Demonstration site.

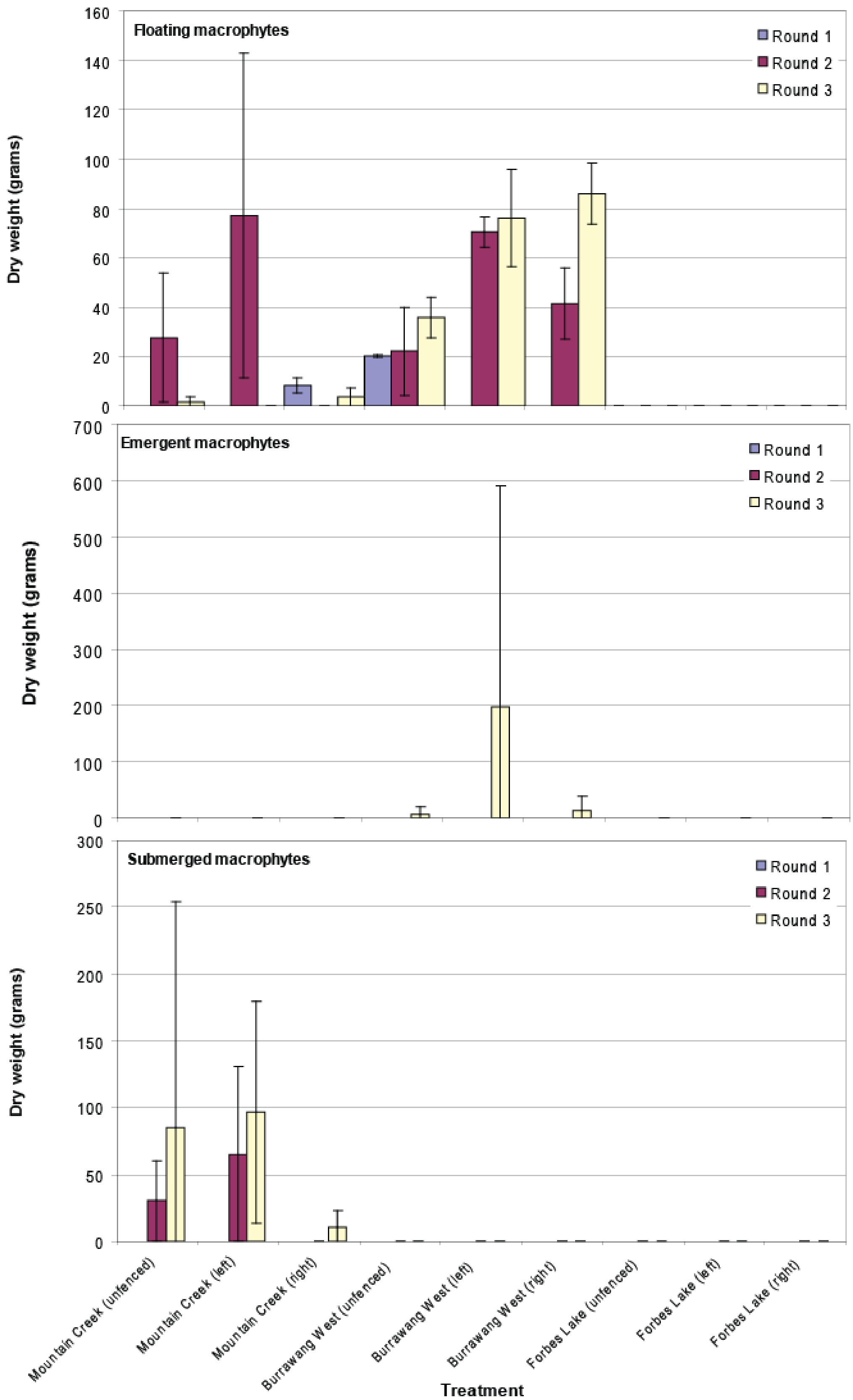


Figure 3.5. Preliminary results from the first three rounds of quarterly floating, emergent and submerged macrophyte biomass monitoring within carp exclusion plots and unfenced (control) plots at three locations within the Lower Lachlan Demonstration site.

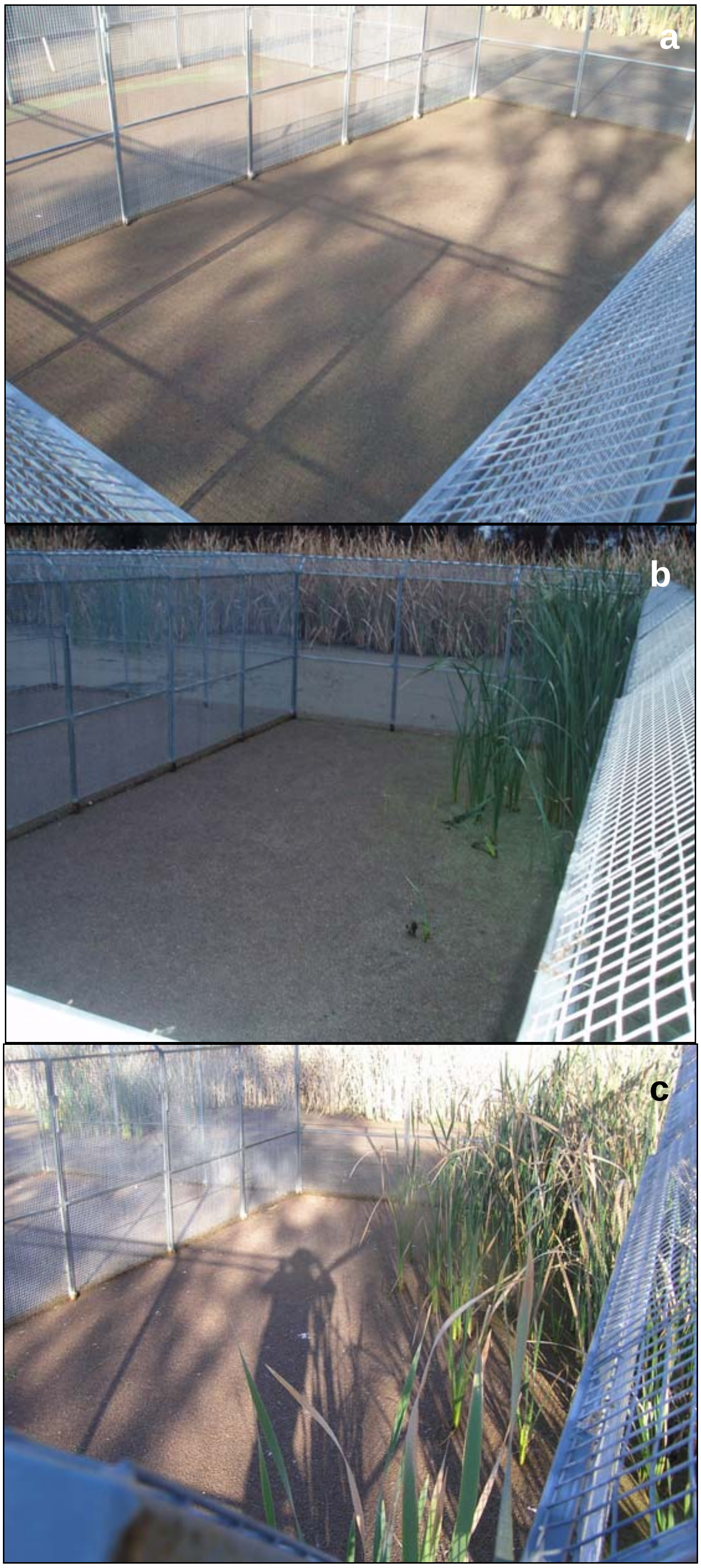


Figure 3.6. Photo-point images of the Burrawang West – left exclusion plot in a) February 2009, b) May 2009 and c) September 2009. The exclusion plots at this site were established in May 2008 and so these images represent 9, 12 and 15 months post carp exclusion.

3.4. Discussion

Preliminary exploration of the data collected to date provides little support for the hypothesis that carp impact upon the diversity and abundance or biomass of small native fish species, emergent or submerged macrophytes or zooplankton density. However, the abundance of benthic macro-invertebrates does appear to show a signal suggesting that the present densities of carp at the three study locations are exerting pressure on benthic macro-invertebrate populations. No benthic macro-invertebrates have been collected from any of the unfenced control plots and only a single individual was collected from any of the carp exclusion plots during the first sampling round in February 2009. In contrast, non-biting midges (Chironomidae), giant water bugs (Belostomatidae) and pond snails (Lymnaeidae) have been collected from four of the six carp exclusion plots in May and September 2009. This result is supported by the meta-analysis results of Matsuzaki *et al.* (2009) who report a general negative effect of carp biomass on populations of benthic macro-invertebrates. The only other variable that is suggestive of a carp treatment affect is the biomass of floating macrophytes (primarily azolla), although this result is difficult to interpret as the results are quite variable and we are unsure about whether the response was a direct result of carp exclusion or an artefact of the exclosure mesh preventing the wind dispersal of the weed.

The preliminary zooplankton and macrophyte results presented here are at odds with the conclusions drawn from the meta-analysis of Matsuzaki *et al.* (2009), with the data suggesting no carp effects. We are able to rule out temporal scale of the dataset as an explanation, as even at this preliminary stage our data spans a period of up to 12 – 18 months of carp exclusion, whilst published studies that have detected carp affects have been undertaken over periods of as little as 15 days and 60 days on average. However, many of these have assessed the addition of carp to un-impacted plots, where the deleterious effects of carp may be noted within a few weeks (Roberts *et al.* 1995; Bajer *et al.* 2009) as opposed to assessing the recovery of plots where carp have been excluded, which is the approach taken here and that may take much longer (Lougheed and Chow-Fraser 2001).

Factors which may have contributed to our lack of a carp exclusion response are that perhaps the density of carp present at the three study locations is below a threshold necessary to differentiate between the carp exclusion treatments and the unfenced control plot at each site (Zambrano *et al.* 2001; Matsuzaki *et al.* 2009). This has been reported variously as carp densities ranging from ~100 kg/ha^{-1} (Bajer *et al.* 2009), < 161 kg/ha^{-1} (Matsuzaki *et al.* 2009), 174 kg/ha^{-1} (Parkos *et al.* 2003), 450 kg/ha^{-1} (Fletcher *et al.* 1985) and 500 kg/ha^{-1} (Miller and Crowl 2006). If after two years of monitoring this is believed to be the case, the hypothesis can be tested by introducing a known high density of carp to exclusion plots, as opposed to the proposed treatment of removing mesh panels and relying on the local carp population to contribute a treatment effect. A second factor could be that the primary impact of carp on aquatic ecosystem variables is the species influence on turbidity rather than direct effects on aquatic macrophytes, with cascading effects on zooplankton, macro-invertebrates and fishes. Because this experiment has used permeable exclosure walls, we have no means to eliminate the effect or carp on turbidity at the study site. This hypothesis could be tested by subdividing the existing exclusion plots using impermeable plastic sheet walls to test for the turbidity effect.

Alternatively, it may actually be the case that carp have little impact on aquatic macrophytes, zooplankton or populations of small native fishes in the lower Lachlan catchment. In the preceding chapter we used simple linear correlations to relate carp biomass with values for a range of aquatic ecosystem variables carp have been proposed to impact upon across 12 riverine monitoring sites spread throughout the lower Lachlan carp control demonstration reach. We found no evidence for negative impacts of carp on any of the variables. Therefore, the results of both our assessments are consistent and support a conclusion that at their current densities, and despite constituting an average 78% of the total fish biomass in the lower Lachlan, carp populations in the lower Lachlan catchment may not be the ecosystem engineers we perceive them to be.

4. ISLAND CREEK WEIR CARP SEPARATION CAGE

4.1. Introduction

Movement studies on common carp (*Cyprinus carpio*) have demonstrated that throughout their range, there is evidence of site fidelity and homing (Reynolds 1983, Schwarz 1987, Rodriguez-Ruiz and Granado-Lorencia 1992, Cooke and McKinley 1999, Crook 2004, Stuart and Jones 2006*a*, Jones and Stuart 2007, Jones and Stuart 2009). However, studies in Australia, Canada, USA and Europe also suggest that aggregations of carp arrive at areas adjacent to shallow marsh habitats prior to spawning, with the bulk of the population arriving in early-mid spring and dispersing by mid summer (Swee and McCrimmon 1966; Rodriguez-Ruiz and Grando-Lorencio 1992; Roberts and Ebner 1998, Brown *et al.* 2005; Penne and Pierce 2008). Combined, these lines of evidence suggest that there must be large-scale movement of a large proportion of the pre-spawning carp population in early spring, with individuals moving from their home sites towards key carp recruitment areas. This is supported by records from fishways within the Murray River, where both adult and juvenile carp are regularly recorded moving upstream and downstream through fishways, at times in very large numbers (Mallen-Cooper 1996; Mallen-Cooper 1999; Stuart and Jones 2006*a*). Therefore, methods of targeting these pre-spawning movements of carp as they travel towards recruitment hotspots would constitute a key means of control within a carp control strategy.

Stuart *et al.* (2003) published the first results of trials assessing the effectiveness of a simple yet novel carp trap design suitable for installation within vertical slot fishway channels. The unique attribute that set this trap apart from standard fishway traps was that it capitalised on a behavioural difference between carp and native fishes in the Murray River to separate trapped carp from native fishes. The initial concept was based on the observation of Mr Alan Williams, a Goulburn Murray Water weir-keeper at Torrumbarry on the mid-Murray River. Mr William's noted that common carp often jumped when confined within a fishway channel, whilst a majority of native fish did not. Mr Williams developed the concept of an internal barrier wall within a standard fishway cage trap. The internal barrier wall is extended a short height above the water surface and is fitted with a simple non-return flap. Whilst confined within the trap, the hypothesis was that carp would leap over the barrier wall into a holding cell, whilst native fishes would remain within the main cell of the trap. Initial trials of a prototype trap found that when the height of the jumping baffle was set at 20 cm above the water surface, between 82 and 100% of carp entering or placed into the trap jumped into the holding cell, whilst all of the native fishes remained within the main body of the trap (Stuart *et al.* 2003). These preliminary findings suggested that the Williams Carp Separation Cage (WCSC) concept could revolutionise carp control programs by providing a low cost method of removing a large biomass of carp from river systems without the need to manually handle every individual trapped fish. Further, the proportion of the carp population removed by WCSCs is roughly equivalent to the 70% reduction in biomass proposed as necessary to minimise the impacts of carp on aquatic ecosystems (Meijer *et al.* 1990; Zambrano *et al.* 2001) and the 75% to 90% reduction in abundance suggested as necessary to reduce carp populations to a relatively stable low population growth rate (Thresher 1997; Brown and Walker 2004).

Further trials of subsequent modifications to the original WCSC design (Mark IV), including an automated mechanism to release native fishes from the main cell of the trap while retaining carp in the holding cell, determined that carp as small as 244 mm FL jumped into the separation cell (Stuart *et al.* 2006). The Mark IV WCSC design retained 88% of migrating carp whilst 99.95% of native fishes were able to pass through the WCSC unharmed (Stuart *et al.* 2006). An important subsequent refinement to the Mark IV design included repositioning the trap from within the vertical-slot fishway channel to within the weir pool at the fishways upstream exit (Stuart and Conallin 2009). The resulting Mark V WCSC design can be installed in fishway types other than vertical-slot designs and the capacity of the holding cell is not restricted by the dimensions of the fishway channel and therefore can operate at high carp biomass (Stuart and Conallin 2009). Further, the Mark V WCSC is more humane than the Mark IV model as carp are held in a still weirpool environment, rather than within the high flow fishway channel (Stuart and Conallin 2009). Stuart and Conallin (2009) report that the Mark V WCSC installed at Lock 1 in South Australia in late 2007 has removed 80 tonnes, or approximately 32,000 individual carp to date, at a separation efficiency of 60 – 70% over a 12 month period.

At a reported construction cost of around US $5,000 (AUS ~$ 6,871) (Stuart *et al.* 2006), Mark V WCSCs currently provide the most cost-effective and efficient means of removing carp from river systems. As a result, the Murray-Darling Basin Commission has produced WCSCs for each of the fishways constructed in the Murray River as part of its Lake Hume to the Sea Program (Barrett and Mallen-Cooper 2006). The installation of WCSCs on existing and planned Lachlan River fishways presents an ideal control option for targeting migrating carp within the Lachlan River and needs to form part of the integrated approach to carp control. There are 22 weirs that obstruct fish passage along the length of the Lachlan River below Wyangala Dam (with most on the Lachlan River channel, but several also on anabranch systems) (see NSW DPI 2006) . Currently, only two of these weirs have operational vertical-slot fishways, Bumbuggan Weir and Island Creek Weir, with plans for a further three at Lake Cargelligo Weir, Booligal Weir and Brewster Weir currently under development (Figure 4.1).

The Lachlan CMA allocated $45,000 for the construction and installation of three WCSCs in preparation for the commencement of the implementation phase of the project. This chapter documents the design and implementation process for installation of WCSCs on State Water Corporation owned fishways, including the total cost of design, construction and installation of a single WCSC.

