The Distribution and Abundance of Fish in the Lake Cargelligo system, New South Wales

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Certificate of Authorship

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Adam Kerezsy June 2005

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Natural resource management in NSW is currently characterised by a plethora of plans, strategies, blueprints and objectives, and administered by a bevy of agencies with changing names and seemingly on-going re-structures. Unfortunately, the fundamental step of actually finding out what's hanging around requiring management sometimes appears to be left out, so I sincerely hope this study is of some use to the governments, agencies, councils and individuals who look after the Lachlan River and Lake Cargelligo.


(Photo by Mick Brigden)

Abstract

This study surveyed the fish communities within different areas of the Lake Cargelligo system, an off-river storage in the lower Lachlan catchment in western New South Wales. Sampling was undertaken in spring 2004 and summer 2005 in four areas within the Lake Cargelligo system, comprising two canals (Canal 1 and Canal 2) and two lakes (Lake Curlew and Lake Cargelligo). Three replicate sites were sampled in each area. Water quality was also sampled at each site in each season, and a habitat assessment was undertaken. The study was carried out during a prolonged drought, and the Lake Cargelligo system was at 21.9% of full capacity in spring 2004 and at 7% of full capacity in summer 2005. There was no connection between the Lake Cargelligo system and the Lachlan River through either the inlet or outlet canals during the study period.

The results of this study were compared to previous fish surveys in the Lachlan catchment, and fish community composition was compared between the different areas within the Lake Cargelligo system. Comparisons of fish abundance were also made between spring and summer, and the recruitment of fish species within the system was investigated.

A total of 3223 individual fish were sampled. Twelve described species were recorded, and up to three species of undescribed carp gudgeons (*Hypseleotris* spp.) were also present. The Lake Cargelligo system was found to contain all species previously sampled in the lower Lachlan catchment except Murray cod

(*Maccullochella peelii*) and Agassiz's glassfish (*Ambassis agassizii*). Within the Lake Cargelligo system, seven species were found in Canal 1 and Lake Cargelligo, and eleven species were found in Lake Curlew and Canal 2. Lake Curlew and Canal 2 contained more in-stream cover than Canal 1 and Lake Cargelligo, and this may explain the greater number of species in these areas. The summer sampling period yielded 79.8% of all caught and observed fish, and western carp gudgeon (*Hypseleotris klunzingeri*) were the most commonly sampled species. Immature fish of all species except fly-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Australian smelt (*Retropinna semoni*) and freshwater catfish (*Tandanus tandanus*) were sampled, indicating that the recruitment of many species occurs within the Lake Cargelligo system and that recruitment is not necessarily related to connectivity with the Lachlan River.

The Lake Cargelligo system should be managed to conserve areas of higher conservation value such as Lake Curlew and Canal 2, as it is in these areas that declining species such as freshwater catfish, silver perch (*Bidyanus bidyanus*) and fly-specked hardyhead were sampled.

Contents

List of Tables

List of Figures

Abbreviations

DPI……………………………………….Department of Primary Industries (NSW)

DSNR…………………………..Department of Sustainable Natural Resources (NSW)

EHN……………………………………………Epizootic Haematopoietic Necrosis

EPA………………………………………...Environment Protection Authority (NSW)

LCMB………………………………………...Lachlan Catchment Management Board

mg/L…………………………………………………………..milligrams per litre

mS/cm…………………………………………………..millisiemens per centimetre

MDBC………………………………………….. .. Murray Darling Basin Commission

NTU…………………………………………………Nephelometric Turbidity Units

SL………………………………………………………………...Standard Length

TL ………………………………………………………………… Total Length

1. Introduction

1.1 Distribution and abundance of fish in western New South Wales

All waterways west of the Great Dividing Range in New South Wales occur within the Murray-Darling Basin with the exception of the far north-western corner of the state which forms part of the Bulloo-Bancannia division (Allen *et al*. 2002). The Murray-Darling Basin drains an area of 1.073 million square kilometres (Humphries *et al*. 1999) and occupies portions of Queensland, New South Wales, Victoria and South Australia.

Australia's long isolation from the other continents has resulted in a highly endemic freshwater fish fauna (Darlington 1957), and the comparative lack of geological events facilitating colonisation across barriers has contributed to more localised endemism within drainage divides (Unmack 2001). The relatively stable prehistory of Australia's native wildlife is supported by the fossil fish record, with ancestral *Macquaria* spp. and Terapontid fishes found in Eocene deposits and fossil *Maccullochella "maquariensis"* found in Miocene deposits (Unmack 2001).

The majority of fish families occurring in western New South Wales have evolved from marine ancestors (Darlington 1957). Up until 6 million years ago, the south-western part of the Murray-Darling Basin was inundated by the sea (Bowler 1990), thus representing the most recent colonisation opportunity for marine species of fresh waters in southern Australia. Following the retreat of the sea to the south-west, Lake Bungunnia, a freshwater lake with an area of 33,000 square kilometres and covering current areas of western New South Wales, north-western Victoria and eastern South Australia (Bowler 1990), is likely to have facilitated evolution and dispersal of species throughout the Murray-Darling Basin until about 500,000 years ago. The most recent opportunity for colonisation and movement of fish species within western New South Wales occurred about 50,000 – 25,000 years ago, when periodically wetter conditions filled the lakes and waterways of western New South Wales (Vickers-Rich 1993). It is therefore likely that the native fish species present in the area have remained generally unchanged for at least the last 25,000 years. In contrast, alien fish species have colonised the rivers of western New South Wales only in the period since European settlement in Australia.

There are approximately 30 native[1] and 10 alien fish species recorded from river systems in western New South Wales (Table 1). This low number of native species has sometimes been described as impoverished when compared with extensive river systems in other parts of the world (Allen 1989), however it has also been described as appropriate when Australia's dry climate is taken into account (Gehrke & Harris 2000). Only 9 of the 30 native fish species in western New South Wales are widespread and abundant, with the remainder either in decline or formally listed as endangered or vulnerable (Table 1). In contrast, of the 10 alien fish species occurring in inland waterways of New South Wales, 6 species are both widespread and abundant (Table 1).

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[1] It is difficult to be precise about the number of fish species in the Murray-Darling Basin and western New South Wales due to taxonomic uncertainty regarding some families, most noticeably the Eleotridae. See Appendix 1 for a more detailed explanation of the Atherinidae, Ambassidae and Gobiidae/Eleotridae families. .

Table 1. Fish species occurring in rivers draining west of the Great Dividing Range in New South Wales. Information relating to the current distribution and abundance of each species is provided, and collated from Allen *et al.* (2002), Murray-Darling Basin Ministerial Council (2003) and NSW Fisheries (2005a).

Family	**Species**	**Common Name**	**Distribution**	**Abundance/ Conservation Status**
Mordaciidae	*Mordacia mordax* **(native)**	Shortheaded lamprey	Lower reaches of the Murray River.	Moderately abundant – probably declining due to migration barriers
Geotriidae	*Geotria australis* **(native)**	Pouched lamprey	Lower reaches of the Murray River.	Unknown - probably declining due to migration barriers
Clupeidae	*Nematalosa erebi* **(native)**	Bony bream	Widespread in slopes and lowlands	Abundant
Galaxiidae	*Galaxias brevipinnis* **(native to Australia but not western NSW)**	Climbing galaxias	Western population spread to the Murray through Snowy River scheme	Not naturally occurring west of the Great Dividing Range.
Galaxiidae	*Galaxias olidus* **(native)**	Mountain galaxias	Widespread both sides of Great Dividing Range at altitude.	Locally abundant
Galaxiidae	*Galaxias rostratus* **(native)**	Murray jollytail	South-western NSW	Endangered
Salmonidae	*Salmo trutta* **(alien)**	Brown trout	Cold-water environments such as deep reservoirs or at altitude.	Self-sustaining populations are established.
Salmonidae	*Salmo salar* **(alien)**	Atlantic salmon	Burrinjuck Dam and Lake Jindabyne	Populations maintained through stocking
Salmonidae	*Salvelinus fontinalis* **(alien)**	Brook trout	Lake Jindabyne and some high altitude streams.	Population generally maintained by stocking.
Salmonidae	*Oncorhynchus mykiss* **(alien)**	Rainbow trout	Cold-water environments such as deep reservoirs or at altitude.	Self-sustaining populations are established.
Retropinnidae	*Retropinna semoni* **(native)**	Australian smelt	Widespread	Abundant
Cyprinidae	*Carassius auratus* **(alien)**	Goldfish	Widespread	Abundant
Cyprinidae	*Cyprinus carpio* **(alien)**	Carp	Widespread	Abundant
Cyprinidae	*Tinca tinca* **(alien)**	Tench	Widespread	Occasionally abundant
Plotosidae	*Tandanus tandanus* **(native)**	Freshwater catfish	Widespread but declining.	Becoming scarce.
Plotosidae	*Neosiluris hyrtlii* **(native)**	Hyrtl's tandan	North-western New South Wales	New South Wales represents south-eastern distributional limit.
Cobitidae	*Misgurnus anguillicaudatus* **(alien)**	Oriental weatherloach	Widespread but localised	Locally abundant
Poeciliidae	*Gambusia holbrooki* **(alien)**	Gambusia	Widespread	Abundant
Atherinidae	*Craterocephalus amniculus* **(native)**	Darling River hardyhead	Upper tributaries of the Darling River.	Restricted
Atherinidae	*Craterocephalus fluviatilis* **(native)**	Murray hardyhead	Reduced to Victorian lakes – threatened.	Endangered Vulnerable (EPBC)**
Atherinidae	*Craterocephalus stercusmuscarum fulvus* **(native)**	Flyspecked hardyhead	Widespread in the north but rare in the south.	As per distribution
Melanotaeniidae	*Melanotaenia fluviatilis* **(native)**	Crimsonspotted rainbowfish	Widespread	Relatively common
Ambassidae	*Ambassis agassizii* **(native)**	Agassiz's glassfish	Previously presumed to be widespread but now rare.	Endangered*