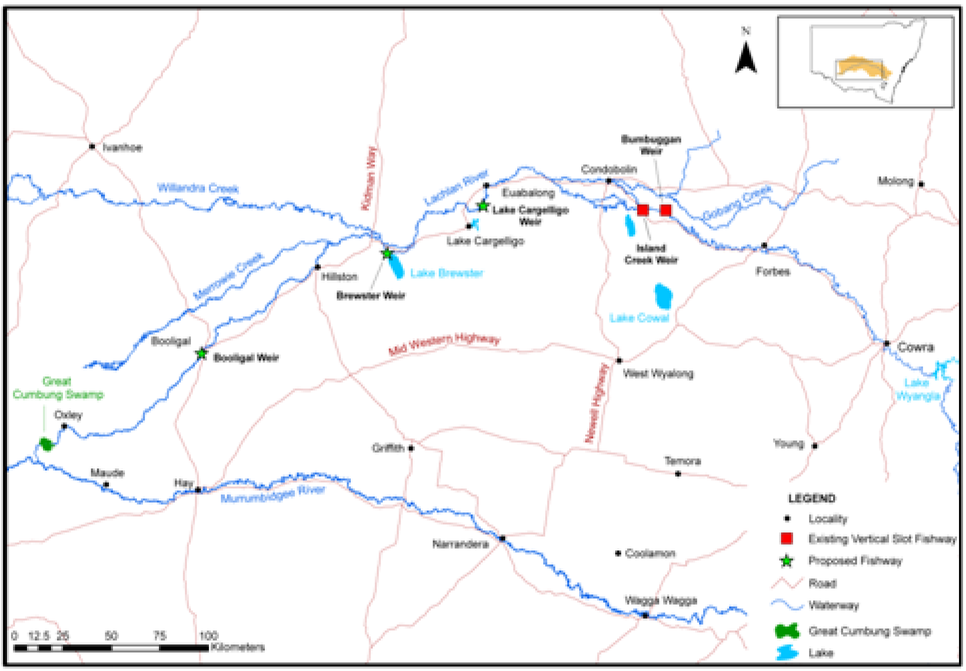


Figure 4.1 Locations for the existing and proposed fishways within the Lower Lachlan Demonstration Reach.

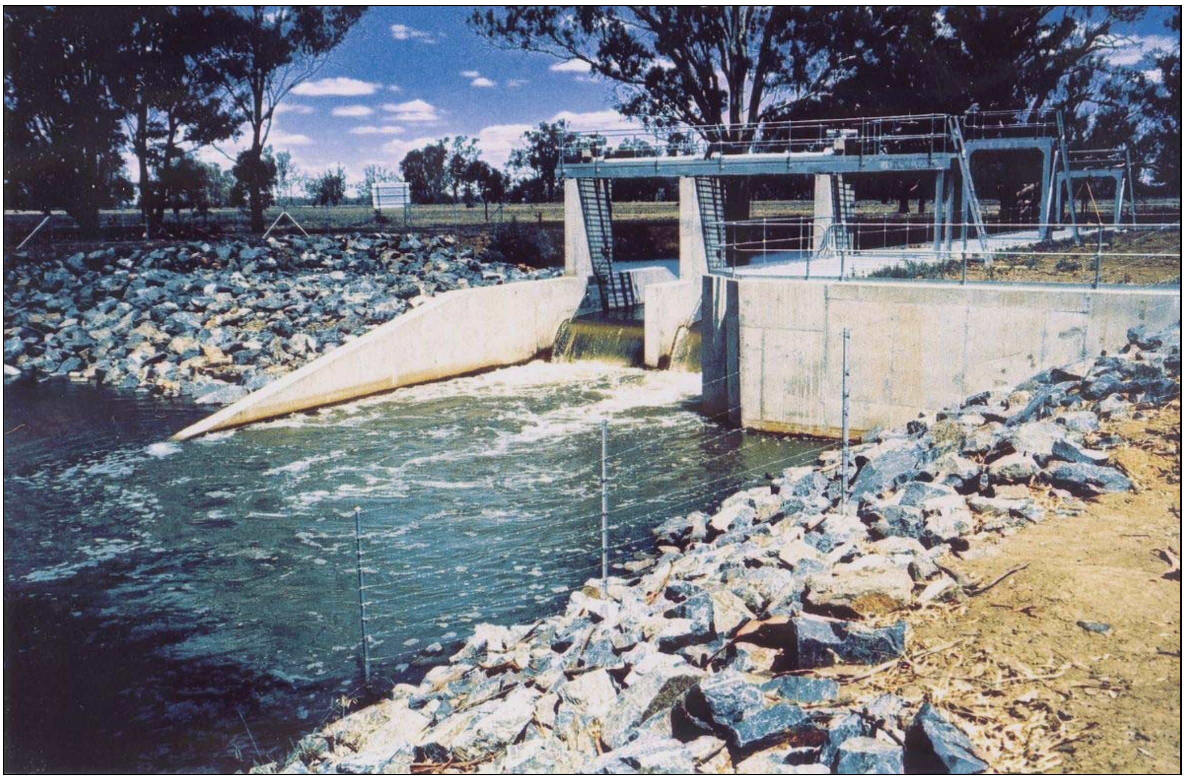


Figure 4.2. Bumbuggan Weir and fishway.

Figure 4.3. The Island Creek Weir and Fishway entrance.

4.2. Study site

Site inspections of both of the existing vertical-slot fishways in the Lachlan catchment, at Bumbuggan and Island Creek Weirs, were undertaken in June 2007 in order to identify any site specific issues that may affect installation of a WCSC or require specific modifications to the Mark V design. The Bumbuggan Fishway is a 1 : 23.4 slope, 11 cell (3 m x 2 m) fishway with a depth of 0.7 m and 300 mm vertical slots with a headloss ranging from 50 – 165 mm (Figure 4.2). The Island Creek Fishway is a 1 : 19.7 slope, 22 cell fishway with similar cell and slot dimensions and slot headloss (Figure 4.3). Because the Island Creek Fishway is only accessible via private property, it was selected as the most appropriate location for the first of the WCSCs given perceived greater site security and reduced public safety implications.

Island Creek is a 43.3 km long anabranch diverging from the Lachlan River channel upstream of Cadow Swamp and re-joining the Lachlan River at the Wallamundry Creek offtake (Figure 4.4). Island Creek Weir is situated 26 km east of Condobolin, ~ 2 km upstream of the Island Creek – Lachlan River confluence (Figure 4.4) The weir regulates the distribution of water to Wallamundry Creek, Wallaroi Creek and Nerathong Creek. Data collected between 1996 and 2004 from gauging stations at Fairholme (Gauging Station No. 550004), Mulgutherie (No. 412024) and Bumbuggan Weir (No. 412017) suggest approximately 39% of the Lachlan flow passes through Island Creek Weir. Originally constructed in 1888, the weir underwent a $2 million environmental upgrade in 2006, which included construction of the vertical-slot fishway.

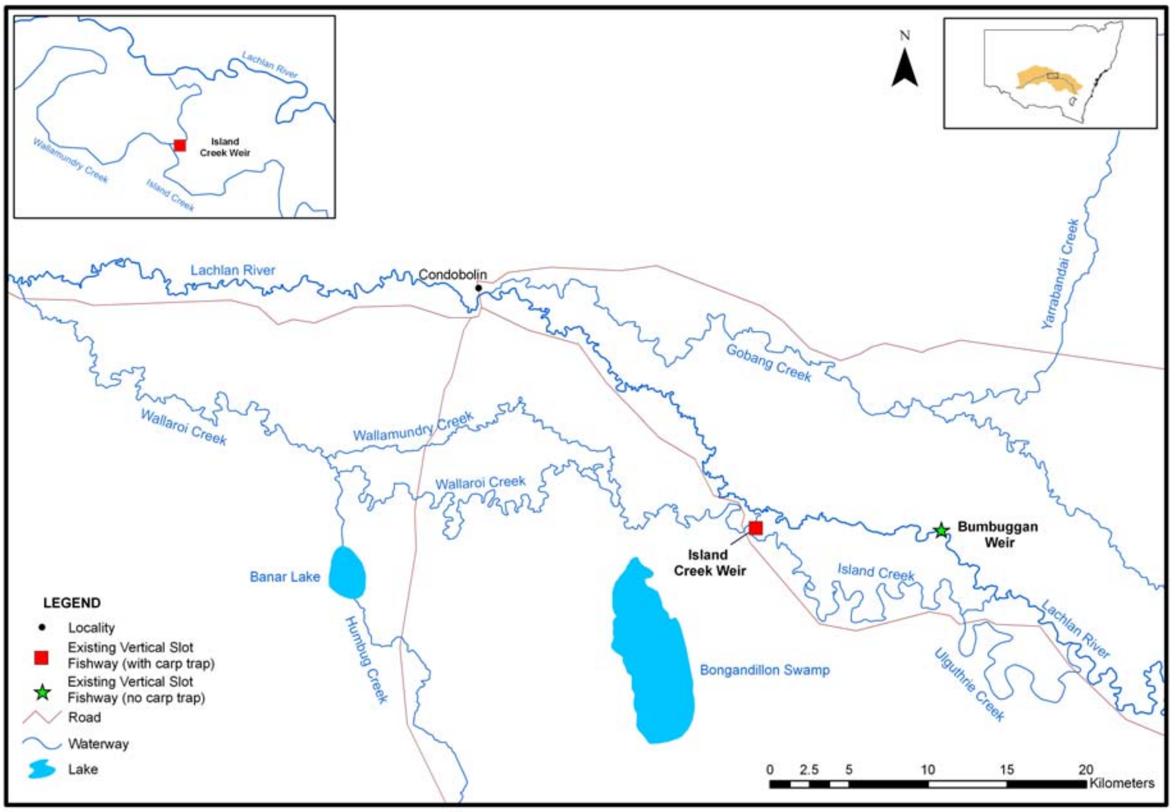


Figure 4.4. Island Creek and the location of the Island Creek Weir Williams Carp Separation Cage.

4.3. Design, approvals and construction process

Following site inspection by project team members from I&I NSW, State Water Corporation and Kingfisher Research, and a local engineer from Condobolin Steel (Condobolin) in August 2007, initial concept designs for a Mark V WCSC were drafted. These concepts detailed the position and dimensions of both trap and holding cells, funnel trap and exit design, jumping baffle design and orientation, concepts for the native fish release mechanism and recommended the WCSC be constructed of aluminium to ensure corrosion resistance and a light weight. However, State Water Corporation requested the WCSC be constructed of stainless steel to guard against electrolysis of the stainless steel trash rack mounts. Detailed drawings were developed based on the concept sketches by Condobolin Steel's works engineer in November 2007 (Figure 4.5).

I&I NSW entered into a formal agreement with State Water Corporation, the owners of the Island Creek Weir and Fishway (*Island Creek Carp Interception Project Agreement*) regarding organisational arrangements, OH&S, liability and miscellaneous issues related to the installation and ongoing management of the WCSC. State Water Corporation required that the WCSC plans be independently reviewed by engineering consultants SJE Consulting (Albury) and that a statement of structural certification was obtained. The review was to include assessment of structural integrity and the potential effects of the proposed design on the existing structures. This process was un-expected as it had not been requested for previous WCSC designs. The review by SJE Engineering was not received until 3 June 2008.

In November 2008, amendments were made to the initial detailed drawings to incorporate important refinements developed at the Lock 1 fishway (which was being field trialled at the time (Stuart 2008)) prior to construction commencing. These included the replacement of the 50 x 50 mm grid mesh panels initially planned for use as the walls of the trap and holding cells with vertical bar panels with a bar spacing of 40 mm to allow continuous fish passage of most species of native fish (Stuart and Conallin 2009), removal of a brace which was creating a potential obstruction to jumping fish, a 15^{o} sloping baffle wall to direct jumping carp to the holding cell entrance, a sloping perforated sheet floor on the holding cell to assist with carp removal, a floating (height-adjustable) jump baffle to accommodate variation in water level within the weir pool (headwater) and replacing the tilting mechanism for native fish release with a dropping floor mechanism.

The WCSC was constructed by Condobolin Steel. Construction commenced in December 2008 and was completed in February 2009.

4.3.1. Cost breakdown

The initial budget proposed for the construction of three WCSC within the Lachlan catchment was based on the reported estimate of around US $5,000 (AUS ~$ 6,871) per trap (Stuart *et al.* 2006) as well as the costs of those traps constructed for Locks 7, 8, 9, and 10 under the Murray Fishways program and incorporating installation as well as construction costs. However, the requirements to have the design structurally certified, fabricated from stainless steel as opposed to aluminium, and the need to provide a power supply adjacent to the WCSC to enable automation of the native fish release mechanism resulted in the total cost of the Island Creek Fishway WCSC being $63,278. Obviously, this was a significant price increase from previous installations of WCSCs and as a result only a single WCSC was installed, rather than the planned three structures. The total cost for design, review, construction and installation consisted of the following elements:

- Preparation of detailed drawings $1,600
- SJE Consulting review $2,500
- Construction and installation $53,648
- Installation of power and programmable timer $5,530

Additionally, there were significant in-kind contributions by I&I NSW and SWC staff to the design and construction phases.

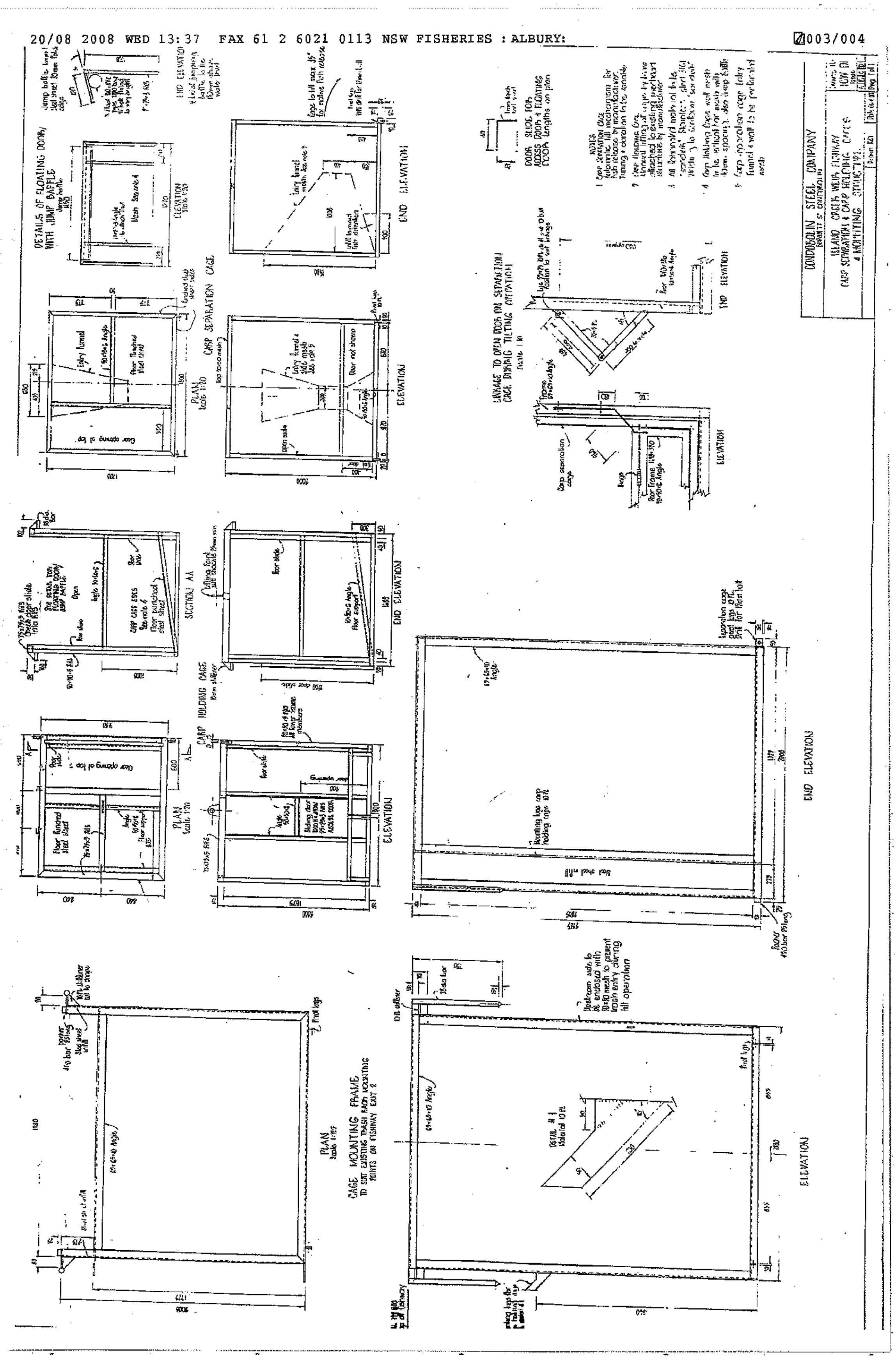


Figure 4.5. Detailed drawings of the WCSC trapping and holding cells.

4.4. Installation and results to date

The Island Creek WCSC (Figure 4.6) was installed on 23 February 2009. Due to the lack of an available power supply adjacent to the WCSC at the time of installation, the native fish release mechanism was not automated at installation. Initially, the WCSC was checked for carp and/or native fish every two to three days. However, as it became obvious that rates of fish passage through the fishway were quite low due to low flows in Island Creek, we reverted to checking and clearing the trap at weekly intervals. The WCSC was operated continuously for only 102 days until low river flows resulted in closure of the fishway on 5 June 2009. Within that period, two carp were removed from the holding cell. A 454 mm fish was removed on 8 March 2009 and a 600 mm fish was removed on 12 March 2009. Because of continued drought conditions in the Lachlan Valley and low river flows that are below the designed operational range of the fishway, it has not been operational since 5 June and consequently no further carp have been removed.