Percichthyidae	*Macquaria ambigua* **(native)**	Golden perch	Widespread	Declining
Percichthyidae	*Macquaria australasica* **(native)**	Macquarie perch	Restricted to cooler upper reaches, from Lachlan River tributaries southwards – threatened.	Vulnerable and protected. Endangered (A.C.T.) Endangered (EPBC)**
Percichthyidae	*Macchullochella peelii* peelii **(native)**	Murray cod	Widespread but fragmented.	Declining. Endangered (EPBC)**
Percichthyidae	*Machullochella macquariensis* **(native)**	Trout cod	Threatened. Two populations exist, but one has been translocated.	Endangered and protected. Endangered (A.C.T.) Endangered (EPBC)**
Terapontidae	*Leiopotherapon unicolour* **(native)**	Spangled perch	North of Balranald area	Locally abundant
Terapontidae	*Bidyanus bidyanus* **(native)**	Silver perch	Widespread but declining – threatened.	Vulnerable Endangered (A.C.T.)
Nannopercidae	*Nannoperca australis* **(native)**	Southern pygmy perch	Reduced distribution in Murray and Murrumbidgee systems – threatened.	Vulnerable
Percidae	*Perca fluviatilis* **(alien)**	Redfin perch	Widespread	Locally abundant
Gadopsidae	*Gadopsis marmoratus* **(native)**	River blackfish	Slope sections of western-flowing streams	Declining
Gadopsidae	*Gadopsis bispinosus* **(native)**	Two-spined blackfish	High country streams from A.C.T. south to the Murray	Locally abundant, vulnerable in A.C.T.
Gobiidae	*Philypnodon grandiceps* **(native)**	Flathead gudgeon	Widespread	Locally abundant
Gobiidae	*Philypnodon sp. 1* **(native - undescribed)**	Dwarf flathead gudgeon	Murray River and Bathurst area – also coastal	Coastal populations abundant
Gobiidae	*Mogurnda adspersa* **(native)**	Southern purple-spotted gudgeon	Patchy distribution throughout western New South Wales – threatened.	Endangered*
Gobiidae	*Hypseleotris klunzingeri* **(native)**	Western carp gudgeon	Widespread	Abundant
Gobiidae	*Hypseleotris sp. 1* **(native - undescribed)**	Midgely's carp gudgeon	Widespread	Common
Gobiidae	*Hypseleotris sp. 2* **(native - undescribed)**	Lake's carp gudgeon	Widespread	Common
Gobiidae	*Hypseleotris sp.3* **(native - undescribed)**	Murray-Darling carp gudgeon	Possibly widespread (recently discovered)	Possibly common (recently discovered)

* Endangered populations of Agassiz's glassfish and purple-spotted gudgeon are the western populations only – ie: those occurring west of the Great Dividing Range, as these species also occur in the eastern drainages.

** Species listed as endangered under the Commonwealth Environment Protection and Biodiversity Act 1999.

1.2 Factors affecting fish distribution and abundance in western New South Wales

Factors that may have an influence on the distribution and abundance of fish in western New South Wales include the impact of alien species, commercial fishing, declining water quality, the amount of in-stream and riparian cover, siltation, unnatural flow regimes and barriers to movement.

Alien fish species are thought to impact upon native species through competition for food and habitat, predation and the introduction of diseases (Fletcher 1986; Ross 1991). However, making an assessment of the direct impacts of alien species is often complicated by an absence of pre-disturbance data (Ross 1991; Crivelli 1995), and the presence of alien populations often provides no clear evidence leading to the decline or extinction of indigenous species (Arthington 1991; Crivelli 1995). Within western New South Wales, this situation is made more problematic as colonisation by alien species has most often occurred in areas which are already degraded and affected by environmental alterations (Arthington 1991). An example of a direct threat caused by alien fish is the redfin perch EHN virus. Both Macquarie perch and silver perch have been demonstrated to be susceptible to this disease (Rowland & Ingram 1991).

Commercial fishing has been implicated in the decline of native fish species in the Murray-Darling Basin (Merrick & Schmida 1984; Allen *et al.* 2002). Commercial fishing in inland New South Wales was practiced from at least the 1880s until the termination of the inland fishery in September 2001 (NSW Fisheries 2005c). The tonnage of Murray cod, silver perch and freshwater catfish caught by commercial fishers all declined from 1948 until the 1980s (Reid *et al.* 1997), and the impact of recreational and illegal fishing has also been implicated in the decline of the larger native species (Rohan 1988; NSW Fisheries 2005b).

Deteriorating water quality has been associated with the decline of native fish species in western New South Wales, and increased phosphorus and nitrogen loads are suggested as main factors leading to the degradation of waterways and fish habitat (Gehrke *et al.* 2003). Pollution, such as pesticides and herbicides, have been proven to accumulate in the flesh of native fish (Mackay & Shafron 1988), and fish kills have been linked to toxic releases of dam water (Cadwallader & Lawrence 1990) and chemical contamination (Lugg 2000). Studies have confirmed that releases of unseasonally cold water from deep impoundments directly affects the survival chances of native fish species (Astles *et al.* 2003).

Land-clearing and agricultural practices on land adjacent to or draining to rivers in western New South Wales has contributed to a loss of riparian shelter, a decrease in stream-bank stability, a reduction in the filtering ability of riparian vegetation and increased sediment loads (Faragher & Harris 1994). In the Murray-Darling Basin, it is estimated that 60% of river channels carry sediment loads derived from river bank and gully erosion 20 times higher than pre-European settlement levels (Gehrke *et al.* 2003). Siltation of fish habitat and recruitment sites has been linked with the decreased distribution and abundance of many species, including golden perch and Murray cod (Cadwallader 1979), Macquarie perch (Harris & Rowland 1996) and the river blackfish (Jackson *et al.* 1996). Removal of in-stream cover has also been implicated in the destruction of habitat for native species (Cadwallader 1978; Cadwallader & Lawrence 1990; Crook & Robertson 1999), and increases in nutrient levels, salinity, turbidity and the ponding of stretches of river through regulation have been associated with the decline of aquatic macrophytes (Sainty & Jacobs 1990).

Altered flow regimes associated with river regulation are thought to impact upon the spawning and recruitment success of many fish species in the rivers of western New South Wales, as large flooding events have been positively associated with the recruitment behaviour of several species (Pierce 1988), and the floodplain environment is often linked with the success of larval and juvenile fishes (Geddes & Puckridge 1988). Physical barriers such as dams, weirs and locks are impediments to fish movement within all regulated rivers in western New South Wales, and long-distance migration has been associated with the spawning and dispersal of species such as golden perch and silver perch (Reynolds 1983; Mallen-Cooper *et al.* 1995), and more recently at localised scales for smaller species (Baumgartner 2004). Although native species also spawn in low-flow environments (Humphries *et al.* 1999; King *et al.* 2003), the abundance of alien fish in the rivers of western New South Wales suggests that the altered flow regimes may be highly favourable to their ecological requirements (Walker *et al.* 1995; Koehn 2004).

1.3 The riverine environment and the status of fish in the Lachlan catchment

The Lachlan catchment is in the southern Murray-Darling Basin (Figure 1) and both the riverine environment and the fish community are considered to be in a degraded condition (NSW EPA 1999a; NSW EPA 1999b; Growns 2001). Storage reservoirs such as Wyangala Dam, which was constructed in 1935, Lake Cargelligo (constructed in 1902) and Lake Brewster (constructed in 1952) are used to regulate flows in the Lachlan River (Water Conservation and Irrigation Commission 1971). High levels of salinity and nutrient concentrations have been detected in the Lachlan catchment (NSW DSNR 2003a; NSW DSNR 2003b), and the degradation of riparian areas and streambanks has been linked to increasing turbidity (NSW DSNR 2003a). Anecdotal records suggest that both goldfish and redfin perch have been present in the Lachlan River since the early 20th century (Roberts & Sainty 1996), and that turbidity increased following the population spread of the Boolara strain of carp in the early

1970s (Roberts & Sainty 1996). Surveys of fish communities in the Lachlan River have been previously conducted by Llewellyn (1983), Harris and Gehrke (1997), Growns (2001) and the MDBC (2004)(Table 2).

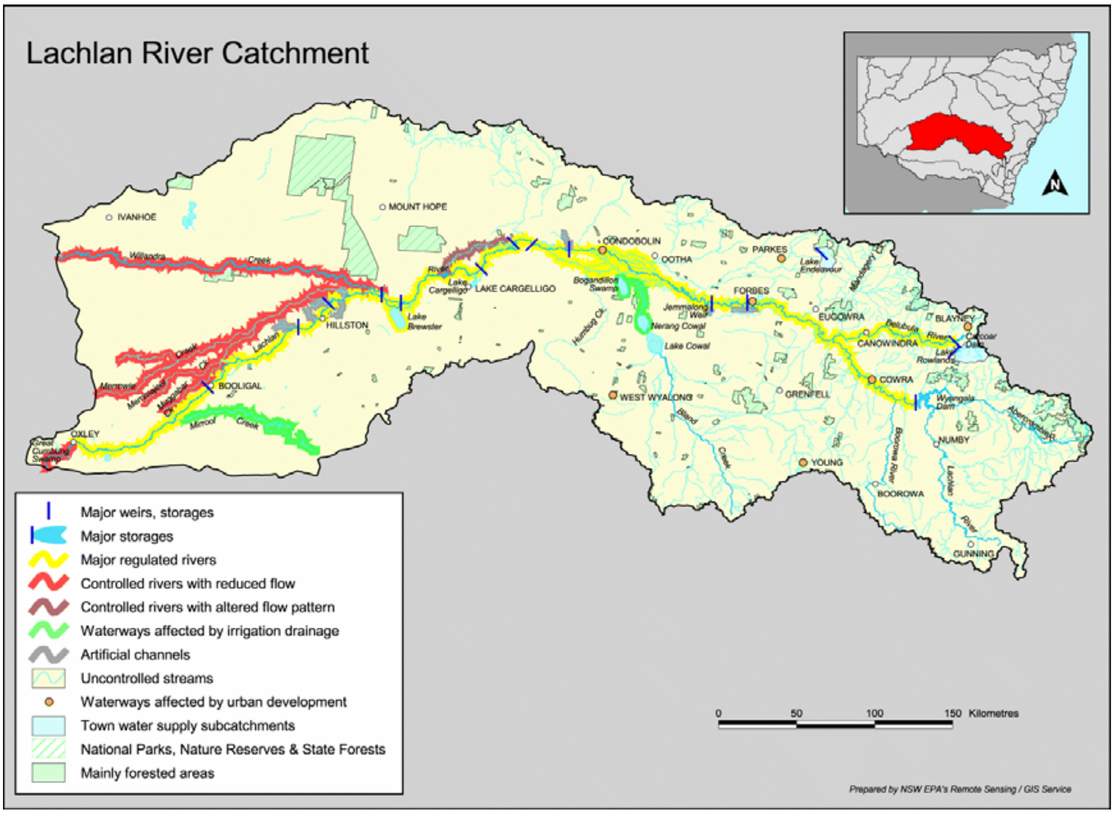

Figure 1. The Lachlan catchment (Source: NSW EPA 2005)

Table 2. Fish species recorded in the Lachlan River (main channel and creeks) in surveys by Llewellyn (1983), Harris & Gehrke (1997), Growns (2001) and MDBC (2004).

Common name	1983 Llewellyn	1997 Harris & Gehrke	2001 Growns	2004 MDBC
Rainbow trout	●	●		●
Brown trout	●	●	●	●
Australian smelt	●	●	●	●
Mountain galaxias	●	●		●
Goldfish	●	●	●	●
Carp	●	●	●	●
Freshwater catfish	●		●	
Gambusia	●	●	●	●
Fly-specked hardyhead	●			
Agassiz's glassfish	●			
Macquarie perch	●	●		
Murray cod	●		●	●
Golden perch	●	●	●	●
Bony bream		●	●	●
Silver perch	●	●		
River blackfish			●	
Redfin perch	●	●	●	●
Carp gudgeons	●	●	●	●
Flathead gudgeon	●	●	●	●
TOTALS	**17**	**14**	**13**	**13**

In the 2001 survey (Growns) only boat electrofishing was utilized to sample fish, whereas in 1983 (Llewellyn), 1997 (Harris & Gehrke) and 2004 (MDBC) a suite of techniques was employed, including nets, traps, electrofishing and, in the case of Llewellyn's survey (1983), the use of Rotenone, explosives and hook and line. Due to the absence of abundance data in Llewellyn (1983), it is impossible to determine whether species recorded in 1983 but not recorded subsequently were either common or uncommon in the Lachlan River during the 1983 survey. These species include fly-specked hardyhead and Agassiz's glassfish.

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The surveys by Harris and Gehrke (1997), Growns (2001) and MDBC (2004) recorded abundance as well as distribution of fish sampled in the Lachlan catchment. Only two silver perch were recorded from upstream of Wyangala Dam during the *NSW Rivers Survey* (Schiller *et al.* 1997). Only single specimens of freshwater catfish and flathead gudgeon were recorded from the effluent creek sites in 2001 (Growns), and only small numbers of Murray cod (3), golden perch (4), and river blackfish (7) were recorded from the main river channel sites in 2001 (Growns). In 2004 (MDBC), similarly small numbers of Murray cod (4), golden perch (5) and flathead gudgeon (4) were recorded, suggesting that the populations of many native species may be depleted within the Lachlan catchment.

Fish surveys of localised areas within the Lachlan catchment are limited, and include a population study of carp in the lower Lachlan River near Oxley (McBryde 1995) and a study of rainbow trout and mountain galaxias in Cadiangullong Creek and Panuara Rivulet in the upper catchment (Laws 1999).

1.4 The riverine environment and the status of fish in the Lake Cargelligo system

Located in central New South Wales, the Lake Cargelligo system is an off-river storage reservoir which both fills from and drains to the Lachlan River (Figure 1). The presence of shell middens and stone tools found at sites within the Lake Cargelligo system (Kabaila 1996) indicates a long period of human occupation and interaction with the aquatic environment. The Lake Cargelligo system is shallow, and evaporation losses result in increased salt concentrations which have been detected in the lower Lachlan River following drainage events (NSW DSNR 2003c). High levels of nutrients have also been detected within the Lake Cargelligo system, and blue-green algal blooms are common in summer (NSW DSNR 2003c). The Lake Cargelligo area has been inhabited by Europeans since the 1860s (Lake Cargelligo Historical Society 1973), and was fished commercially until the closure of the inland commercial fishery in September 2001 (Colin Sibraa pers. comm.).

Anecdotal evidence presented in Roberts and Sainty (1996) indicates that turbidity increased within the Lake Cargelligo system following the population spread of the Boolara strain of carp in the early 1970s, and that prior to this the water was much clearer and dominated by ribbon weed (*Vallisneria* spp).

Knowledge of the fish communities present within the Lake Cargelligo system is incomplete and fragmentary as the area was not included in widespread fish surveying of the Lachlan catchment by Llewellyn (1983), the *NSW Rivers Survey* (Harris & Gehrke 1997), Growns (2001) or during the *Sustainable Rivers Audit Pilot Study* (MDBC 2004). Anecdotal evidence suggests that native species such as freshwater catfish, golden perch and Murray cod were more common within the Lake Cargelligo system prior to the population spread of the Boolara strain of carp in the 1970s (Roberts & Sainty 1996). Recent results from an annual fishing competition held at Lake Cargelligo each spring suggest that alien species dominate the assemblage of larger fish species which can be caught by recreational methods. In 2003, 715 fish were caught, consisting of 535 carp, 178 redfin and 2 golden perch (*The Lake News*, October 22, 2003).