Figure 4.6. The Island Creek fishway exit with the WCSC separation cage fitted to one of the fishways upstream exit gates (on right). The WCSC can be mounted on either of the fishways exit gates using the same mounting brackets that support the trash racks (on left). Only the exit gate fitted with the WCSC is opened.

On 8 September 2009, electrical contractors (GS & BD Electrics, Narrandera) installed a power supply to the WCSC along with a 24 hour timer to enable automatic operation of the native fish release mechanism. The 24 hour timer is programmable so that the timing and frequency of fish release can be managed appropriately. Therefore, upon recommencement of flows in Island Creek, the WCSC will be fully functional.

4.5. Ongoing operation and management

4.5.1. Ongoing obligations under the Island Creek Carp Interception Project Agreement

The existing *Island Creek Carp Interception Project Agreement* expires on 1 January 2010. Under the agreement, I&I NSW are required to:

- Adaptively manage requirements and logistics of maintaining the WCSC at Island Creek Fishway and refine logistics and operational plans for the long-term installation of such devices at other State Water Corporation assets.
- Evaluate the effectiveness of the WCSCs contribution to overall alien species management.
- Provide State Water Corporation with a list of all staff members that may access the site.
- Provide State Water Corporation staff with an orientation of trap operation.
- I&I NSW will undertake to arrange any maintenance to the trap as advised by State Water Corporation. Maintenance will be carried out by an agreed local contractor.
- I&I NSW are responsible for disposal of carp.
- I&I NSW will undertake monitoring and activities in accordance with the agreement under the supervision of the principal investigator.
- I&I NSW staff are to adhere to directives of any State Water Corporation staff with regard to site management, access, operation or maintenance.
- The WCSC and associated infrastructure retro-fitted to the State Water Corporation assets are assets of I&I NSW. As such, any damage or impact caused by the asset will be responsibility of I&I NSW.

State Water Corporation are required to:

- Provide I&I NSW with State Water Corporation's OH&S requirements and practices.
- Attend the site on a weekly basis for the duration of the project unless other timeframes are agreed.
- Provide I&I NSW with weekly feedback on the status of the trap, including observations on general trap condition, maintenance requirements, visual observations of carp condition and their abundance. Native fish are not to be collected and State Water Corporation will report any observed bycatch issues.
- State Water Corporation are authorised to utilise or operate the trap under the I&I NSW principal investigators sampling permit.
- In the case of an emergency or other event which threatens capital assets, property, life or the economic welfare of any person or organisation, State Water Corporation may take an action at the site without complying with the conditions of this arrangement. At a suitable time, State Water Corporation is to advise I&I NSW of its actions under this part.
- SWC will notify I&I NSW of the approximate numbers of carp within the trap each week.

4.5.2. Operational procedures

Data collected from the Lock 1 Mark V WCSC over its first year of operation indicate that in that region (the South Australian lower Murray River), the greatest abundance of carp move upstream through the fishway and WCSC in October and November, with lower abundances moving through in September and from December through until March (Stuart and Conallin 2009). Relatively low catch rates were recorded during the five months between April and August (Stuart and Conallin 2009). Capture efficiency was found to be greatest for pre-spawning females during the peak October – November period (Stuart and Conallin 2009). These results suggest that within the Lachlan, WCSCs should be operational between late August and early April, with the holding cell checked and cleared weekly. However, from late September through until mid December, the WCSC should be checked and cleared at least every two to three days. Because of the low catch rates observed between April and August in the Murray River (Stuart and Conallin 2009), it is probably feasible to either check the WCSC trap fortnightly to monthly, or to remove the trap completely for scheduled maintenance and cleaning.

Observations at Lock 1 suggest that carp entered the WCSC and jump more readily during the day than at night (Stuart and Conallin 2009). Further, separation efficiency improved when the native fish release mechanism was not activated during the day. Following the recommendations of Stuart and Conallin (2009) the timer will be programmed to release native fish twice daily. First at sundown and again prior to sunrise. This requires that the timer be reprogrammed regularly to ensure that the automated cycle is adjusted to account for changes in day length throughout the year.

4.5.3. Carp disposal

The volume of carp likely to be collected will remain unknown until the trap has been in operation for its first October – November peak period. At the Lock 1 WCSC, the daily maximum catch to date was 2,705 kg day^{-1} (Stuart and Conallin 2009). Given the high density of carp known to aggregate below Lock 1, this volume is unlikely to be exceeded at any site within the Lachlan. Therefore, if a trap is cleared daily during the peak migration period, an absolute maximum of one combined ute and trailer load per day is likely to be harvested from each WCSC in operation. Although this volume is logistically easy to transport, suitable equipment, facilities and man-power will be required to transfer the catch from the WCSC to the vehicle. And options for the regular disposal of tonnes of carp over a two month period, with lesser volumes for a further five months will need to be considered.

Jackson (2009) reports progress on the development of a carp disposal strategy for WCSCs installed at Murray River fishways. He reports that viable commercial utilisation of harvested carp would require in the order of 40 to 50 tonnes of carp per annum to support a crayfish bait or fertiliser business. If no local commercial operator was available to take receipt of the carp, Jackson (2009) suggests storage of harvested carp in freezer units until sufficient numbers have been accumulated to make collection by commercial operators cost-effective. If no commercial interest can be generated, the most feasible alternatives for disposal are either burial or composting, with either disposal method required to comply with DECCW and local council requirements.

Disposal arrangements should be negotiated with commercial operators such as K. & C. Fisheries, established fertiliser companies such as Charlie Carp (Deniliquin, NSW) or Margan Pastoral Co. (Boorowa, NSW) and local councils (regarding approvals to utilise council tips) prior to September 2010 to ensure plans are in place for carp storage or disposal prior to the harvest of carp from Lachlan WCSC during the next available peak migration period.

4.5.4. Relocation (potential contingency plan for ongoing drought)

The mounting system of the Island Creek WCSC was designed to ensure that the structure can be easily relocated with a minimal requirement for modification to the WCSC or to the fishway the trap is being moved to. In the event that the Island Creek Fishway remains offline, consideration can be given to relocating the Island Creek WCSC to Bumbuggan Weir. The requirements for relocation include a structural certification certificate for the Bumbuggan Fishway, the installation of mounting brackets and support infrastructure on the Bumbuggan fishway exit, the provision of power to the WCSC site, installation of a 24 hour programmable timer to allow automation of the native fish release mechanism and the costs associated with removal, transport and fitting of the WCSC at Bumbuggan. The total cost of relocating the existing WCSC from Island Creek weir to

Bumbuggan Weir has been quoted at $29,893. Given that the quoted price is 50% of the cost of building and installing an completely new WCSC for Bumbuggan, consideration should also be given to the alternative strategy of building a second WCSC for the catchment for ~$59,000, rather than simply relocating the existing single unit, as this may represent a more cost-effective strategy over the life of the carp control plan.

4.6. Recommendations on the design of subsequent WCSC

In the process of designing and installing the Mark V WCSC at Island Creek Weir a number of key lessons were learnt that should be considered when designing and constructing subsequent traps.

- Permanent or temporary solid panels may be required on some faces of the trap to ensure that the predominant flow through the WCSC is perpendicular to the jumping baffle so that carp are cued to jump towards the holding cell opening.
- Relatively expensive vertical bar panels are only required on those faces of the trap where native fish are intended to escape. Less expensive grid mesh can be used elsewhere.
- The mesh used to construct the cone trap should minimise the accumulation of debris upon the cones surface.
- Avoid using expensive materials such as stainless steel unless absolutely necessary. Aluminium is the preferred material. At Island Creek Fishway, it may have been more cost effective to retrofit aluminium mounting brackets for the trash racks rather than construct the entire WCSC out of stainless steel.
- Consideration should also be given to using other alternative materials such as plastics (Australian standards UV rated low density polyethylene: Durapoly, Lake Cargelligo).
- Future designs need to ensure that both the trap cell and holding cell can be lifted from the water.
- Sharp edges and points need to be minimised.
- The trap cell needs to be fitted with an anti-tamper/anti poaching lid.

5. SCOPING THR FEASIBILITY OF A CARP ERADICATION PROGRAM FOR THE BLAND CREEK – LAKE COWAL SUB-CATCHMENT

5.1. Introduction

It is widely acknowledged within the field of invasive species management that once invasive species have become established, the potential for successful eradication can be exceedingly low (Trexler *et al.* 2000; Chick and Pegg 2001: Simberloff 2003; Koehn and MacKenzie 2004; Lintermans 2004; Braysher 2007). Generally eradication attempts have only been successful when the invading population is localised, which is usually only in the early stages of establishment (Simberloff 2003; Lintermans 2004). However, carp population modelling undertaken by Thresher (1997) suggested that environmental variability, such as drought and flood cycles, can increase the likelihood of success of physical removal control options. Under severe drought conditions, remnant waterholes confine aquatic organisms within manageable sized units, creating a window of opportunity where eradication becomes temporarily feasible. For example, Roberts *et al.* (1997) assessed the cost-effectiveness of alternative carp eradication strategies in the Murrumbidgee Irrigation Area and determined that undertaking carp eradication during the irrigation off-season, when the distribution of water within the irrigation system was at its lowest, was substantially more cost effective than attempting to implement equivalent control actions when the irrigation system was full. This information supports the inference that carp eradication from heavily drought affected waterways, or naturally ephemeral waterways during dry periods, is likely to be the most cost-effective control strategy. Further, in situations where refugia are upstream of natural or artificial instream barriers that limit re-invasion, or where artificial barriers can be created, the eradication of invasive populations from drought refugia has the potential to be a highly effective local eradication strategy.

Bland Creek is a generally endorheic sub-catchment of the Lower Lachlan River, that under most flow conditions terminates in Lake Cowal or Nerang Cowal (Figure 5.1). The Bland Creek sub-catchment only reconnects to the Lachlan River during breakout flows from the Lachlan River during major floods or when local runoff from its own drainage (9,500 km^2) fills and overtops Lake Cowal, flows northwards into Nerang Cowal, then into Manna Creek, Bogandillon Creek and Swamp, Wallamundry Creek and ultimately into the Lachlan River near Condobolin via either Wallaroi or Island Creeks. Historical records indicate that Lake Cowal contains water in 5 out of 10 years on average (Brock *et al*. 2005).

When last sampled in 1998, Lake Cowal contained a huge biomass and abundance of young of year carp (Gilligan, pers. obs.) at densities equivalent to some of the major carp recruitment hotspot areas within the Murray-Darling Basin, such as the Gwydir wetlands, Barmah-Millewa forest and Macquarie Marshes (Gilligan, in prep). On this basis, Lake Cowal was identified as one of the key carp recruitment hotspots within the lower Lachlan catchment. However, because of its endorheic nature, most carp breeding activity within Lake Cowal only contributes recruits to the tributary streams of the lake, with less frequent dispersal of fish between Lake Cowal and the Lachlan River. But the Bland Creek sub-catchment has suffered persistent drought for several years and has been drought declared since 2002 (with the exception of a seven month period between October 2005 and April 2006). Lake Cowal dried out completely in 2001 and remained dry until September 2005, when inflows flooded ~800 ha (9% of its surface area). This area remained inundated for 10 – 12 weeks before the lake bed dried again and has remained dry since(Mal Carnegie, Lake Cowal Foundation, pers. comm.). Further, many of the tributary streams of the catchment have retracted to isolated waterholes (drought refugia).

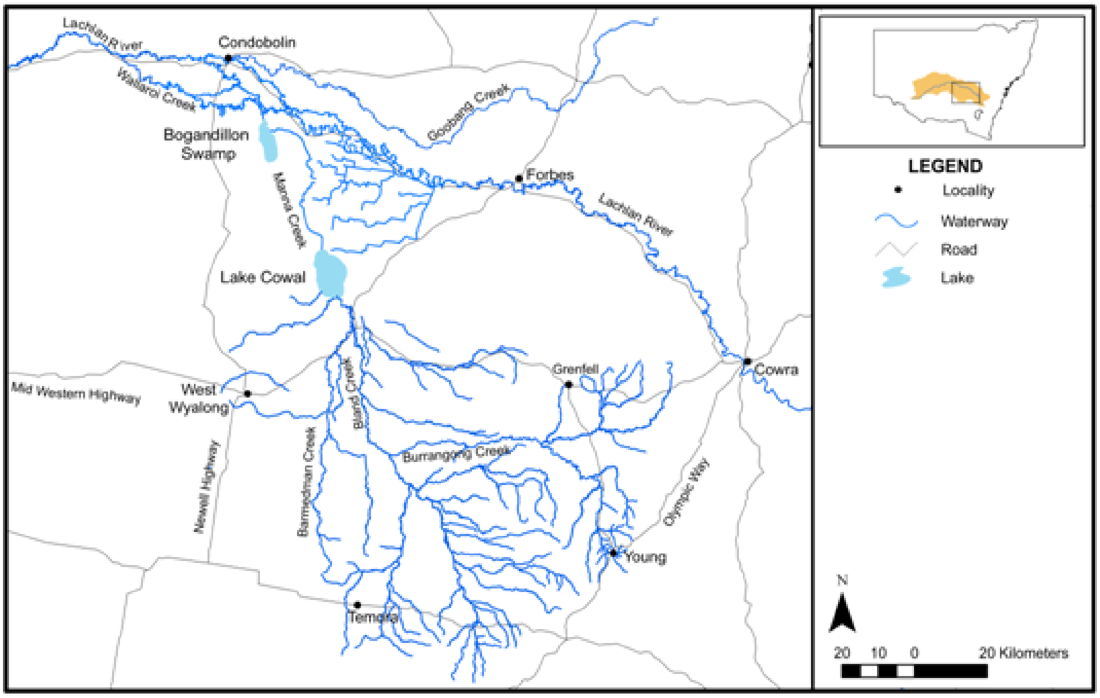


Figure 5.1. Bland Creek subcatchment.

With the current total absence of carp in Lake Cowal, and the isolation of those within tributary streams to waterhole refugia, the potential cost-efficiency of carp eradication from the Lake Cowal sub-catchment, or at least within individual tributary streams draining into Lake Cowal, is likely to be the greatest it has been since the initial invasion of carp. If a sufficiently finite number of waterhole refugia remain, and they are of a reasonably manageable size, then eradication from the entire Bland Creek sub-catchment may be possible. Even in the event that total sub-catchment-wide eradication as not feasible, it may still be possible to eradicate local carp populations from reaches upstream of existing fish passage barriers in the system. Or alternatively, new infrastructure could be installed in the lower reaches of individual tributary streams to prevent recolonisation of carp when Lake Cowal re-fills. However, local scale carp eradication within tributaries would have little benefit in the context of eliminating Lake Cowal as a carp recruitment hotspot within the broader lower Lachlan catchment. Unless total eradication is achieved throughout the sub-catchment, Lake Cowal will always have the potential to inject large numbers of carp recruits into the Lachlan River under conditions of widespread flooding.

To assess the feasibility of total carp eradication from the Bland Creek sub-catchment, we mapped the number, distribution and size of all remnant waterholes present in August 2007. We used these data to derive a rough estimate of the resources required to achieve carp eradication.

5.2. Methods

5.2.1. Waterhole Mapping

All waterways within the Bland Creek subcatchment were mapped from a light aircraft at a cruising altitude of 500 feet on 20th, 22nd and 23rd of August 2007. Mapping was undertaken on hand-held PDA units (Dell Axim X51U or MIO Digi-walker pocket PC) loaded with ESRI Arcpad 6.0.3 data acquisition software. Each PDA was uploaded with a 1: 50,000 topographic map of the region

(GDA 94_MGA Zone 55) for use as a digitising template. The start and end points of wet reaches were digitised using a stylus on the topographic base layer. The presence of off-channel water storages (farm dams) was also digitised. On completion, data were uploaded into ArcGIS 9.1 (ESRI). The AUSLIG 1:250,000 stream network layer was divided into dry versus remnant waterhole features by clipping the stream network at each waterhole start and end point.

5.3. Results and Discussion

Of the 2,048 km of stream channel that was mapped, 1,829 km (89%) was dry between 20 and 23 August 2007 (Figure 5.2). The remaining 219 km (11%) consisted of waterhole refugia assumed to be of sufficient depth to sustain populations of fish. The average (± SD) length of the 145 individual remnant waterholes within the system was 1.51 ± 1.86 km. The largest waterhole within the sub-catchment was a continuous 11.34 km reach in Bribbaree Creek. However, the distribution of waterhole size was heavily skewed, with 11% of waterholes less than 250 m long, 34% less than 500 m long and 59% less than 1 km long (Figure 5.3).

A rapid assessment of whether carp are present within each of the 145 remnant waterholes would cost around $275,000 (at $1,897 per site) based on current I&I NSW field sampling costs for a two person field crew assessing up to ten locations per week. This cost increases to $345,000 (at $2,379 per site) if it is assumed that just a single day is spent removing carp from each of the 145 refugia using electrofishing and netting methods. These estimates exclude those costs that may be required for carp disposal and does not account for follow-up sampling to ensure eradication success, which would be the sum of the two figures above. Further, although we have not located any data that provide guidance on how the feasibility and costs of eradication programs change as stream length increases, it is reasonable to assume that the probability of success would decrease and the costs of treatment would increase markedly as stream length of the treatment area increased. Therefore, for at least the largest 14 (10% of total) refugia which are > 4 km in length, it would be necessary to partition each waterhole into smaller manageable units (~2 km), using temporary earthen coffer dams, aquadams or stop nets before attempting carp removal from each section. Therefore, the number of treatment sites increases by an equivalent of 34 additional treatment sites, or a total budget of $765,404. However, more intensive activities involving more than two staff, requiring the purchase of biocides, the lease or purchase of machinery required to drain waterholes, the costs of earth works to partition larger refugia into manageable units or the fees to commission explosives contractors would require considerably greater funding. If it is assumed that an average of $2,000 in operating costs is required to cover these costs at each site, the total cost of the project is likely to be in the order of $1.15 million to eradicate all carp from all 145 drought refugia within the Bland Creek – Lake Cowal sub-catchment.

5.4. Potential carp eradication strategy

In order to reduce the number of waterholes that require rapid assessment or field inspection, landowners adjacent to each of the remnant waterholes within the treatment areas should be contacted. If they advise that waterholes had dried out since the last flow event occurring within the stream, these locations will not contain any fish fauna and they can be considered carp free and require no further action. In contrast, those waterholes which have retained permanent water, or have reconnected with adjacent waterhole refugia since completion of refugia mapping in August 2007, must be physically inspected for depth, width, length, substratum and instream habitat complexity. These data will guide decisions on the most appropriate eradication strategy for each waterhole. Availability of temporary native fish holding facilities (fish free farm dams) should also be assessed.

Application of the following control/removal techniques should be undertaken as determined as the most appropriate for each site.

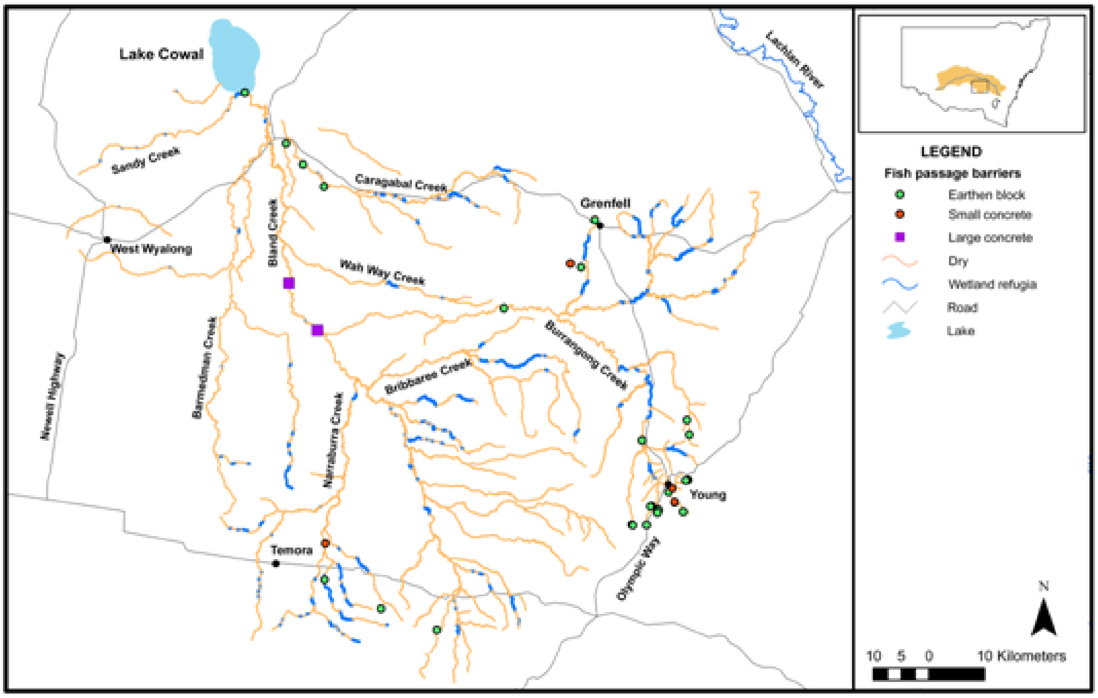


Figure 5.2. Distribution and size of remnant waterholes within the Bland Creek subcatchment in August 2007.

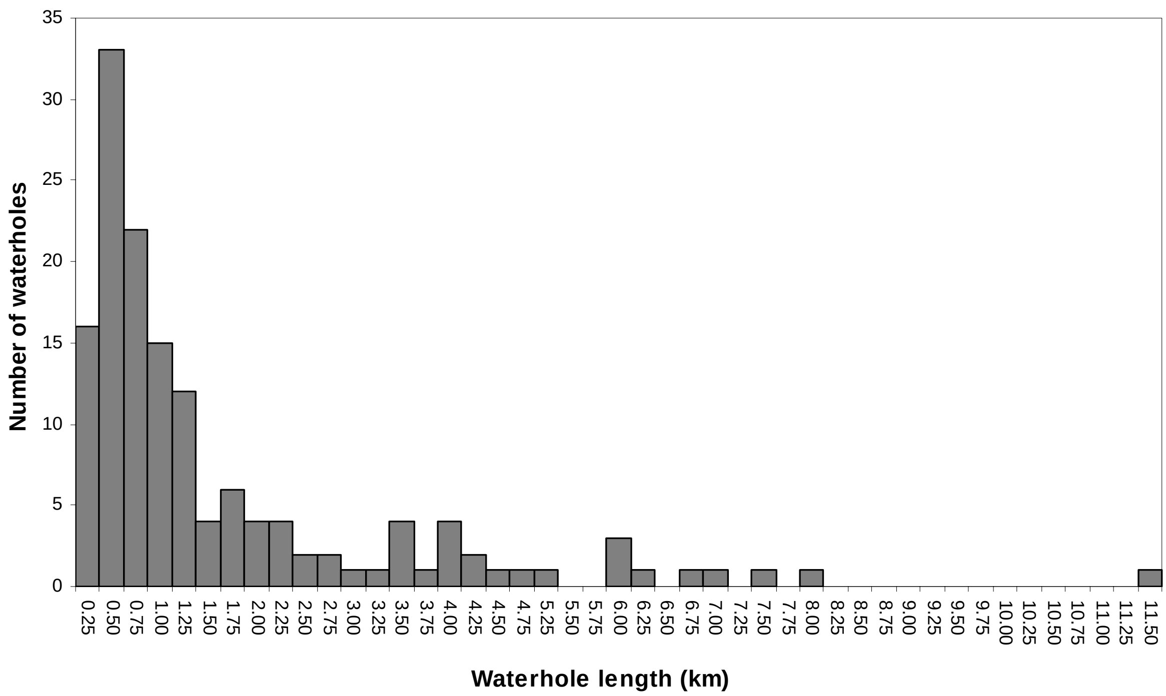


Figure 5.3. The number of waterholes ranging from < 250 m to < 11.5 km in length within the Bland Creek sub-catchment as mapped between 20 and 23 August 2007.

5.4.1. Seine netting

Repeat-haul seine netting using haul nets fitted with extra floats and weights can be used in small, shallow (< 1 m) and narrow waterholes that have little to no habitat complexity. Hauls should be repeated until five subsequent hauls return no carp.

5.4.2. Waterhole pump-out

This is likely to be the most effective carp removal strategy for many waterholes. Pump-out would involve the installation of a temporary aquadam (water filled tube: Waters Excavations Pty Ltd., Mildura, Victoria) or earthen block bank at the upstream limit of the remnant waterhole. A high capacity pump would then be used to transfer water from the remnant waterbody to the dry streambed on the upstream side of the aquadam. Outflow from the pump must be screened in order to remove any carp or other pest fish during water transfer. The substrate of the original waterbody should be left exposed until dry. The aquadam or block bank would then be removed and the water would return to its original position. The maximum volume of water at which this method becomes impractical needs to be assessed during pilot exercises as we are not aware that this strategy has been used in previous pest fish eradication exercises.

5.4.3. Piscicides

At sites where the pump-out technique cannot remove the last of the water present, and seine nets cannot be used in the remnant pools due to high habitat complexity, piscicides should be applied to eliminate any carp that may remain. Piscicides have been used previously to successfully eradicate carp from enclosed waterbodies (Crivelli 1981; Hall 1988; Sanger and Koehn 1997). Rotenone is currently the only chemical licensed as a piscicide in New South Wales.

Pump-out should be used initially to reduce the volume of water requiring piscicide application. This would have the added potential benefit of reducing the water-level below the complex habitats adjacent to the banks and littoral weed beds which have been demonstrated to reduce the effectiveness of rotenone applications (Rayner and Creese 2006). Smaller quantities of rotenone could then be applied to the residual pools. Following treatment, the rotenone should be neutralised before the block bank is removed and the pumped water returns to its previous location.

Carp have also been found to be especially sensitive to the herbicide acrolein (Jackel 1993). Acrolein dissipates rapidly, leaving no phytotoxic residues and has a first order half life of 4 – 5 hours (Bowmer 1987). However, acrolein is a restricted use herbicide, requiring specialised application equipment and specific storage requirements. Most importantly, acrolein is not licensed for use as a piscicide and a lengthy approval process would be required in order to obtain approval for its use.

5.4.4. Explosives

Under the unlikely scenario that an un-pumpable remnant pool is too deep for effective rotenone application, professional explosives contractors could be commissioned to detonate a sufficient density of explosive within the remnant pool to kill remaining fish.

5.4.5. Options for larger waterbodies

If the remnant waterbody is too large to implement any of the methods described above, commercial carp fishermen should be contracted to implement high intensity large-scale hauling activities. Local communities should be encouraged and assisted in the coordination of recreational fishing based carp removal events and flow and bait attractants should be used to maximise the efficiency of carp traps. However, eradication of carp from larger water bodies is unlikely to be a feasible option using these methods. Therefore, efforts to isolate these larger waterbodies from downstream waters should be investigated and implemented.

5.4.6. Native fish management

Native fish collected during seine netting or waterhole pump-out activities can be housed in temporary on-site holding facilities, or transferred to the water held upstream of the aquadam for pump-out exercises. If piscicides or explosives are being used to eradicate carp, attempts must first be made to remove native fishes and other native aquatic animals from the site prior to treatment. Following completion of carp removal activities, these native fish should then be returned to the waterbody that they were removed from. If few native fish were collected prior to or during carp eradication exercises, consideration should be given to the release of native threatened species such as silver perch, freshwater catfish, purple spotted gudgeon, southern pygmy perch or olive perchlet in the pest fish free waterbodies.

5.5. Conclusions

Even given that Lake Cowal is known to be a major carp recruitment hotspot when full, the fact that it is mostly an endorheic system suggests there is a low likelihood that it will contribute any carp recruits to the lower Lachlan River demonstration site within the immediate future. Greater benefits could be achieved by allocating available funding to control carp recruitment at those non-endorheic hotspots that are much more likely to contribute to the carp population of the broader lower catchment area on a more regular basis, such as Lake Brewster, the Great Cumbung Swamp and Lake Cargelligo. Resources of the scale required to achieve total carp eradication from the Bland Creek sub-catchment should only be allocated to that activity after carp control has been achieved at higher priority locations. But in the event that carp eradication is attempted, we recommend strongly that the activity is undertaken during a period of extensive drought and that a similar strategy to the ones presented here be adopted. Further, any actions taken need to be implemented over a short period of time to ensure that all populations are eradicated before a breeding and dispersal event within the treatment area repopulates the system.

6. THE GREAT CUMBUNG SWAMP: A PRESUMED CARP RECRUITMENT HOTSPOT

6.1. The Great Cumbung Swamp

Some 1,450 kilometres from its headwaters, the Lachlan River evolves into a series of ephemeral wetlands, terminating in the Great Cumbung Swamp (hereafter referred to as GCS) near Oxley (Figure 6.1). Together with the contiguous floodplain of the lower Murrumbidgee River (into which the Lachlan discharges) the area is a significant complex of wetlands recognised nationally and listed in the Directory of Important Wetlands (Australian Nature Conservation Agency 1996) and in the Register of the National Estate (Brady *et al.* 1998).

This vast area of 16,000 hectares (Environment Australia 2001) is a typical semi-arid terminal Reed Swamp, characterised by dense pure stands of common reed (*Phragmites australis*) and cumbungi (*Typha* spp.). It relies on surplus flows from either the Lachlan or Murrumbidgee Rivers as its main water source. Three depositional environments exist within the swamp: the Lachlan channel, the Phragmites marshes and the marginal lakes and alluvial plains (O'Brien and Burne 1994). The edge of the Phragmites marsh corresponds roughly with the 71 m AHD. Maximum water depths within the inundated Phragmites marsh are in the order of 0.3 m. Within the marsh are areas of open water, termed marsh lakes (O'Brien and Burne 1994). The lakes grade into the surrounding marsh and are less than 0.75 m deep. In contrast, the marginal lakes are not surrounded by extensive *P. australis* but by ground cover, lignum (*Muehlenbeckia florulenta*), river redgum (*Eucalyptus camaldulensis*) and black box (*Eucalyptus largiflorens*) woodlands.

The hydrology of the wetland is impacted by river regulation and abstraction, with analysis of historical records demonstrating a progressive reduction in the volume of mainstream flows (Brady *et al.* 1998). Historically, natural flooding onto the floodplain occurred during late spring to summer with a commence to flow volume of 1,500 ML day^{-1} at Oxley (Driver *et al.* 2005*c*). A hydrographic monitoring program to assess water reaching the GCS was established in 1995 (Brady *et al.* 1998). In 1998, the Lachlan River Management Committee developed environmental flow rules to deliver 350,000 ML per year of environmental flow (measured in the Lachlan River near Lake Brewster) during the natural flood months of June – October, to achieve substantial flooding of wetlands and the river channel (LRMC 1999). In 2000, these were revised for the Water Sharing Plan (WSP), which was gazetted in 2003 and the changes included extending the high flow period by one month to November. Lachlan River riparian wetlands receive 30% less inundation time under the MDBCs cap on diversions than they did in undeveloped condition. The WSP improved this by 1, 10 and 18% in the mid-Lachlan billabongs, lower Lachlan Swamps and Lower Lachlan Billabongs respectively (Driver *et al.* 2005*a*). However, even under the WSP conditions, the number of inundation days for each of these wetland systems is 78%, 62% and 72% of the unregulated condition respectively. Further, very long periods of inundation ≥ 160 days are more common under the WSP model than even under undeveloped conditions (Driver *et al.* 2005*a*). However the GCS has had little overall gain in flows (1%) as a result of the WSP, which is reflected in the marginal increase in the number of floods that reach the extent of the Phragmites marsh and edge of the river red gum forests (Driver *et al*. 2005*c*). The average inundation days in the GCS is 56% of undeveloped conditions.

A peak flow of over 3,000 ML day^{-1} at Booligal is reported as necessary for inundation of the full extent of the wetland (Brady *et al.* 1998). However, flows above this have failed to inundate the area on a number of occasions, suggesting that more than just peak flow at Booligal determines inundation area (Brady *et al.* 1998). Although, the influence of the Murrumbidgee inflows on inundated area of the GCS is less than that from Lachlan River flows at Booligal, the contribution is still significant (Shaikh *et al.* 1998). The actual contribution to the GCS can be gauged based on transmission losses between Maude and Redbank weirs on the Murrumbidgee River. Therefore, water level data from each of Booligal Weir, Redbank Weir and Maude Weir are required parameters when monitoring and modelling inundation of the GCS (Shaikh *et al.* 1998).

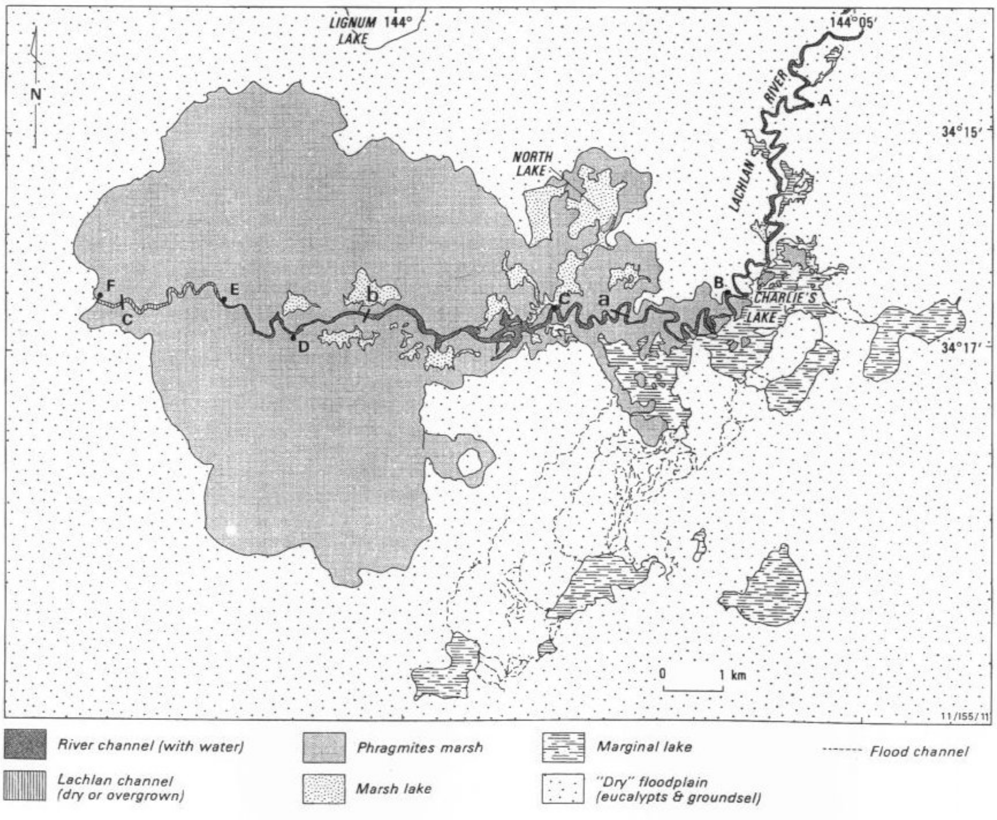


Figure 6.1. Great Cumbung Swamp showing the extent of the floodplain and associated lakes. Image from O'Brien and Burn (1994).