As the main channel of the Lachlan River was closed to commercial fishing in 1959, all subsequent commercial fishing in the Lachlan catchment occurred in Lake Cowal, Lake Brewster and Lake Cargelligo (Reid *et al*. 1997). In the period from 1948 until the closure of the inland commercial fishery in September 2001 (NSW Fisheries 2005c), the tonnage of Murray cod, freshwater catfish, silver perch and redfin perch from the Lachlan catchment all declined, the tonnage of golden perch remained stable and only the tonnage of carp increased (Reid *et al.* 1997). Observations by a former commercial fisher of Lake Cargelligo suggest that golden perch, redfin perch, carp, goldfish and bony bream were caught in variable numbers from the 1980s, Murray cod were caught in small numbers (10 -12 per year), silver perch were absent and very small numbers of undersize freshwater catfish were caught (Colin Sibraa pers. comm.).

Formal sampling of the fish communities within the Lake Cargelligo system is limited to records from 1972 held at the Australian Museum (Australian Museum Fish Database 2005), and boat electrofishing carried out by staff from NSW DPI in July 2004 (Andrew Bruce NSW DPI pers. comm.)(Table 3).

Table 3. Existing records of fish species recorded in the Lake Cargelligo system.

Species	**Australian Museum 1972 (exact numbers)**	**NSW DPI 2004 (approximate numbers)**
Gambusia	2	-
Flathead gudgeon	5	2
All carp gudgeons	48	-
Fly-specked hardyhead	7	-
Carp	-	300+
Goldfish	-	600+
Bony bream	-	100+
Redfin perch	-	6
Golden perch	-	5
Freshwater catfish	-	2
Silver perch	-	1

Species with a known preference for higher altitudes such as rainbow trout, brown trout, mountain galaxias, river blackfish and Macquarie perch are unlikely to inhabit the Lake Cargelligo system which is 169 metres above sea level. Results from both the Australian Museum in 1972 (Australian Museum Fish Database 2005) and from the NSW DPI sampling in 2004 (Andrew Bruce NSW DPI pers. comm.) suggest that the Lake Cargelligo system contains populations of many fish species that inhabit the lowland section of the Lachlan River.

The existing records indicate that species that have previously been sampled regularly in the Lachlan catchment such as gambusia, flathead gudgeon, carp gudgeons, carp, goldfish, bony bream, redfin perch and golden perch are present within the Lake Cargelligo system.

Freshwater catfish and silver perch are considered to be declining within the Murray-Darling Basin, however the existing records suggest that both species also occur within the Lake Cargelligo system. Neither species was sampled by MDBC (2004) in the Lachlan catchment, only two silver perch were recorded by Harris and Gehrke (1997), and only a single freshwater catfish was sampled by Growns (2001) in Wallaroi Creek.

Fly-specked hardyhead are thought to have a greatly reduced range in the southern Murray-Darling Basin (Allen *et al.* 2002). The presence of fly-specked hardyhead in the Lake Cargelligo system in 1972 (Australian Museum Fish Database 2005) suggests that this species may still be present in the Lake Cargelligo system, despite the fact that fly-specked hardyhead were not recorded from the Lachlan River or the effluent creeks by either Harris and Gehrke (1997), Growns (2001) or the MDBC (2004).

The Lake Cargelligo system is affected by many of the impacts that have been associated with the decline of native fish in western New South Wales, including alteration of natural flows, increasing turbidity and sedimentation, loss of aquatic macrophytes and colonisation by alien fish species (Roberts & Sainty 1996). Despite these impacts, existing fish surveys, commercial records and anecdotal evidence indicate that many fish species of the lower Lachlan River inhabit the area. It is also possible that the Lake Cargelligo system may represent suitable habitat for the recruitment of some species, although this has never been investigated.

1.5 The current study

Surveys such as *The Distribution of Fish in New South Wales* (Llewellyn 1983), the *NSW Rivers Survey* (Harris & Gehrke 1997), *An Assessment of the status of Native Fish and Fish Habitats in the Lachlan River* (Growns 2001) and the *Sustainable Rivers Audit Pilot Study* (MDBC 2004) are invaluable in providing a summary of patterns of fish distribution and abundance at catchment, state or drainage divide scales. Perhaps their obvious drawback is the possibility that faunally significant areas within catchments may be excluded from their survey design and process. Although there are many agencies and organisations with interests in riverine health and fish community rehabilitation, it is acknowledged in several reports (NSW EPA 1999a; NSW EPA 1999b; LCMB 2003; MDBC 2003) that a paucity of information exists with regard to localised fish communities in specific areas and that this information is required in order to successfully implement successful restoration and rehabilitation projects such as the *Native Fish Strategy for the Murray-Darling Basin 2003 – 2013* (MDBC 2003). The Lake Cargelligo system of the Lachlan River is an example of an unsurveyed area, as no formalised audit of the fish community has been undertaken.

1.6 Aims

The current study aims to answer the following questions relating to fish communities in the Lake Cargelligo system:

- Which Murray-Darling Basin fish species are present in the Lake Cargelligo system, and how do the fish populations compare with previous studies undertaken in the Lachlan catchment?
- What habitat characteristics, water quality parameters and other factors appear to influence the spatial and temporal distribution and abundance of fish species within the system?
- Is there evidence of fish recruitment within the system?

2. Methods

2.1 Study Area

The Lake Cargelligo system comprises three lakes and interconnecting canals which are filled intermittently from a diversion channel and regulator on the Lachlan River downstream of Euabalong in central New South Wales (Figures 1 & 2). Although primarily used as an off-river storage, the Lake Cargelligo system also provides the water supply for the townships of Lake Cargelligo, Murrin Bridge and Tullibigeal. When full, Lake Cargelligo covers an area of 1500 hectares, holds 36 000 megalitres of water and has a maximum depth of 3.7 metres (NSW DSNR 2003c).

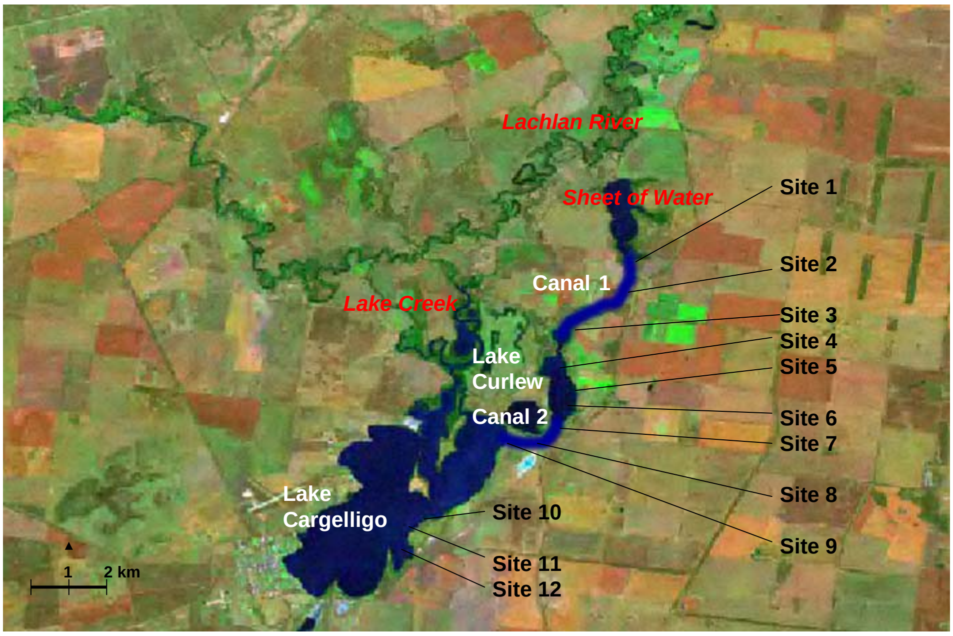

Figure 2. Site map of the Lake Cargelligo system, showing Sites 1, 2 and 3 in Canal 1, Sites 4, 5 and 6 in Lake Curlew, Sites 7, 8 and 9 in Canal 2 and Sites 10, 11 and 12 in Lake Cargelligo.