Historically, the flood return frequency that links the Lachlan and Murrumbidgee rivers through the GCS was 1 in 10 years, corresponding to a flow of about 3.9 GL at Booligal (Pat Driver, DECCW Office of Water, pers comm.). Based on this, the GCS would have flooded into the Murrumbidgee in 1931, 1950 – 52, 1956, 1974 (coinciding with the rapid expansion of carp throughout the MDB) and most recently in 1990.

6.2. The Great Cumbung Swamp as a carp 'hotspot'

The complex of wetlands available in the inundated GCS provide a wide range of habitats for many terrestrial and aquatic organisms. Not only are they a critically important habitat and breeding site for waterbirds (Kingsford 2000, Kingsford and Auld 2005, Driver *et al.* 2005*a*) and a site of high floodplain productivity, but they are also likely to represent an important recruitment area for native fish. However, the physical characteristics of the GCS closely resemble those of wetlands recognised as 'hotspots' of carp recruitment in other areas of the Murray-Darling Basin, such as the Macquarie Marshes, Gwydir Wetlands and Barmah-Millewa Forest (Gilligan, in prep). The GCS is a large floodplain area with large areas of shallow inundated terrestrial vegetation, which is recognised as the preferred spawning habitat for common carp (Sigler 1958; Swee and McCrimmon 1966; Crivelli 1981; King *et al.* 2003; Brown *et al.* 2005; Stuart and Jones 2006*a*) and post-inundation productivity will provide an abundance of zooplankton to support larval and juvenile carp growth and recruitment.

The existence of a potentially massive source of carp recruitment in the Lower Lachlan demonstration reach requires that strategies to control carp recruitment within the GCS, or strategies to prevent or limit their dispersal into the catchment upstream will be critical components of a long-term carp control program for the Lachlan. Options for managing carp within the swamp are limited in that once the swamp is inundated, access for implementation of control actions is extremely limited. Therefore the management of the swamp is dependant on limiting or preventing spawning fish accessing spawning habitats and in limiting or preventing the dispersal of recruits from migrating upstream into the Lachlan catchment. Information on the distribution of carp spawning and recruitment within the inundated GCS, as well as information on the growth rates of carp larvae and juveniles, the timing and size at which they commence dispersing into riverine reaches upstream and identification of potential environmental triggers that cue that dispersal is critically important. These data will direct the application of carp control activities within the GCS during an inundation event and provide guidance on the most effective methods (mesh sizes, trap placement and timing etc) to achieve effective control.

6.3. Sampling of Great Cumbung Swamp during an inundation event

The Lachlan CMA provided I&I NSW with funding to undertake an assessment of carp recruitment within the swamp (as well as to assess the importance of the GCS to native fish recruitment) as part of the *River Revival – Lachlan River Carp Cleanup*. However, ongoing drought has meant that no water has entered the GCS, although some water persists in some areas of the Lachlan River channel within the swamps boundaries. As a result, I&I NSW have been unable to deliver upon this project component to date. It will remain impossible to undertake any studies of the aquatic processes within the GCS until such time as sufficient rainfall and flooding inundate the floodplain, or sufficient EWAs are available to simulate a natural inundation event. I&I NSW are committed to undertaking this work during the next inundation. A flow exceeding 1,500 ML day^{-1} passing Booligal Weir will trigger the following research plan, which will encompass substantial field data collection during the full inundation and subsidence phases of the inundation event.

Marsh lakes are likely to be the locations that get inundated first and we will establish sampling sites within each inundated lake. An equivalent number of sites in the *Phragmites* marsh (if it is penetrable), river channel sites (within the marsh boundary) and marginal lake sites will be established. If the flooding event establishes a wetted connection between the Lachlan and Murrumbidgee rivers, additional sites in the Murrumbidgee River upstream and downstream of the point where water transfer occurs will also be sampled.

Standard Sustainable Rivers Audit (SRA) protocol sampling (MDBC 2006) will be undertaken at all sites within days of the water arriving. This will be repeated 4 – 5 weeks after the initial inundation in addition to further fish recruitment sampling methods described within King *et al*. (2003). Where possible, we will note the distribution of spawning carp, describe the habitat features of spawning and non-spawning sites and conduct quadrant counts of carp eggs.

At intervals after the date that water arrives in the swamp, we will set a pair of standard 6 mm mesh fyke nets and a pair of 2 – 3 mm mesh larval fyke nets (~24 hour sets) at sites spread every 25 km from our existing GCS site (Boyong) upstream to Booligal. One of each pair of fyke nets will sample fish moving upstream and the other fish moving downstream. If water exits the swamp into the Murrumbidgee River, we will establish additional fyke net sites in the Murrumbidgee River upstream and downstream of the point where water transfer occurs. Fyke net sites will be re-sampled weekly for the first 4 weeks and then fortnightly at week 6, 8, 10, 12, 14 and 16 to look at the timing and size at which dispersal occurs.

7. TAGGING

7.1. Introduction

The information obtained from tagging programs can be used in a few general ways: To provide evidence of migration and dispersal, to provide information on growth and mortality rates and to estimate population size (Royce 1972). Additionally, a pool of tagged fish within a system may enable the project team to gauge the relative effectiveness of specific control techniques based on the proportion of the known tagged population that that technique removes. The latter was the primary objective for this activity within the *River Revival – Lachlan River Carp Cleanup*. A large pool of tagged fish can be used to gauge the cost-effectiveness of a range of carp removal strategies applied during the implementation phase of the project, via a basic financial analysis (see Roberts *et al.* 1997). During the benchmarking phase of the project, a target of ~10,000 tagged carp was proposed based on pre-existing estimates of catch per unit effort from electrofishing surveys undertaken within the lower Lachlan catchment between 1994 and 2006 (I&I NSW, Freshwater Fish Research Database). These data suggested that it would be feasible to collect ~10,000 carp within six weeks of intensive field sampling in the Lachlan demonstration site.

To gauge the contribution that recreational fishing mortality had towards carp control and to foster community involvement, recreational anglers were encouraged to target carp and report tag numbers via a toll free phone number. Tags were individually numbered and labelled with the following:

NSW DPI Ph 1800 185 027 REWARD, Record Date + Place + Length.

Anglers were contacted by research staff to validate the return and to ensure correct recording of all relevant information. Anglers were rewarded with a fishing lure and other project merchandise (hat, drink cooler etc.).

Inherent within many tagging studies however, are issues such as the number of fish tagged, the sometimes small number of recaptures, temporal variability of tag recoveries and the effects of emigration and tag shedding (Kirkwood and Walker 1984). As tagged fish are lost from the system, the number of fish assumed to be at liberty within the study area naturally declines and has flow-on consequences for the financial analysis. Estimates of emigration rates from the population, tag shedding rates and natural mortality need to be accounted for as part of the planned financial analysis at the conclusion of the implementation phase of the project.

7.2. Methods

Tagging of common carp was conducted within the main channel of the Lachlan River between the Wyangala Dam wall and the Lachlan River downstream of Booligal, including within Lake Brewster and Lake Cargelligo (Figure 7.1). Over an 18 month period, sampling was conducted at 56 individual locations by both I&I NSW and K. & C. Fisheries. All carp greater than ~120 mm FL collected during the first and second rounds of benchmarking sampling (chapter 2) were tagged. I&I NSW undertook further electrofishing at an additional 42 sites spread throughout the lower Lachlan demonstration site specifically to tag as many carp as was possible within the resources allocated to the activity. Carp were collected and tagged by staff of K. & C. Fisheries at Lake Brewster and Lake Cargelligo (including internal channels) using boat electrofishing, large gill nets and seine nets.

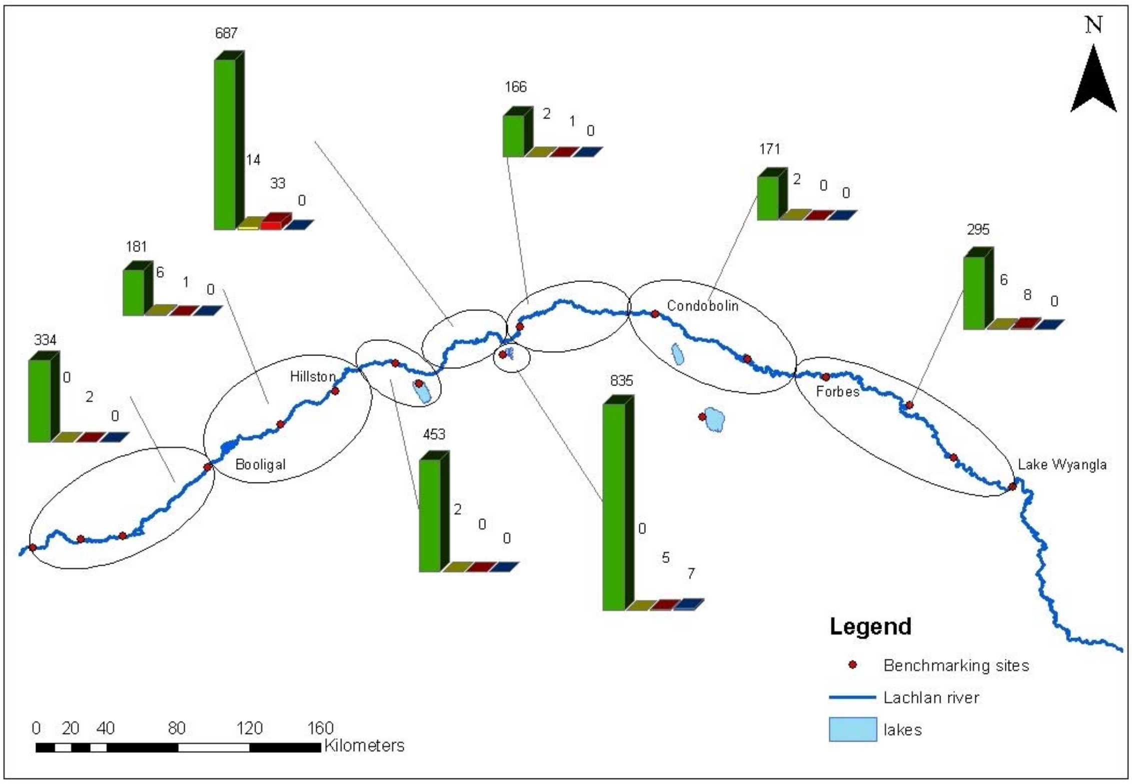


Figure 7.1. Map of sampling reaches (dark circles) and number of tagged fish and recaptures within each reach. Green columns are total tagged fish, yellow columns are recreational angler returns, red columns are Industry and Investment NSW recaptures and the blue column commercial fisher recaptures.

All carp were double-tagged with individually numbered Hallprint® plastic tipped dart tags. Double tagging was undertaken in order to obtain estimates of the tag shedding rate and minimise the loss of too many study animals through tag shedding. Tags were inserted on the left-hand side of the fish approximately 5 mm below the dorsal fin. The first tag was inserted between the third and fourth soft fin rays and the second between the fifth and sixth. All tags were inserted at approximately 45^{o} to the dorsal surface. Information recorded for each fish included; the tag numbers, length (FL), health condition, sex (if possible) and capture location. All tagged fish were released near their capture location. Three different tag sizes were used depending on fish length: 145 mm plastic for large carp (> 600 mm), 100 mm for medium fish (280 – 600 mm) and 50 mm tags for small fish (< 280 mm).

Methods outlined by Kirkwood and Walker (1984) were used to estimate the tag shedding rate from double tagged carp, pooling all tag sizes used.

7.3. Results

A total of 3,122 common carp were tagged, with a total sampling effort of approximately 16 weeks of field sampling. Division of sampling effort and the number of fish tagged were as follows; benchmark sampling (four weeks and $n = 198$), targeted electrofishing (8 weeks and $n = 1{,}541$) and commercial fishing methods (4 weeks and $n = 1{,}383$). Tagged fish ranged in size from 116 mm to 771 mm, with the majority of fish ranging between 400 – 600 mm (53% of total).

A total of 79 recaptures have been recorded to date (2.53% of the tagged fish). Of these, 40 (1.24%) were recaptured by non-targeted electrofishing, 32 (1.0%) by recreational anglers and 7 (0.22%) by commercial fishing (0.22% of total tagged population but 0.84% of the tagged population within the fished areas). All fish were recaptured within 1 km of their original capture location. Fish grew whilst at liberty for 19 – 643 days, with an average daily growth rate of 1.5 mm day^{-1}.

Fish captured by recreational anglers and commercial fishers were not returned to the water, representing a 1.3% reduction in tagged fish from the system.

Seven of the 79 individuals recaptured had shed a single tag. An estimated tag retention rate of 82.6% was derived following the analytical procedure described in Kirkwood and Walker (1984). However, tag retention rates derived from fish recaptured by recreational anglers were lower at 54.7%. Due to uncertainty in whether recreational anglers were reporting both or just one tag from each recaptured fish, recreational fisher returns were only included in analyses if both tag numbers were reported or if the capture report could be verified with the angler within a three day period of capture.

7.4. Discussion

Following a financial analysis of alternative carp eradication strategies in the Murrumbidgee Irrigation Area, Roberts *et al.* (1997) recommended strongly that investment into research assessing the relative efficiency of various control options was essential in developing a cost-effective carp control program. This demonstration site project is following this recommendation. We tagged a large population of carp within the demonstration reach during the benchmarking phase of the *River Revival – Lachlan River carp Cleanup*, so that the relative efficiency of alternative carp removal exercises implemented during the subsequent implementation phase can be compared, based on the number of carp each method removes from the overall carp population at liberty. For example, at its simplest, if a particular method recaptures 200 tagged fish amongst its catch, and the population of tagged carp assumed to be at liberty at the time of capture was 2,000, it can be estimated that that technique removed 10% of the existing total carp population within the demonstration site. By accurate record keeping of the costs to implement that control method, estimates of relative cost-efficiency can be derived and standardised to a similar unit, i.e., dollars per carp.

Despite our inability to capture and tag the intended target of 10,000 carp within the benchmarking phase of the project, the incidental recapture of 2.5% of the tagged fish during the benchmarking phase suggests that the pool of 3,122 individuals dispersed throughout the demonstration site may be sufficient to serve the purpose of providing data on the relative efficiency of carp removal exercises planned to be undertaken. The recapture rate is consistent with that reported from other studies of carp populations, with Rodriguez-Ruiz and Granado-Lorencia (1992) recapturing 1.23% of tagged carp over a 3 month period, but is much lower than that of Stuart and Jones (2006*a*), who recaptured 8.8% of tagged fish. Although the catchment-wide estimate of 0.22% efficiency of commercial fishing is accurate across the lower Lachlan carp population overall, the 'relative' capture efficiency of commercial methods is actually 0.84% as all commercial fishing to date has been undertaken within Lake Cargelligo, which has been isolated from the broader Lachlan River population and represents a smaller pool of available tagged carp (7 recaptures from 835 tagged fish).

All fish recaptured in the present study showed minimal movement from their initial capture location. Stuart and Jones (2006*a*) in their study of carp within the Murray River and Barmah-Millewa forest system found that most carp made localised movements, but others were capable of moving large distances. The majority (66%) remained within 1 km of their initial release location (Stuart and Jones 2006*a*). Not unlike the present study, repeat electrofishing at capture sites may have biased the result and the fate of un-recaptured individuals remains unknown. Sampling during the implementation phase of the current project will not only involve a monitoring component (re-visiting existing sites) but will also involve identifying randomly chosen sites between existing sites to attempt an assessment of the effectiveness of electrofishing as a carp control method.

As all common carp were double tagged during sampling, we were able to estimate the tag retention rate over the benchmark phase study period. Our tag retention rate of 82.6% over the benchmarking phase of the study is higher than that reported by Stuart and Jones (2006*a*) of 71% and Brown *et al.* (2003) of 58%. Both these studies used similar dart tags. The estimated tag retention rate not only enables us to gauge the current status or number of pooled fish within the current population, but via further calculations, can be used to estimate the potential longevity of a pool of tagged fish in the population. For example, using our derived instantaneous rate of tag retention, 0.82 after Kirkwood and Walker (1984), the number of tagged fish remaining within the population after two years (the term of the initial implementation phase of the project) can be explored:

The proportion of fish which will have lost both their tags after two years:
$P\ (0 \text{ tags at time } 2) = (1 - 0.82^2)^2 = 10.7\%$

The proportion of fish which have retained both tags after two years:
$P\ (2 \text{ tags at time } 2) = (0.82^2)^2 = 45.2\%$

The proportion of fish which have retained a single tag after two years:
$P\ (1 \text{ tag at time } 2) = 2 \times 0.82^2 \times (1 - 0.82^2) = 44.1\%$

Therefore, we can assume (albeit based on the small number of recaptures to date) that the pool of tagged carp within the Lachlan will decline by only ~11%, or remain at ~ 2,750 tagged individuals by October 2011 (not accounting for emigration, natural mortality or non-reported capture).

Following the implementation of integrated carp control strategies as part of a demonstration site carp control plan, we expect that the recapture rates of tagged fish should increase markedly and provide sufficient data for subsequent financial analysis.

8. INTRODUCTION TO THE IMPLEMENTATION PHASE

The purpose of the implementation phase of the *River Revival – Lachlan River Carp Cleanup* is to apply carp control options developed through the IA CRC Freshwater Products & Strategies program within the established demonstration site for the purpose of trialling and show-casing carp control techniques. The intention is that carp biomass can be reduced relatively quickly and to an extent that the reduced impacts of carp on the aquatic environment can be demonstrated by measurable recovery of aquatic ecosystem variables.

Of the Freshwater Products and Strategies projects funded by the Pest Animal Control CRC or Invasive Animals CRC to date, four have thus far produced output products or strategies that can be applied in the lower Lachlan demonstration reach over the next two years:

1. The strategy to identify and target carp recruitment hotspot locations to achieve catchment-wide population control (IA CRC Project No. 4.F.5).
2. Installation of traps installed in inlet and outlet channels of identified carp recruitment hotspots that capitalise on carp's predicable and innate behaviours in accessing these locations, preventing or limiting their access to preferred spawning sites and maximising the harvest of pre-spawning fish (IA CRC Project No. 4.F.12)
3. Use of hormone implants in 'lure' fish to maximise trapping catch rates in and around spawning sites and perhaps also more broadly in flowing water environments (Sorensen and Stacey 2004)(IA CRC Project No. 4.F.4).
4. The CARPSIM population model (Brown and Walker 2004) (PAC CRC project) is currently available as a tool to model the predicted outcomes of alternative control strategies, but requires parameterisation with data representative of the lower Lachlan system in order to be applicable.

Additional high profile products being developed by the IA CRC, such as Daughterless Carp and other gene technologies (Thresher 2008; Bax and Thresher 2009) (IA CRC Project No. 4.F.3), assessing the feasibility of bio-control using Koi herpes virus (IA CRC Project No. 4.F.7) and the identification and synthesis of natural chemical carp attractants (Project No. 4.F.13) are still in development and are unlikely to be available for field trials within the initial two year term of the implementation phase of the demonstration site project.

There are five additional control tools or strategies developed independently of the IA CRC that are also available for implementation within the *River Revival – Lachlan River Carp Cleanup*:

1. The installation of William's carp separation cages in existing and planned fishways within the Lachlan River channel (Stuart *et al.* 2006; and see chapter 4).
2. The use of the 'Judas Carp' approach to maximise the commercial harvest or efficiency of removal exercises by targeting spawning or winter aggregations of carp (Diggle *et al*. 2004; Inland Fisheries Service 2004; Inland Fisheries Service 2009).
3. The strategic non-consumptive (en route) use of environmental water allocations or other flow deliveries to induce carp spawning activity, followed by a rapid short-term reduction in water level and subsequent carp recruitment sabotage (Shields 1958; Gafny *et al.* 1992; Verrill and Berry 1995; Summerfelt 1999, Brown *et al.* 2003, Inland Fisheries Service 2004).

4. The strategic consumptive use of environmental water allocations to trap and eradicate adult carp on inundated floodplains (Stuart and Jones 2006*b*).
5. Maximising the cost-efficiency of physical removal efforts in the Lachlan River channel by capitalising on the current drought conditions which have resulted in the reduction or total cessation of flows in the Lachlan River below Condobolin. Over the next 12 months or more, a persistent lack of rainfall in the catchment will result in the river channel drying to a finite number of isolated remnant waterholes (Roberts *et al.* 1997).

8.1. Carp control options and strategies for the *River Revival – Lachlan River Carp Cleanup*

8.1.1. CARPSIM parameterisation and modelling

Brown and Walker (2004) produced an age-based meta-population model for carp (CARPSIM) as a tool for modelling the probabilistic outcomes of alternative carp control strategies. The following range of control strategies could be modelled under a meta-population structure representative of the lower Lachlan demonstration reach in order to determine the most effective integrated pest management strategy for the demonstration site. Resources should be allocated to facilitate this task.

8.1.2. Targeting hotspots

Following a basic financial analysis, Roberts *et al.* (1997) determined that if carp abundance was driven by recruitment at a few key wetland sites, wetland drying and subsequent exclusion would be the most cost-effective carp control strategy. This was later reiterated by Stuart and Jones (2006*b*), who recommended targeting control efforts towards off-stream floodplain systems favoured by carp as spawning sites (Sigler 1958; Swee and McCrimmon 1966; McCrimmon 1968; Crivelli 1981; Rodriguez-Ruiz and Grando-Lorencio 1992; Roberts and Ebner 1998, Villizi 1998; King *et al.* 2003; Sommer *et al*. 2004; Brown *et al.* 2005; Penne and Pierce 2008). Recent basin-wide sampling by Gilligan (in prep) has demonstrated that although carp populations are widespread across the Murray-Darling Basin, there is a distinct source-sink population structure. Therefore, controlling carp at the key source areas should facilitate catchment-wide population control. It is this strategy which will be adopted within the Lower Lachlan demonstration site.

Otolith microchemical analysis (Macdonald *et al.* 2009 – see appendix 2) undertaken during the benchmarking phase of the project suggest that Lake Brewster and Lake Cargelligo have been the two key carp recruitment areas within the lower Lachlan catchment over the last two spawning seasons. Additionally, the collection of young of year carp in the lower Lachlan River at sites downstream of Corrong and the upper Lachlan River near Cowra during benchmark sampling (see chapter 2) suggests that these areas are also possibly carp recruitment areas within the catchment. Therefore, these four locations should be the initial focus of carp control activities.

The annual collection and micro-chemical analysis of post-larval and young of year carp otoliths should continue in order to determine the locations of key carp recruitment areas within the catchment as flow conditions change and as a means to gauge the effectiveness of out ‘targeting hotspots’ carp control strategy.

8.1.3. Inlet/Outlet traps and screens

Thwaites *et al.* (2007) and Ben Smith's team at SARDI have refined modifications to the Williams Carp Separation Cage concept for installation in confined waterbodies such as wetland inlet and outlet channels and irrigation systems. Preliminary designs were trialled at Lake Brewster, Lake Cargelligo and the Great Cumbung Swamp by McNeil *et al.* (2010)(see appendix 3) during the benchmarking phase of the *River Revival – Lachlan River Carp Cleanup*. Because these three sites represent carp recruitment hotspots within the lower Lachlan demonstration site, the installation of traps within inlet and outlet channels of these systems should be a priority carp control option. Removal of fish moving into and out of these systems could potentially have a significant and rapid impact on the carp population within the lakes and a significant impact on the catchment-wide carp population. For example, after installation of a barrier excluding > 300 mm carp from entering Cootes Paradise Marsh (Ontario), carp biomass within the marsh declined by 90% in the first year and by 97% after two years (Lougheed and Chow-Fraser 2001). Installation of inlet/outlet traps and screens becomes particularly important in the event that the target wetland system can be drained or dried to eliminate any resident population of carp, with the traps and screen preventing or limiting re-invasion of the waterbody. This is anticipated to occur at Lake Brewster (see appendix 4: McNeil *et al.* 2009) and may occur at Lake Cargelligo within the near future, depending on rainfall within the catchment over the next 12 months.

In addition to the strategic benefits of eliminating these wetland systems as sources of carp recruits, by trapping and removing carp as they make predictable annual migrations towards these key recruitment areas, large numbers of pre-spawning fish can be removed from the system (Jones and Stuart 2009). For instance, K. & C. Fisheries have annually removed between 20 and 76 tonnes of carp from the entrance/exit channel of Moira Lake on the Murray River each year as the Lake is drained back into the river through a single outlet channel (Jones and Stuart 2009).

Installation and ongoing maintenance and management of inlet/outlet traps and screens at Lake Brewster and Lake Cargelligo should be one of the highest priority activities under the carp control plan. The current dry state and existing current works at Lake Brewster make this an immediate priority at this site. Similarly, if Lake Cargelligo does dry within the next 12 months or more, the installation of inlet/outlet traps and screens within this system is an equally immediate priority as an opportunity to eliminate the resident population of carp within the Lake Cargelligo system may not present itself again for some time.

We anticipate that inlet/outlet traps or screens will also be required for various marginal and marsh lakes within the Great Cumbung Swamp and other wetland areas within the lower Lachlan demonstration site. But without additional data on which of these locations represent major carp recruitment hotspots, we are not in a position to prioritise which wetland systems should be targeted or prioritised.

8.1.4. Hormone implants, 'lure' fish and pheromone traps

The development of the strategy to use implanted osmotic pumps to induce the extended excretion of post-ovulatory pheromones in female carp, and to use implanted carp as 'lures' to attract and trap aggregations of male carp in spawning habitats was achieved by Prof. Peter Sorenson and his staff and students at the University of Minnesota, USA. Osmotic pumps are available for field trials in the lower Lachlan Demonstration Reach project.

The recommended strategy is to implant osmotic pumps into female carp during the spawning season (late September to December). Implanted females (lure fish) are placed in pens within or adjacent to known spawning habitats where male carp have aggregated. Traps or nets are set surrounding the penned lure fish (pheromone traps) to harvest males attracted by the pheromones excreted by the lure female. It is anticipated that each lure fish should excrete post-ovulatory pheromones for a period of at least 14 days. This strategy should be field trialled in Lake Cargelligo, Lake Brewster, the Great Cumbung Swamp, or at any other spawning aggregation of carp identified during the implementation phase of the project in order to document the cost-effectiveness of using hormone implanted lure fish relative to other carp removal strategies undertaken under the carp control plan.

Based on laboratory experiments, Smith *et al.* (2005) concluded that current is important in aiding fish to find the source of diffuse odours and combining flows with odour attractants should maximise the attraction of carp into traps. Therefore, in addition to using pheromone traps within known shallow lentic spawning areas as above, field trials of pheromone traps should also be undertaken in flowing riverine sites and strategically placed in inflow points to the three wetland systems to gauge and report on the relative efficiency of these alternative deployment strategies.

8.1.5. Fishway William's Carp Separation Cages

Williams Carp Separation Cages (WCSC) provide a means of removing a large biomass of carp from river systems (Stuart *et al.* 2006). The Mark V design is effective at removing over 60% of carp passing through fishways, whilst at the same time providing fish passage for native fish (Stuart and Conallin 2009). During the benchmarking phase of the demonstration reach project, a single WCSC was designed, constructed and installed at the Island Creek Weir fishway (see chapter 4). Although the Island Bend WCSC was over an order of magnitude more expensive to construct and install than was anticipated based on Stuart *et al.* (2006), given the extended life-span of the WCSCs and their reported efficiency in the Murray River (Stuart *et al.* 2006; Stuart and Conallin 2009) the potential long term benefits of installation of WCSC at all available fishway locations within the Lower Lachlan justifies the higher than anticipated initial establishment costs. We recommend that installation of a WCSC be undertaken at the single existing fishway present within the demonstration site, Bumbuggan Weir, as an immediate priority. We also recommend that WCSCs be integrated into the design and construction process for the Booligal Weir, Cargelligo Weir and Brewster Weir fishways currently planned for construction in 2010/2011, and any other fishways planned for construction in the near future (Jemalong Weir).

8.1.6. Judas carp

The Tasmanian Carp Management Program reported that following the initial reduction in carp biomass in Lakes Sorell and Crescent, fishing effort was substantially enhanced by incorporation of a 'Judas fish' strategy into the control program, where a number of males were radio-tagged in order to lead the project team to spawning and winter aggregations (Diggle *et al.* 2004). In large lake and floodplain wetland systems that retain water for several years, and thus have the capacity to retain resident populations of sexually mature carp, the 'Judas fish' approach may provide a cost-effective means of maximising carp removal. For example, targeted netting of winter aggregations of carp in Iowa and Wisconsin, USA, reduced common carp populations by up to 90% (Rose and Moen 1952, Neess *et al.* 1957).

Within the lower Lachlan Demonstration reach, Lake Cargelligo represents such a system. Within Lake Cargelligo, a small number (12 – 20) of Judas carp could be tagged and released. A group of community members willing to commit to tracking the fish on a regular basis could be trained and provided with the equipment necessary to manually track the Judas carp. In the instance that an aggregation of fish was detected, the project team would be notified and steps taken to harvest the aggregation. The Judas fish would be released and the remainder of the catch removed from the system.

Given the small amount of funding required to implement this strategy, we recommend it be implemented in Lake Cargelligo as part of the carp control plan. However, if drought predictions suggest that Lake Cargelligo is likely to dry within the period of the initial implementation period of the project, or that the salinity is likely to exceed the limitations of radio telemetry for a substantial period of time (> 750 µS cm^{-1}), it may be prudent to delay release of tagged fish until such time that the tagged fish will remain in the lake (and be detectable) for a reasonable period of time, and at least for the period from early winter to early summer when winter and spawning aggregations are likely to form (Swee and McCrimmon 1966, Johnsen and Hasler 1977, Verrill and Berry 1995, Cooke & McKinley 1999, Brown *et al.* 2000, García-Berthou 2001, Bauer and Schlott 2004, Penne and Pierce 2008; Jones and Stuart 2009).

8.1.7. Water level manipulation

Wetland draw-down has been proposed and tested as a method of disrupting spawning and recruitment success (Shields 1958; Gafny *et al.* 1992; Verrill and Berry 1995; Summerfelt 1999, Inland Fisheries Service 2004). Rapid reduction in water level by only a small amount (50 – 60 cm) within 1 – 2 days following a spawning event could be used to desiccate eggs, with Swee and McCrimmon (1966) reporting total carp egg mortality after being exposed for only several hours. Therefore, it is feasible that if water was delivered to a known spawning site to deliberately initiate a carp spawning event, and then the water level was rapidly dropped to desiccate the eggs, carp recruitment at that site could be sabotaged. The water used could be utilised non-consumptively *en route* as part of a environmental or other water allocation to a site downstream of a known spawning site, or a specific carp control allocation could be negotiated from the Lachlan catchments environmental water allocation under the Water Sharing Plan. An alternative recruitment sabotage strategy, as used in Tasmania (Inland Fisheries Service 2004), was to deliberately maintain water levels at below the commence-to-fill levels of known carp spawning sites. This strategy was considered an integral part of a suite of management activities that have successfully reduced the abundance of carp in Lake Sorrell to < 50 individuals and achieved pseudo-extinction in Lake Crescent (Inland Fisheries Service 2009). Simulations of 'recruitment-sabotage' undertaken using CARPSIM suggest that recruitment sabotage may be a very effective management strategy if recruitment can be largely eliminated (e.g., 99 years in 100), in which case carp populations can decline rapidly (Brown and Walker 2004). However, the strategy may be counter-productive if recruitment cannot be controlled with a high probability of success over a 30 – 40 year period, with simulations suggesting that a significant risk of an increase in carp biomass exists if recruitment cannot be controlled with a probability of 50% (Brown and Walker 2004). Therefore, the use of water level manipulations with the aim of reducing recruitment success may not be a high priority strategy within the carp control plan.

An alternative means to utilise water level manipulations as a carp control tool capitalises on carp's rapid behavioural response to floodplain inundation. Jones and Stuart (2009) report that carp are often the first species to enter inundated floodplain habitat and are the last fish species to evacuate the floodplain as water levels recede. Therefore, in particular locations, it may be possible to utilise environmental water allocations to deliberately inundate a floodplain to induce a lateral movement of carp out of the river channel, and then subsequently drain the floodplain to trap the carp, or to isolate the floodplain from the river and allow it to dry naturally.

However, both these strategies require detailed information on the specific locations where the water level manipulation strategies may be feasible, the support of State Water Corporation in order to implement them effectively, and approval for the non-consumptive use of water allocations or a specific carp control allocation negotiated from the Lachlan catchments environmental water allocation under the Water Sharing Plan. Further, any manipulation of water levels will require increased knowledge of native fish species inhabiting wetlands, and assessment of the potential impacts of the activity on native fish communities. Therefore, considerable planning, negotiation and consideration is required in order to make implementation of this strategy feasible. This is unlikely to be achieved within the period of the initial implementation phase, but should be considered for implementation as part of the longer term carp control plan.

8.1.8. Targeting drought refugia

The ongoing drought in the Lachlan Valley has resulted in the implementation of a critical water plan to preserve the available water for as long as possible. As of late October 2009, dam releases from Wyangala Dam have only been sufficient to provide flows to Condobolin. By the end of 2009, the Lachlan River downstream of Condobolin had ceased to flow and the river receded to a series of disconnected waterholes and weir pools. Although unfortunate from a social perspective, this scenario provides immense benefits for the carp control plan. In addition to reducing the carp population substantially, it poses opportunities for cost-effective targeted physical removal within drought refugia remaining within the river channel downstream of Condobolin (Roberts *et al.* 1997; and see chapter 5). Resources should be allocated to identifying those drought refugia that are likely to persist throughout the period of the critical water plan and to remove as many carp as possible from each.