Regulation of the historically ephemeral Lake Cargelligo system began in an ad hoc fashion by landholders in 1885 (NSW DSNR 2003c). In 1902, channels were excavated to link the current water bodies known as Sheet of Water, Lake Curlew and Lake Cargelligo, and an inlet canal was excavated from Sheet of Water to the Lachlan River (Figure 2). An outlet regulator was also installed on Lake Creek in order to drain the Lake Cargelligo system back to the Lachlan River, and a levee bank was constructed on the southern shore of Lake Cargelligo to prevent inflow water following its natural course through a series of (now dry) former lakes. Although a future irrigation industry was envisaged, drought amelioration for the lower Lachlan was the primary motivation behind the engineering work of the early 20th century (NSW DSNR 2003c). In general, the effect of regulation has been to increase flows in the lower Lachlan during summer and decrease flows during winter (NSW DSNR 2003c). In times of severe drought (1968, 1983, 2004/05), the Lake Cargelligo system has become isolated from the Lachlan River for long periods (ie: over 12 months) and has dropped to below 20% capacity (Barry Orr NSW State Water pers. comm.)

Water enters the Lake Cargelligo system from the weir pool on the Lachlan River upstream of Lake Cargelligo weir. Water then flows through the inlet canal, which is approximately 800 metres long, before reaching Sheet of Water, which is approximately 2 kilometres long and up to 800 metres wide. Sheet of Water is very shallow, with a mean depth of 1 metre when the Lake Cargelligo system is at 100% capacity (Figure 2). Water exits Sheet of Water via a longer canal (3.9 kilometres) which varies in depth between 30cm and 1.5 metres and in width between 8 and 15 metres depending upon how much water is stored in the Lake Cargelligo system. This canal is referred to as Canal 1 in the current study (Figures 2 & 3).

Figure 3. Site 1 in Canal 1.

Canal 1 delivers water to Lake Curlew, the second small lake within the Lake Cargelligo system (Figure 2). Lake Curlew is approximately 2.3 kilometres long and 800 metres wide. Lake Curlew was up to 1.5 metres deep during the current study and is up to 3.7 metres deep when the Lake Cargelligo system is full. As it is oriented in a north-south direction, the narrowness of Lake Curlew creates a relatively sheltered lake environment which does not experience the full effects of the prevailing south-westerly winds. Although a small amount of residential development has occurred along the western shore of Lake Curlew, the majority of riparian land is agricultural, and the eastern shoreline of Lake Curlew is characterised by stands of river red gum (*Eucalyptus camaldulensis*), white cypress pine (*Callitris columellaris*) and willow (*Salix* spp). The habitat of Lake Curlew is characterised by large areas of open water with intermittent standing dead trees and fallen timber (Figure 4).

Figure 4. Site 5 in Lake Curlew, looking south-west and showing standing dead trees.

Water moves through Lake Curlew and enters another canal which is referred to as Canal 2 in the current study (Figure 2). Canal 2 is 1.9 kilometres long and was approximately 8 metres wide and up to 1.5 metres deep during the current study (Figure 5). In July 2004, the amount of riparian vegetation was substantially reduced in Canal 2 following the removal of large numbers of willows (*Salix* spp.) by State Water staff (pers obs).

Figure 5. Site 9 in Canal 2, showing fallen timber and cumbungi (*Typha* spp.)

Canal 2 flows into Lake Cargelligo, which is up to 7 kilometres long and between 2.5 and 3.5 kilometres wide (Figure 2). Water entering the Lake Cargelligo system reaches Lake Cargelligo after passing through Sheet of Water, Lake Curlew and the associated system of interconnecting canals. During the current study, Lake Cargelligo was up to 1.2 metres deep, however the northern half of Lake Cargelligo was very shallow (< 30cm) due to low water levels. Although fringing vegetation and woody debris are present along the shoreline of Lake Cargelligo, these habitat features were separated from the water's edge due to the low water levels experienced during the current study (Figure 6). Lake Cargelligo experiences considerable wind and wave activity, and is consequently a turbid environment as it is relatively shallow (NSW DSNR 2003c).

Figure 6. The open-water habitat of Site 12 in Lake Cargelligo.

Lake Cargelligo is the primary water-storage body within the Lake Cargelligo system. When water is released from Lake Cargelligo to service the lower Lachlan River it passes through Lake Creek (Figure 2), a meandering riverine environment characterised by extensive riparian vegetation, standing dead trees and submerged woody debris.

2.2 Sampling Design

The study was undertaken in four areas; Canal 1, Lake Curlew, Canal 2 and Lake Cargelligo (Figure 2). Both Sheet of Water and Lake Creek contained insufficient water to allow sampling and were not included in the study. The Lake Cargelligo system was not connected to the Lachlan River throughout the study, and by January 2005 there was no connection between Canal 1 and Lake Curlew or between Canal 2 and Lake Cargelligo. Water last entered the system from the Lachlan River on 15 December 2003, and last exited the system via Lake Creek on 8 January 2004 (Nachi Nachiappan NSW State Water pers. comm.). Consequently, water levels within the Lake Cargelligo system were far lower than full capacity for the duration of the study.

Sampling was undertaken in September 2004 (spring) when the system was at 21.9% of capacity, and in January 2005 (summer) when the system was at 7% of capacity.

Three replicate sites were chosen within Canal 1, Lake Curlew, Canal 2, and Lake Cargelligo (Figure 2). Sites 1, 2, and 3 were spaced approximately 800 metres apart in Canal 1. In September 2004, Canal 1 had an average depth of approximately 40cm and in January 2005 this dropped to 30cm at Site 1 and Site 2, and 5cm at Site 3. Consequently, Site 3 was sampled in September 2004 but was not sampled in January 2005. Sites 4, 5 and 6 were spaced approximately 600 metres apart along the eastern shoreline of Lake Curlew, and Sites 7, 8 and 9 were spaced approximately 500 metres apart in Canal 2. Sites 11, 12 and 13 were situated on the eastern shoreline of Lake Cargelligo approximately 600 metres apart.

2.3 Field Sampling Techniques

In order to assess habitat, four 50 metre sections were assessed in the vicinity of each site for the presence of in-stream cover and riparian vegetation. Each section received a score for both in-stream cover and riparian vegetation (Table 4), and physical characteristics such as plant species present and the complexity of in-stream debris were observed and recorded. The scores from the four 50 metre sections were then combined in order to calculate a total figure (out of 12) for both riparian vegetation and in-stream cover at each site. Area totals were calculated by adding the totals from Sites 1, 2 and 3 for Canal 1, Sites 4, 5 and 6 for Lake Curlew, Sites 7, 8 and 9 for Canal 2 and Sites 10, 11 and 12 for Lake Cargelligo, and the final score for each area (out of a possible 36) was converted back to a percentage. The depth of water and unconsolidated material (silt) was measured in centimetres at each site.

Table 4. Scoring index used to assess habitat during the current study in each 50 metre section at each site.

Riparian vegetation	Score	In-stream cover
Continuous understorey of grasses/weeds with overhanging tree canopy covering > 75% of the streambanks	**3**	Complex habitat architecture including snags and aquatic macrophytes present in > 75% of the 50 metre section
Grasses and isolated weeds, shrubs or trees covering between 30 and 75% of the streambanks	**2**	Multiple snags and/or aquatic macrophytes present in between 30 and 75% of the 50 metre section
Isolated vegetation covering < 30% of the streambanks	**1**	Isolated stumps or logs present in < 30% of the 50 metre section
Bare streambanks without fringing vegetation	**0**	Open water without snags or aquatic macrophytes

A multi-parameter water quality meter (Hydrolab) was used at each site in each sampling period to measure temperature, dissolved oxygen, pH, conductivity and turbidity.

Fish were surveyed using a combination of fyke nets, bait traps and backpack electrofishing at each site. All sampling was carried out under Scientific Research Permit P04/0078 issued by NSW Fisheries and CSU Animal Care and Ethics Committee permit 04/028.

Two double-winged fyke nets with a stretched mesh of 20mm were used to sample fish at all canal sites and were set in order to sample fish moving both upstream and downstream. Two single-winged fyke nets with a stretched mesh of 20mm were used to sample fish in all lake sites and were set with the funnels facing in opposite directions from a central post. Fyke nets were set in water less than a metre deep and were set for a period of 24 hours at each site and in each season. Fyke nets were checked twice a day to remove air-breathing vertebrates in accordance with Charles Sturt University Animal Care and Ethics Committee guidelines.

Ten unbaited bait traps with a mesh size of 2mm and an opening of 45mm were set at each site for 24 hours. Bait traps were set within 30 metres of each pair of fyke nets and were set at a variety of depths depending upon the characteristics of each site.

A Smith-Root backpack electrofisher was used in accordance with the Australian Code of Electrofishing Practice (NSW Fisheries 1997) in the vicinity of each site to complete 8 x 150 second shots at 300 – 400 volts DC. Backpack electrofishing was undertaken in water between 20 and 70cm deep at all sites.