8.2. Monitoring of carp impacts

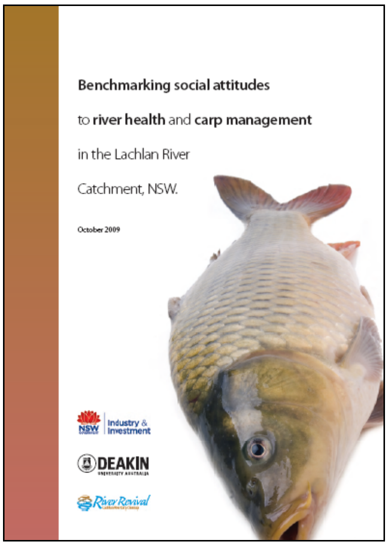
The establishment of national and local benchmarks for invasive animal impact, density and distribution (from which performance on delivery of all outcomes can be assessed) is one of the 13 goals of the Invasive Animals CRC and is particularly relevant for demonstration site projects such as the *River Revival – Lachlan River Carp Cleanup*. The monitoring program established during the benchmarking phase provides a scientifically robust and standardised assessment framework for the carp control plan. New data can be compared with that collected during the benchmarking phase (see chapter 2) via a BACI-style comparison of the before data versus similar sized blocks of data collected during the implementation stage (i.e., data from years 1 & 2 versus years 3 & 4 under the current IA CRC funding arrangement, or years 1 & 2 versus years 9 & 10 etc. if the project continues beyond 2011), or trend analyses can be undertaken using the full data set, with years since the beginning of the implementation phase as the independent variable within regression models. Given that it has been recommended that pest management targets should aim to minimise the impacts of established pest populations (Bomford and Tilzey 1997; Koehn *et al*. 2000; Koehn and MacKenzie 2004; Braysher 2007), a monitoring program such as the one developed is required in order to gauge progress towards that goal.

8.3. Ongoing communications plan

As a demonstration site project, a central component of the ongoing *River Revival – Lachlan River Carp Cleanup* is the ongoing implementation and development of the project's communications strategy (see appendix 5). Within the implementation phase of the project, particular emphasis will be on engaging the community of the Lachlan catchment and encouraging them to become involved with implementing aspects of the carp control plan wherever possible.

9. APPENDICES

APPENDIX 1: Benchmark social attitudes towards carp and their impacts

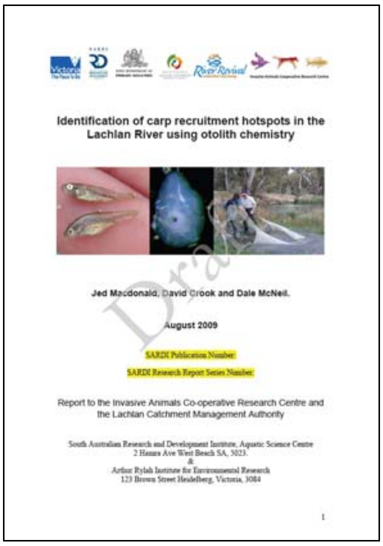


Wallis, A., Kelly, A., Salzmann, S., Gilligan, D. and Hartwell, D. (2009). Benchmarking social attitudes to river health and carp management in the Lachlan River catchment, NSW. Deakin University, Geelong, Australia.

Abstract

Carp, *Cyprinus carpio*, are a large freshwater fish native to Asia and considered a significant pest in Australia. The introduction of carp into Australian inland waters has raised serious concerns about the impacts the species is having on these aquatic systems and a strong interest in devising ways to manage carp populations. This paper reports on the analysis of responses from a survey conducted in the Lachlan River Catchment, NSW, which aimed to benchmark the community's perceived assessment of the health of the river, impacts of carp on that health and options for future management of carp in the river system. The research indicated that there is a general belief that the condition of the Lachlan is degraded and that the carp population is a contributing factor. There is also a perception that insufficient resources are being allocated to carp management. The survey results indicate the community will support carp management programs but that they will have certain expectations in terms of carp control and improving river features. The baseline data provides an insight into local opinions and expectations and can be a starting point for engaging the community to help manage carp in the Lachlan River Catchment.

APPENDIX 2: Use otolith micro-chemical analysis as a means of determining the relative contribution of hotspots within the system to the overall carp population within the lower Lachlan


Identification of carp recruitment hotspots in the Lachlan River using otolith chemistry

Jed Macdonald, David Crook and Dale McNeil.

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Macdonald, J., Crook, D. and McNeil, D.G. (2010), Identification of carp recruitment hotspots in the Lachlan River using otolith chemistry. Report to the Invasive Animals CRC and Lachlan CMA. SARDI Report Series, South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

Executive Summary

Fish otoliths (ear stones) are calcareous structures that develop as fish grow, forming layers, similar to an onion, with the central core produced during larval life with outer layers formed as fish grow. As such, otoliths are often used to age fish by counting the number of rings, which may be lain down in daily or annual rings similar to a tree. The chemical composition of each ring is believed to represent the environmental in which the fish lives, and therefore, as a fish moves between different habitats, the chemical composition of layers will also change to reflect the different habitats. The chemical composition at the core of the otolith should therefore reflect the nursery habitat in which the fish was spawned and lived out its early juvenile life.

The aim of this project was to determine wether chemical signatures could be identified within otoliths from common carp (*Cyprinus carpio*) that distinguish different nursery habitats across the Lower Lachlan Catchment. The identification of nursery wetland signatures in carp otoliths will enable managers to identify the source of adult carp across the Lachlan catchment and determine which areas are producing large numbers of carp and acting as recruitment hot-spots for the catchment.

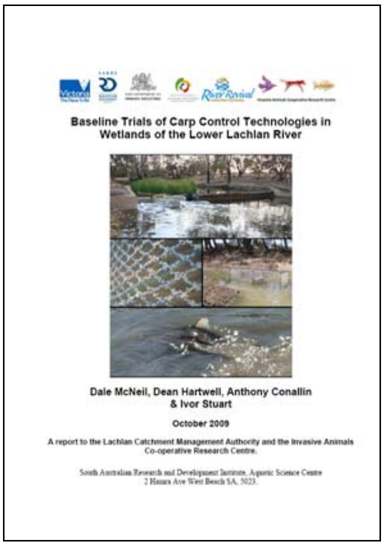
Furthermore, the successful suppression of carp populations through control actions, targeted towards hot-spot habitats should result in the decline of carp possessing signatures for those habitats. This information could then be used to determine the success or failure of control actions and to effectively capture the outcomes of investment by Natural Resource and Invasive Species managers.

Elemental ratios successfully discriminated carp from several nursery areas. However, elemental ratios alone, failed to discriminate successfully between carp from two geographically distinct nursery habitats at Lake Cargelligo and Mountain Creek. Analysis of isotopic ratios, however, did successfully distinguish between post larval carp from those two sites, but did not provide the excellent overall separation revealed through the elemental ratio analysis. It is suggested, therefore, that the combined analysis of elemental and isotopic ratios should be used for determining discrete chemical signatures for differentiate between nursery wetlands in the Lower Lachlan.

The analysis revealed that Lake Brewster and Lake Cargelligo were the most significant source of carp recruitment for the lower Lachlan during 2007/08 and other sites in the Lachlan, Mountain Creek and the Great Cumbung Swamp showed little evidence of spawning and/or recruitment over the study period. This pattern is linked to the availability of off channel habitat during the current drought and more sites are expected to ‘switch-on’ as recruitment sources once drought conditions have abated.

It is concluded that otolith chemical analysis can provide an extremely useful tool for supporting carp control programs and should be pursued as part of the ongoing Lachlan carp clean-up program. In particular, Sampling should target larger numbers of YOY fish and ensure that new habitats are surveyed for post-larval carp as soon as they become inundated, especially following the recent period of drought as spawning is predicted to respond strongly to the resumption of flows. Additionally, regular samples should continue to be taken from year to year to explore the issue temporal replicability of nursery specific otolith signatures.

APPENDIX 3: Field trials of carp trapping tools at Lake Brewster, Lake Cargelligo and the Great Cumbung Swamp


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

Dale McNeil, Dean Hartwell, Anthony Conallin & Ivor Stuart

October 2009

A report to the Lachlan Catchment Management Authority and the Invasive Animals Co-operative Research Centre.

South Australian Research and Development Institute, Aquatic Science Centre 2 Hamra Ave West Beach SA, 5023.

McNeil, D., Hartwell, D., Conallin, A. and Stuart, I. (2010). Baseline trials of carp control technologies in wetlands of the lower Lachlan River. Report to the Lachlan Catchment Management Authority and Invasive Animals CRC. SARDI Report Series, South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

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 Co-operative Research Centre (IA CRC) have committed to exploring technologies and methodologies for maximising the physical removal of carp.

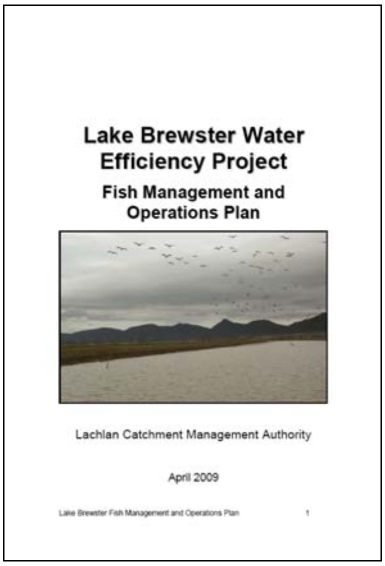
This project outlines the first steps in exploring control technologies targeted to specific hot-spot wetlands, where carp are known to breed in large numbers and contribute a disproportionally high numbers to the overall catchment population. In particular, the use of carp separation cages (CSCs), and 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 turn-around facility was not comprehensively assessed. Other data including native fish patterns, auditory cues and an exploration of the commercial utilisation from 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.

APPENDIX 4: Development of a carp management plan for Lake Brewster in concert with current water resource development within the storage


Lake Brewster Water Efficiency Project

Fish Management and Operations Plan

Lachlan Catchment Management Authority

April 2009

Lake Brewster Fish Management and Operations Plan 1

McNeil, D., Stuart, I. and Thurtell, L. (2009). Lake Brewster Water Efficiency Project: Fish Management and Operations Plan. Lachlan Catchment Management Authority, Forbes. 52 pp.

Executive Summary

Lake Brewster, as a nationally significant wetland, is recognised as a wildlife reserve and provides a habitat for waterbirds and native fish. However, as a result of inappropriate land use and water regime management, the ecological health of the Lake has been deteriorating over a number of years. The Lake Brewster Water Efficiency Project has been implemented to improve the water quality, hydraulic efficiency and wetland environment within the Lake and to improve the quality and biological benefit of water released to the Lower Lachlan Catchment.

Along with adaptive land and water management plans for the newly configured Lake, a management plan for fish is an important component in the restoration of Lake Brewster. The objective of the Lake Brewster Fish Management and Operations Plan is to ensure that suitable habitat for the survival, spawning and recruitment of native fish, as well as opportunities for fish passage and migration between the lake and the wider Lachlan Catchment are provided within Water Efficiency Project. A key factor in restoring healthy wetlands, water quality and native fish communities within the lake is the control of introduced carp.

Operational procedures regarding the filling and draining of the lake, as well as the protocols used for moving water between lake units will be critical in restoring and maintaining healthy populations of native fishes within the Lake and adjacent reaches of the Lachlan River. Recent research also suggests that these operational protocols will be critical in controlling pest carp populations within the Lake.

The operation of regulating structures, such as undershot weirs, is critical to facilitating the movement of native fishes into and out of the lake. By carefully managing gate opening heights, tailwater depths and regulator water velocities, fish passage can be maximised and fish deaths caused by the structures minimised.

The aim of the present plan is to restore native fish populations by promoting suitable aquatic habitat and spawning sites as well as seasonal flow related exit and entry opportunities. This will be achieved through flow management, provision of essential habitat and ecosystem processes (such as food webs) and carp control. The specific strategies to improve native fish communities can be summarised as:

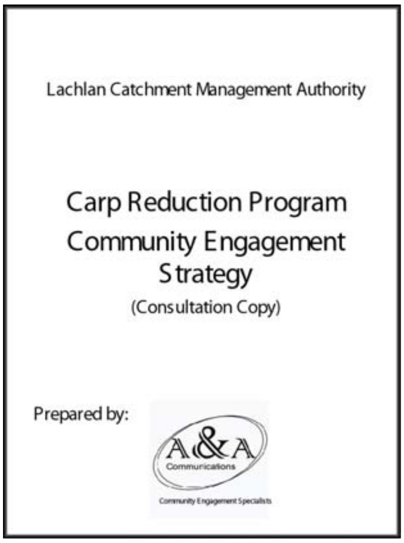
- To the greatest practical extent prevent adult carp from entering Lake Brewster.
- Exploit opportunities to trap carp at key sites in Lake Brewster.
- Create or facilitate critical hydrological events that maximise habitat and food availability for native fish.
- Facilitate key hydrological elements that trigger movement, breeding and recruitment of native fish.
- Create or facilitate critical hydrological events that trigger safe native fish movement between Lake Brewster and the Lachlan River.

To facilitate these strategies, this plan has addressed a number of key management units within the Lake and high priority management actions have been summarised for each of these units. An operations calendar has also been developed as a reference to assist on-ground staff in implementing the plan’s objectives and to maximise the long term viability of Lake Brewster as a healthy wetland supporting a strong community of native fishes.

We advocate that an adaptive management strategy be put in place in close consultation with fish and fisheries expertise. This strategy must incorporate effective monitoring and documentation of wetland operations and the impacts and effects that these operations have on native and pest fish populations, as well as wetland ecosystem health within the Lake.

By restoring and actively facilitating key habitat, life cycle, and migrational requirements of native fish combined with high impact carp control actions, Lake Brewster can be restored as a principal native fish refuge for the critically endangered lower Lachlan ecological community (EPBC Act 1999) and contribute significantly to the sustainability of fish populations in the Lachlan River Catchment.

APPENDIX 5: Development of a formal communications plan for the project


Lachlan Catchment Management Authority

Carp Reduction Program
Community Engagement
Strategy
(Consultation Copy)

Prepared by:

A & A Communications (2007), Carp reduction program community engagement strategy. Lachlan Catchment Management Authority, Forbes. 49 pp.

Project Overview

The Lachlan Catchment Management Authority (LCMA) has initiated a carp eradication program in response to the community identifying carp as a major issue impacting on water quality and native fish in the Catchment. The project is a partnership with key organisations and aims to improve the water quality and sustainability of the Catchments waterways.

The project has secured funding until June 2008 from the Invasive Animal Cooperative Research Centre Ltd (CRC), with an option for an additional further three years.

The project aims to reduce the density of carp in the Lachlan river system and other waterways within the Catchment through the implementation of applied research and community engagement activities.

The project is specifically targeting:

- The lower reaches of the Lachlan River
- Lake Brewster
- Lake Cargelligo
- Lake Cowal
- The Great Cumbung Swamp

There are a range of methods being used to harvest carp in this project. They are all in accordance with the Prevention of Cruelty to Animals Act and have been endorsed by an Animal Ethics Committee.

This Community Engagement Strategy outlines a range of communication activities for the initial two years of the project. The activities will raise the awareness of the project with the Lachlan

Catchment community and engage them to participate in some of the key communication initiatives. It also addresses the issues of internal communication within the LCMA, with project partners and the wider community of NSW.

The Strategy aligns with the Lachlan Catchment Action Plan (LCAP) and aims to meet several Catchment, Management and Natural Resources Commission (NRC) targets.

It is considered that implementing the Strategy in its entirety will gain the LCMA the maximum benefits, however there is scope to modify the components to be consistent with budget restrictions.

APPENDIX 6: Facilitate community engagement by attendance at and sponsorship of community carp – muster events

River Revival
Lachlan River Carp Cleanup

Community Engagement
Benchmarking Phase 2007 – 2009

Michelle Jefferies – Lachlan Catchment Management Authority

The Lachlan River Carp Cleanup is a collaborative project funded by the Lachlan Catchment Management Authority and the Invasive Animals Co-operative Research Centre, with components lead by the Lachlan CMA, I&I NSW and SARDI Aquatic Sciences. The project aims to utilise available control technologies to reduce the impact of carp within the Lachlan catchment and incorporates strong community involvement.

With existing community networks and expertise the Lachlan CMA was identified as being ideally positioned to develop and implement the engagement strategy for the Lachlan River Carp Cleanup. A local communication expert was engaged to compile an overall strategy for the engagement program and implementation commenced following the survey of community attitudes undertaken on behalf of the Carp Cleanup by Deakin University. Commencement was delayed to avoid confounding the results of this survey.

The main objective of the strategy is to inform the Lachlan Catchment community and the wider community of the carp reduction project, engage them to participate and acknowledge the contribution of all project partners.