Fish sampled by all three methods were held in water-filled buckets following the emptying of fyke nets and bait traps or the netting of fish during electrofishing. Sampled native fish were identified, counted, measured (fork length for fork-tailed species and total length for other species) and returned to the water. Where positive identification was possible, specimens which were observed but not caught were also recorded. Identification of the *Hypseleotris* gudgeon complex was completed in the field (Unmack 2000; Allen *et al.* 2002), and identification was confirmed by photographic evidence sent to Peter Unmack (Peter Unmack Arizona State University pers. comm.)(Figure 7). All Hypseleotris gudgeons were identified as either 'undescribed carp gudgeons' (*Hypseleotris* sp. 1, sp. 2 or sp. 3) or western carp gudgeon (*Hypseleotris klunzingeri*) (Appendix 1).

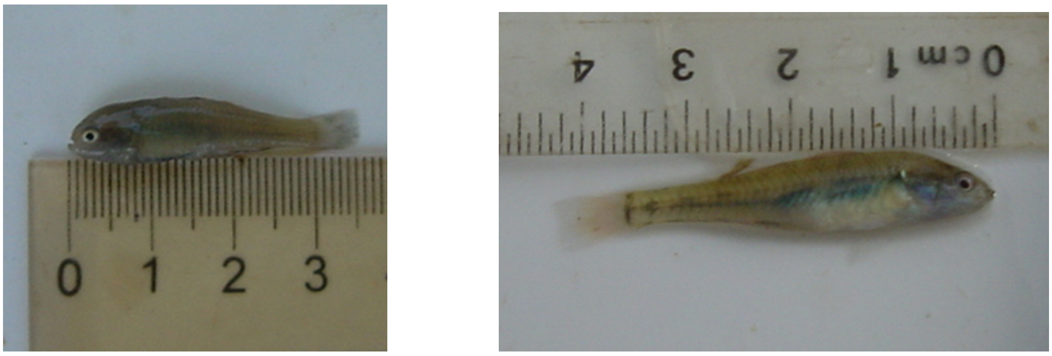

Figure 7. Examples of *Hypseleotris* gudgeons sampled during the current survey. The specimen on the left was identified as *Hypseleotris* spp. (undescribed carp gudgeon), whereas the specimen on the right was identified as *Hypseleotris klunzingeri* (western carp gudgeon).

Alien fish were counted, measured and humanely euthanased in accordance with Charles Sturt University Animal Care and Ethics Committee guidelines (protocol number 04/028).

2.4 Data Analysis

The total number of species occurring in each site was calculated by combining data from all sampling methods. The data was tested for normality using the Shapiro Wilk test and for heterogeneity using Levene's test. A one-way analysis of variance (ANOVA) test in SPSS Version 11.5 was used to compare the number of fish species between sampling areas, and significant results were further analysed using a Tukey's post hoc test.

The weight of each specimen caught by backpack electrofishing, bait traps and fyke nets at each site was estimated using published biomass equations (MDBC

2004)(Appendix 2). The maturity of all measured fish was estimated using figures collated from previous studies for the species concerned (Table 5).

One-way analysis of variance (ANOVA) tests were used to compare the temperature, dissolved oxygen, pH, conductivity and turbidity between areas and between seasons. Conductivity and turbidity data was log transformed. A paired t-test was used to analyse seasonal variation in depth between the 12 sites.

In order to investigate fish community composition, the abundance of each species obtained from each sampling technique (observed, bait traps, fyke nets and backpack electrofishing) was combined to represent the fish community at each site, and analysed in PRIMER 5.2.9 (Plymouth Marine Laboratory). To reduce the effect of common species and emphasise the contribution of less-common species, the abundance data was log+1 transformed (Clarke & Warwick 1994).

Similarities between fish communities at each site were calculated using the Bray-Curtis similarity measure (Bray & Curtis 1957). One-way ANOSIM (Analysis of Similarities) was performed in order to compare the fish community composition between Canal 1, Lake Curlew, Canal 2 and Lake Cargelligo, and a multi-dimensional scaling (MDS) ordination in two dimensions was performed in order to create a visual representation of the relationships between sites and areas (Clarke 1993).

Table 5. Minimum length and age at sexual maturity for species sampled in the current study.

Species	**Minimum length at sexual maturity**	**Age at sexual maturity (years)**	**Location**	**Reference**
Western carp gudgeon	23.6mm ♀, 22mm ♂	1	Mary River, Queensland	Pusey *et al.* 2004
Undescribed carp gudgeon: *Hypseleotris* sp. 1	30.8mm ♀, 32.4mm ♂	1	Mary River, Queensland	Pusey *et al*. 2004
Redfin perch	104mm ♀, 102mm ♂	2 ♀, 1 ♂	Western Australia (south-west)	Morgan *et al.* 2002
Gambusia	21mm ♀ (♂smaller)	1	Not stated	McDowall 1996
Australian smelt	36mm	<1	Goulburn River, Victoria	Hume *et al*. 1983, cited in Pusey *et al*. 2004
Flathead gudgeon	42mm ♀, 48mm ♂	Not stated	Campaspe River, Victoria	Serafini 1998, cited in Pusey *et al*. 2004
Bony bream	150mm ♀, 130mm ♂	>1 ♀, <1 ♂	Murray River, South Australia	Puckridge and Walker 1990
Goldfish	100 – 150 mm	<1	Victoria	Brumley 1996
Carp	Maturity related to age rather than size	3 - 4 ♀, 1 - 2 ♂	Various Victorian rivers and the Murray River	Sivakumaran *et al.* 2003
Fly-specked hardyhead	27mm	<1	Alligator Rivers region, Northern Territory	Bishop *et al*. 2001, cited in Pusey *et al*. 2004
Golden perch	397mm ♀, 325mm ♂	4 ♀, 2 - 3 ♂	Murray River NSW/Victoria	Mallen-Cooper and Stewart (2003), cited in Pusey *et al*. 2004
Silver perch	340mm ♀[1], 233mm ♂[1]	5 ♀[2], 3 ♂[2]	Murray River, NSW/Victoria [2]	[1] Merrick and Schmida 1984 [2] Mallen-Cooper *et al.* 1995
Freshwater catfish	335mm ♀, 380mm ♂	4 - 5	Gwydir River, NSW	Davis 1975, cited in Pusey *et al*. 2004

Results from ANOSIM calculate a test statistic ‘R’ identifying the observed differences between treatments compared with the differences among replicates within treatments (Clarke & Warwick 1994). ‘R’ values are generated for both global and pairwise comparisons and can be interpreted as follows in this study:

R = 1	indicates total separation of areas
R = >0.75	indicates the areas are well separated
R = >0.5	there may be overlap but the areas remain different
R = <0.25	indicates the areas are hardly separated
R = 0	indicates the areas are indistinguishable from one another

As there were only three sites in each sampling area, the statistical power of the one way ANOSIM could only generate significant results at P = 0.1 (Clarke & Warwick 1994).

Species contributing to the differences between areas were examined using the SIMPER analysis, which calculates the average dissimilarity between paired samples and then allocates the contribution each species makes to this dissimilarity (Clarke & Warwick 1994).

Comparisons of fish abundance between seasons were made using data pooled from all sampling techniques. Observed data were excluded for the comparison of biomass between seasons as an estimate of the weight of each fish could not be made. Totals were log+1 transformed, however in the case of western carp gudgeon, the totals were fourth root transformed to test for seasonal abundance of this species across all areas The data was tested for normality using the Shapiro Wilk test and tested for heterogeneity using Levene's test. One-way analysis of variance (ANOVA) tests in SPSS Version 11.5 were used to compare the following:

a) The seasonal abundance and seasonal biomass of all fish in all areas combined
b) The seasonal abundance (in all areas combined) of species occurring in a majority of sampling areas and both seasons
c) The seasonal abundance within areas of those species for which a significant result was obtained in b).

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The Kolmogorov-Smirnov two-sample test in SPSS was used to analyse length frequency where 25 or more individuals of a species were present in samples from the same areas in both seasons (Sokal & Rohlfe 1995). The only species which satisfied these requirements was western carp gudgeon in Lake Curlew and Canal 2. Undescribed carp gudgeon were not analysed using the Kolmogorov-Smirnov test as the samples may have contained representatives of multiple species.

3. Results

3.1 Habitat Assessment

In-stream habitat was more abundant in Lake Curlew and Canal 2 than in Canal 1 or Lake Cargelligo (Figure 8). At most sites, in-stream habitat consisted of stumps or fallen trees, however stands of cumbungi (*Typha* spp.) were present at all sites in Canal 2, and standing dead trees were present at Sites 5 and 6 in Lake Curlew (Table 6). Standing dead trees, stumps and fallen timber were all river red gum (*Eucalyptus camaldulensis*), with the exception of willow (*Salix* spp.) stumps at Sites 8 and 9 in Canal 2.

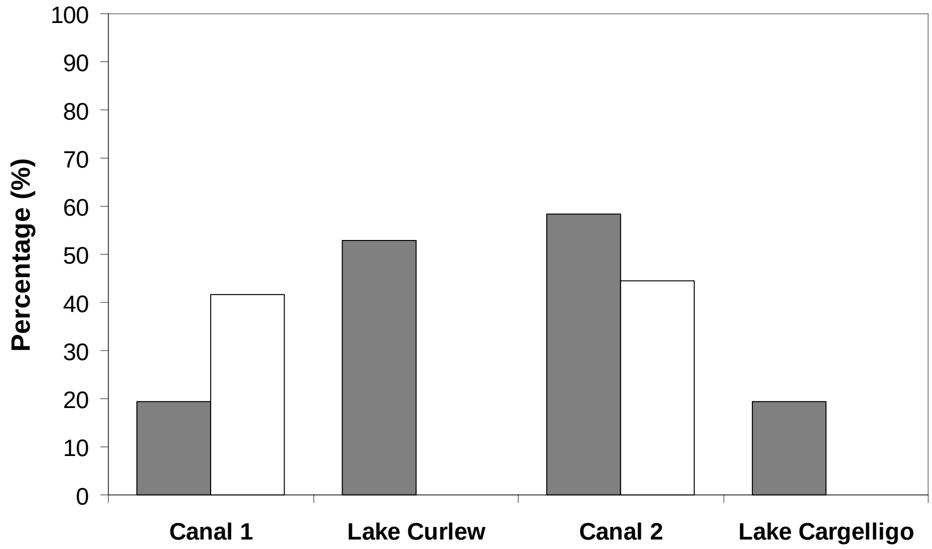

Figure 8. A comparison of the amount of in-stream cover (grey bars) and riparian vegetation (white bars) in Canal 1, Lake Curlew, Canal 2 and Lake Cargelligo during the current study.

Table 6. Habitat characteristics of sites sampled during the current study.

Area	Site Number	Silt depth (cm)	Riparian vegetation	In-stream cover
Canal 1	1	0	Isolated trees	Nil
	2	20	River red gum along canal banks; understorey of grasses and weeds	Fallen timber
	3	60	Grasses and weeds	Isolated logs
Lake Curlew	4	30	Water's edge >20m from riparian vegetation	Isolated red gum stumps
	5	10	Water's edge >10m from riparian vegetation	Fallen timber, stumps and standing dead trees
	6	10	Water's edge >10m from riparian vegetation	Fallen timber, stumps and standing dead trees
Canal 2	7	20	River red gum along canal banks; understorey of grasses and weeds	Fallen timber and stands of cumbungi
	8	30	River red gum along canal banks; understorey of grasses and weeds	Fallen timber, stands of cumbungi and willow stumps
	9	30	Isolated willows	Stands of cumbungi and willow stumps
Lake Cargelligo	10	15	Water's edge >50m from closest riparian vegetation	Isolated red gum stumps
	11	0	Water's edge >30m from closest riparian vegetation	Isolated red gum stumps
	12	0	Water's edge >100m from closest riparian vegetation	Isolated red gum stumps

Riparian vegetation consisting of river red gum and willow communities was separated from the water's edge by between 10 and 100 metres in both lakes during the current study (Table 6). With the exception of willow trees at Site 9 in Canal 2, riparian vegetation consisted of an understorey of weeds and grasses and a canopy of river red gum in both canals (Table 6). At all sites except Site 1 in Canal 1 and Sites 11 and 12 in Lake Cargelligo, a layer of loose silt was present between 10 and 60cm deep (Table 6).

At almost all sites the water was shallower in summer than in spring (t = 3.614, df: 11, $p < 0.01$)(Figure 9). Site 3 (Canal 1) was too shallow to sample during the summer sampling period.

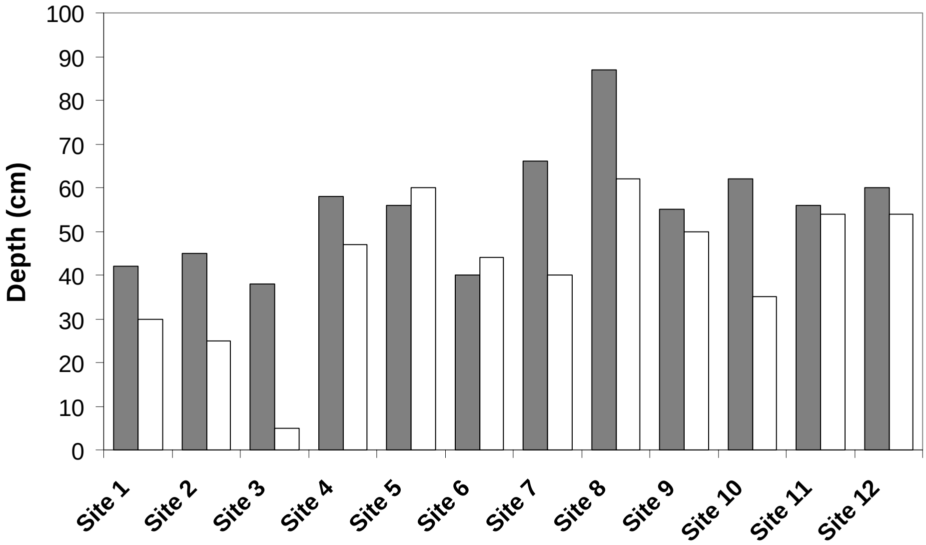

Figure 9. Depth in centimetres of each site in spring (grey bars) and summer (white bars).

3.2 Spatial and temporal water quality

Electrical conductivity varied among areas (p = 0.000) and between seasons (p = 0.001)(Figure 10)(Table 7). The highest conductivity figure (1.88 mS/cm^{-1}) was recorded at site 11 in Lake Cargelligo in summer, and conductivity exhibited a consistent pattern in both seasons of increasing from Canal 1 to Lake Curlew, from Lake Curlew to Canal 2 and from Canal 2 to Lake Cargelligo (Figure 10). Statistically significant variation in conductivity existed between Canal 1 and Canal 2 (p = 0.019), Canal 1 and Lake Cargelligo (p = 0.000) and Lake Curlew and Lake Cargelligo (p = 0.024).

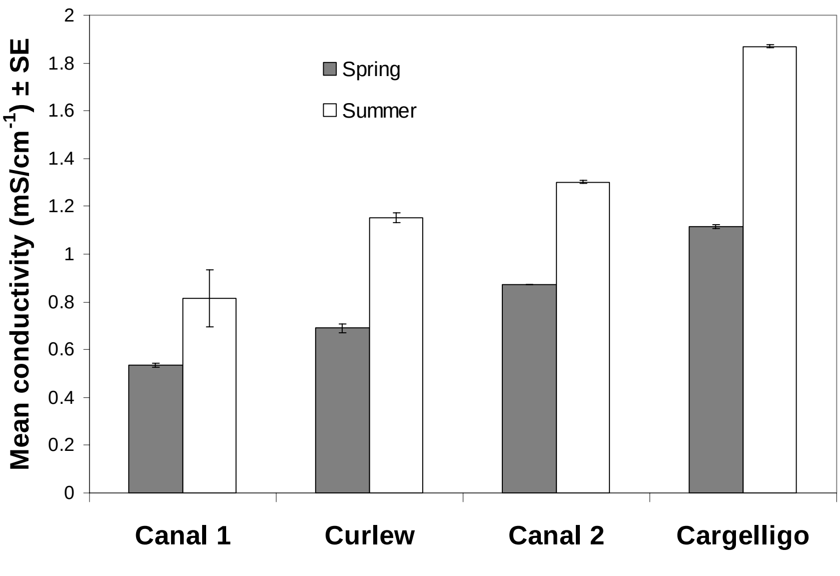

Figure 10. Mean conductivity ± standard error for all areas in spring and summer**.**

Table 7. Mean water quality (± standard error) at four areas in the Lake Cargelligo system in spring 2004 and summer 2005.