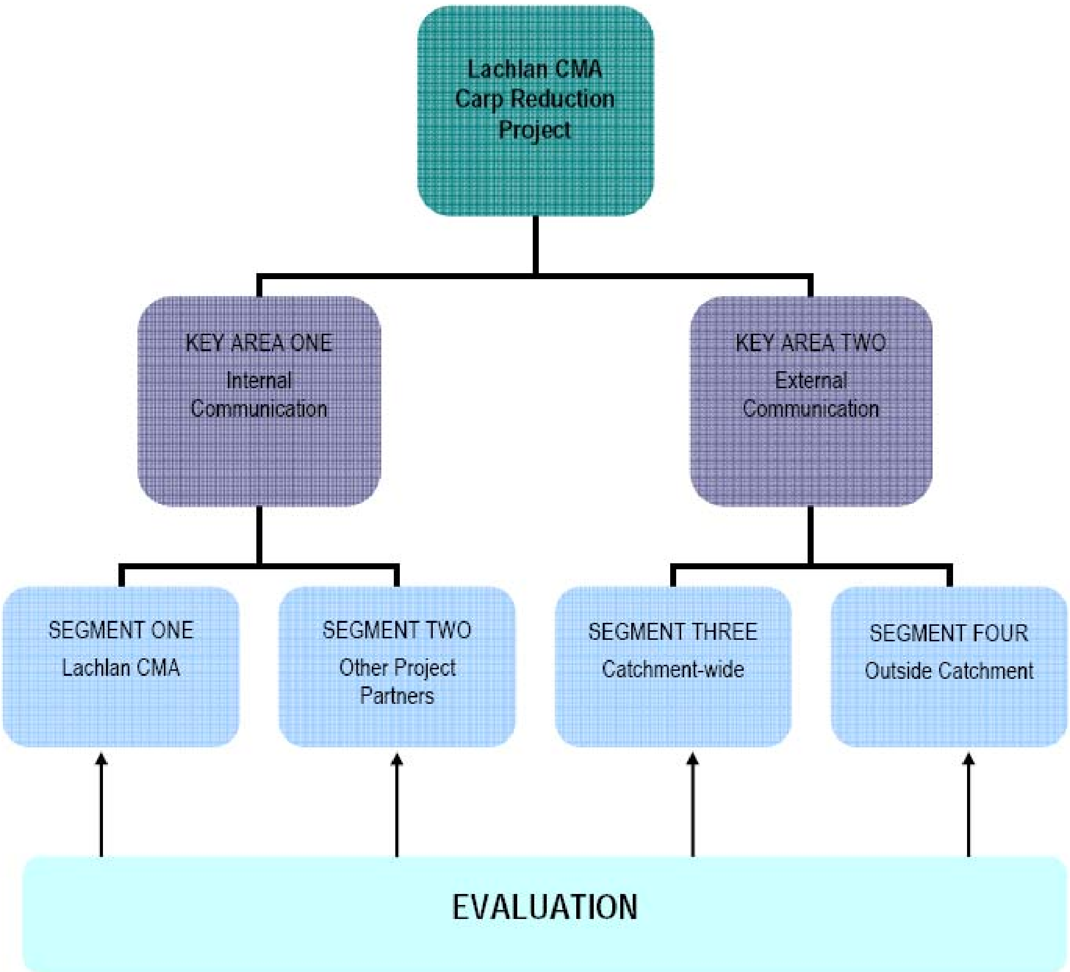
It also aims to:

1. Increase the awareness of the project with LCMA staff, the LCMA management board and other key stakeholders (e.g., project partners).
2. Increase awareness of the project within the Lachlan Catchment community.
3. Engage the Lachlan Catchment community in participating in the project.
4. Raise the awareness of the project with other interest groups (e.g., recreational anglers and Scouts) and engage them in participating in the project.
5. Raise awareness of the project with the wider community outside the Lachlan Catchment.

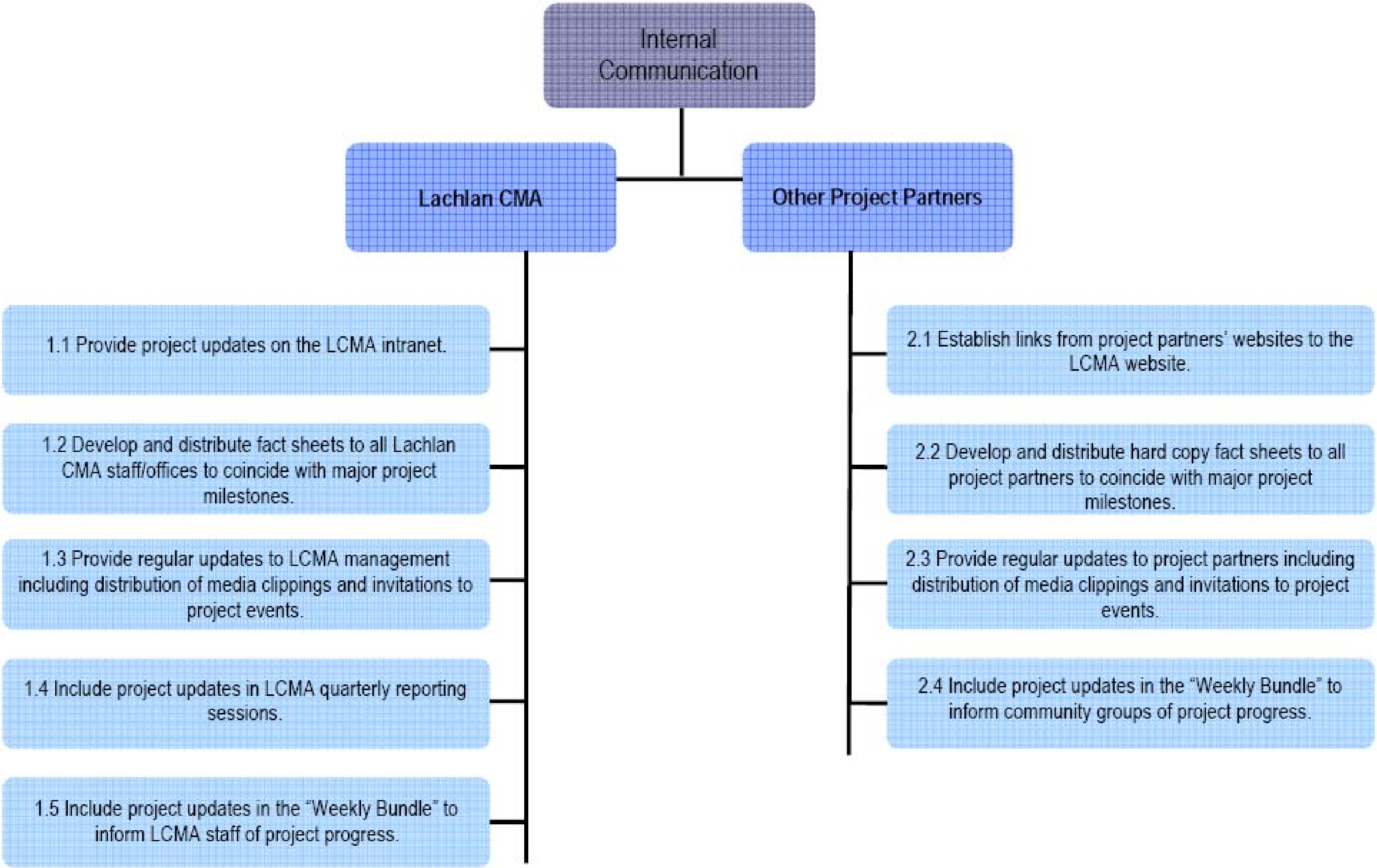
The primary target audience of the Strategy is the 106,000 residents living in the Lachlan Catchment. However, there are more specific groups that the Strategy targets. These are:

- Lachlan CMA staff and management board.
- Project partners.
- Project Steering Committee and Community Reference Group.
- 25 Local Government Areas within the Lachlan Catchment.
- Catchment schools.
- Indigenous groups.
- Recreational anglers.
- Community groups.
- Local and regional media outlets.
- Specialty media.

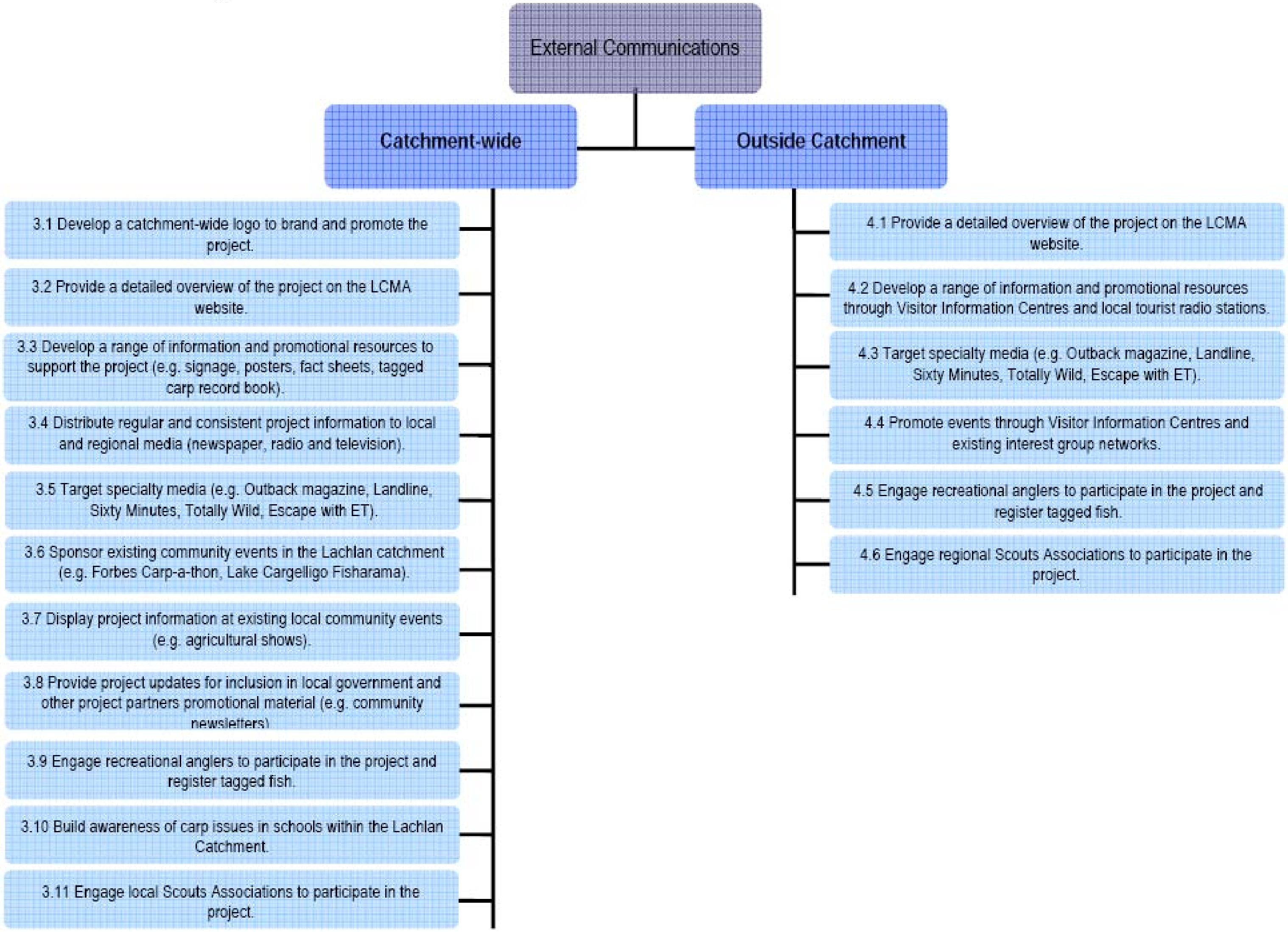
Community Engagement Strategy Overview:



Internal Communication – Breakdown of key activities:



External Communication – Breakdown of key activities:



It should be noted that a number of the activities detailed in the strategy do cross target segments and are used for multiple purposes.

Implementation began with the development of a logo and assorted merchandise, including caps, beanies, drink coolers, polo shirts, fishing record cards, business cards, posters, informational fliers, tote bags, fishing lures, fridge magnets and pens. All merchandise was badged with the *River Revival – Lachlan River Carp Cleanup* logo, and where practical, partner logos as well.

Examples of products developed for use in promoting the River Revival Carp Cleanup

Design and construction of the *River Revival – Lachlan River Carp Cleanup* display trailer was completed in early 2008. The trailer has two small display tanks that usually house small bodied native fish, as well as one large tank usually displaying carp, goldfish and sometimes large bodied native fish. The trailer also has a small television and DVD player on which news stories and Carp Cleanup information can be shown. There are also three large display boards built into the trailer which provide ample space for display of project materials and handouts. Another popular component of the *River Revival* trailer equipment is the scale model Carp Separation Cage, built by Gary McLean of I&I NSW.

Colin the Carp being admired at the Hillston Hook Line and Sinker Fishing Festival

Hillston locals learning how Carp Separation Cages operate

While a key activity put forward under the strategy was the initiation of and/or support of existing, recreational fishing events targeting carp, a number of other communication activities have been held since the completion of the Community Attitudes survey. A summary of the events supported in the benchmarking phase is below:

Event	Date	Location	Event Description	River Revival Contribution	Attendance
Carp Cleanup Team Meeting 2007	26 – 28th June 2007	Hillston and surrounds	Internal Communication and engagement of key community members – attended by LANRMG* representative.	Staff attendance, electrofishing demonstration, venue and catering.	20 project partner / collaborator representatives
Condo carp caper – part of the Native Fish Strategy Awareness Week	19th May 2008	Condobolin	Event initiated by Native Fish Strategy, Community information session.	Electrofishing demonstration, River Revival Trailer and staff.	30 community members
Carp Cleanup Team Meeting 2008	21 – 22nd May 2008	Forbes	Internal Communication and engagement of key community members – attended by LANRMG* representative.	Staff attendance, River Revival Trailer, venue, catering, accommodation and transport.	25 project partner / collaborator representatives
Hillston Hook Line and Sinker Fishing Festival	28 – 31st August 2008	Hillston	Community Recreational Fishing Event with carp target section.	$700 cash sponsorship of carp section prizes, River Revival merchandise for minor prizes, River Revival Trailer on display for 4 days and staff in attendance for 1 day.	450 participants
Hillston Agricultural Show	27th September 2008	Hillston	Community Event initiated by Agricultural Show Society, project information distribution opportunity.	River Revival Trailer and staff attendance.	100 community members
Lake Cargelligo Fishermen	October 2008	Lake Cargelligo	Community Recreational Fishing Event with carp target section.	Provision of drink coolers, hats and tote bags for registration prizes.	150 participants
Booligal Carp Fishing Competition	28th March 2009	Booligal	Landcare event targeting carp only.	$1000 cash sponsorship, River Revival merchandise for minor prizes, River Revival Trailer on display for 4 days and staff in attendance for 1 day, Commercial carp utilisation display and cooking demonstrations, administrative support.	100 participants
Carp Cleanup Team Meeting 2009	7th April 2009	Lake Cargelligo	Internal Communication and engagement of key community members – attended by LANRMG* reps and Lake Cargelligo Wetlands Council representatives.	Staff attendance, venue, catering, accommodation.	20 project partner / collaborator representatives

Promotion of the Carp Cleanup has also generated media coverage during the benchmarking phase. A summary of print, radio and television media coverage is below.

Media	Outlet	Date	Title	Editorial/Advert
Print	Western Division Newsletter	1/11/2006	Working Group Formed to Target European Carp	Editorial
Print	Western Division Newsletter	1/11/2007	Lachlan River Carp Cleanup	Editorial
Print	Western Magazine	3/12/2007	Rare Fish Captured	Editorial
Print	Southern Weekly	10/12/2007	Endangered fish found in the Lachlan River	Editorial
Print	The Land	15/05/2008	Have your say in the Lachlan!	Advertisement
Print	Narrandera Argus	11/12/2007	Endangered fish found in the Lachlan River	Editorial
Print	Area News	19/12/2007	Perchlet not MIA in MIA	Editorial
Print	The Land	13/12/2007	Near-extinct fish back from the brink	Editorial
Print	The Land	15/05/2008 & 25/05/2008	Have your say in the Lachlan!	Advertisement
Print	The Rural	15/05/2008 & 22/05/2008	Have your say in the Lachlan!	Advertisement
Print	Southern Weekly	19/05/2008 & 26/05/2008	Have your say in the Lachlan!	Advertisement
Print	Western Magazine	19/05/2008 & 26/05/2008	Have your say in the Lachlan!	Advertisement
Print	Hillston Spectator	12/12/2007	Endangered fish found in the Lachlan River	Editorial
Television	Win News Wagga Wagga	Jan 08	Drought Impacts and Hotspots for Carp Breeding	Editorial
Print	Uptake Update	Aug 07	Targeted Carp Control options for the Lower Lachlan Catchment	Editorial
Radio	ABC Radio Central West/Western Plains	26/03/2009	Island Bend WCSC	Interview
Print	Fish	Jun 09	Lachlan Trial for Carp Removal	Editorial

For the purposes of the communications strategy, the Implementation Phase of the Carp Cleanup commenced with the official launch of the project on 16th September 2009. It is expected that much greater media coverage and wider community exposure will be forth coming as more carp control works and actions are implemented across the Lachlan catchment.

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