Parameter	**Unit of measurement**	**Canal 1** *Spring*	**Canal 1** *Summer*	**Lake Curlew** *Spring*	**Lake Curlew** *Summer*	**Canal 2** *Spring*	**Canal 2** *Summer*	**Lake Cargelligo** *Spring*	**Lake Cargelligo** *Summer*
Temperature	^{o}C	18.21 (0.79)	23.02 (0.885)	19.13 (0.475)	28.29 (0.205)	14.713 (0.4628)	27.213 (0.506)	12.627 (0.0895)	21.54667 (0.127845)
Dissolved oxygen	mg/L^{-1}	11.84 (1.188)	8.71 (1.15)	12.27 (0.232)	8.55 (0.177)	8.06 (0.3946)	8.07 (1.7197)	9.6133 (0.1328)	9.83 (0.124231)
Conductivity	mS/cm^{-1}	0.535 (0.007)	0.815 (0.12)	0.6903 (0.0189)	1.153 (0.021)	0.872 (9E-04)	1.302 (0.109)	1.114 (0.007)	1.87 (0.0058)
pH		9.22 (0.14)	7.88 (0.03)	8.873 (0.033)	8.363 (0.009)	8.3067 (0.1189)	8.3433 (0.0285)	8.4333 (0.0484)	8.44 (0.0115)
Turbidity	NTU	93.3 (14.61)	202 (54)	62.133 (9.4171)	221.3 (77.47)	74.03 (11.77)	92.5 (13.7)	119 (12.53)	418.7 (38.35)

Turbidity was higher in Canal 1, Lake Curlew and Lake Cargelligo in summer than in spring, however this pattern was not statistically significant (p = 0.057) (Figure 11). Turbidity was highest at Site 11 in Lake Cargelligo during the summer sampling period (474 NTU)(Table 7).

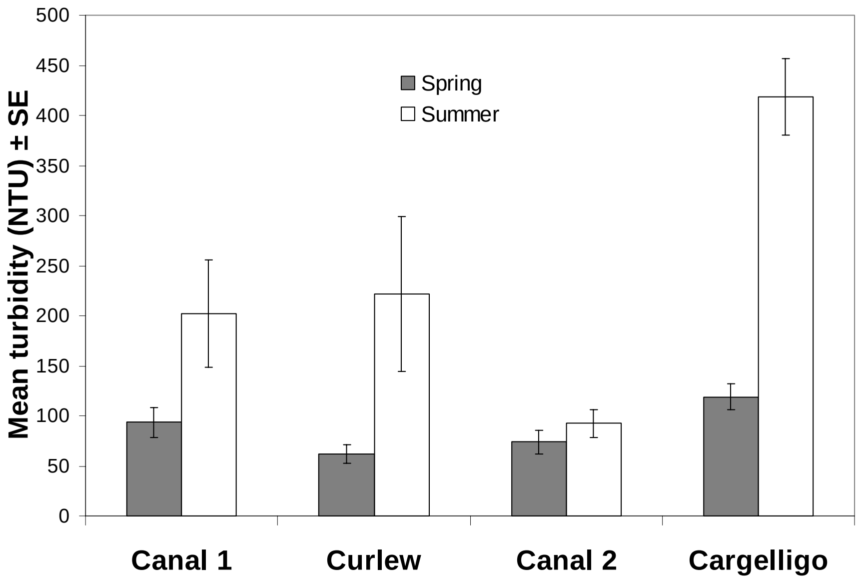

Figure 11. Mean turbidity (NTU) ± standard error for all areas in spring and summer.

Temperature was higher in summer than in spring in all areas (p = 0.000) (Figure 12), and dissolved oxygen was lower in both Canal 1 and Lake Curlew in summer than in spring (p = 0.043) (Figure 13)(Table 7).

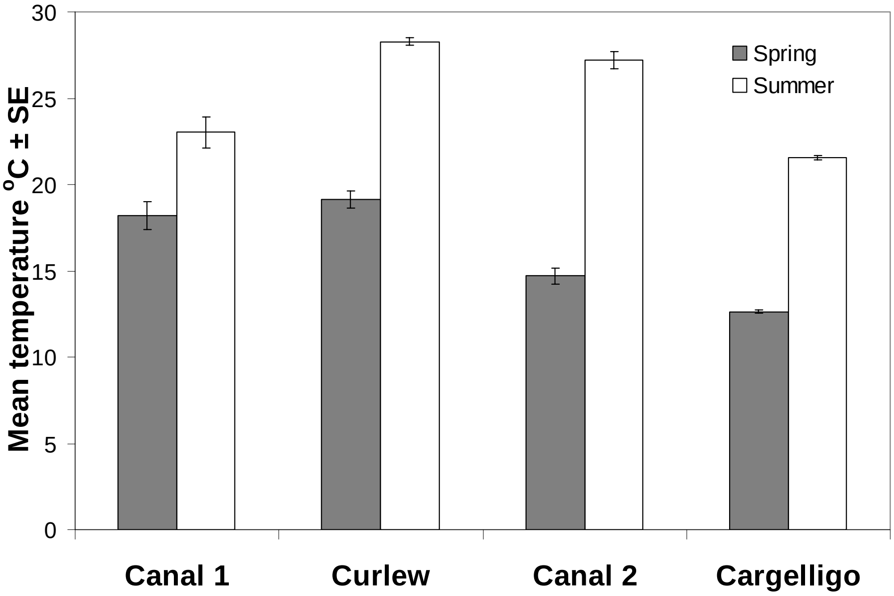

Figure 12. Mean temperature ± standard error for all areas in spring and summer.

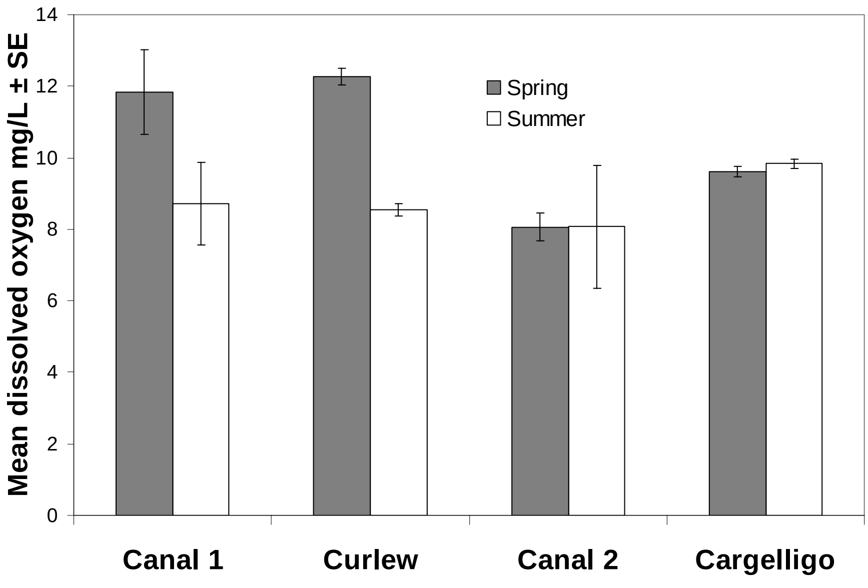

Figure 13. Mean dissolved oxygen ± standard error for all areas in spring and summer.

3.3 Fish species

A total of 3223 individual fish from 12 described species was recorded from the Lake Cargelligo system, and undescribed carp gudgeons were also sampled (Table 8). Western carp gudgeon were the most abundant species (2273 individuals), accounting for 70.5% of all fish caught. More than 100 carp, undescribed carp gudgeons, gambusia and redfin were sampled, and more than 50 flathead gudgeon, Australian smelt and bony bream were sampled. The remainder of the species were sampled in smaller numbers, and included goldfish (44), fly-specked hardyhead (18), golden perch (11) and freshwater catfish (1) (Table 8). Silver perch (4) were observed but not caught (Table 8).

Species which were low in abundance, such as golden perch (11), were high in biomass (Table 9). Carp made up 42.2% of total biomass, and larger species such as redfin, bony bream and golden perch made up 19.5%, 18.8% and 9.5% of total biomass respectively. The smaller species and a single freshwater catfish accounted for the remaining 10.05% of the total biomass (Table 9).

Turtles were also caught during the sampling events in fyke nets. Two species were sampled, the common snake-neck turtle (*Chelodina longicollis*) and the Macquarie turtle (*Emydura macquaria*). Although turtles were caught in all areas, 78.9% were caught in Lake Curlew in summer (Appendix 3).

Table 8. Total abundance of fish caught in four areas of the Lake Cargelligo system across two seasons. Numbers of species observed but not caught are given in brackets. * denotes alien species.

Scientific Name	Common Name	Canal 1		Lake Curlew		Canal 2		Lake Cargelligo		Total species abundance (individuals)	Proportional abundance (%)
		Spring	*Summer*	*Spring*	*Summer*	*Spring*	*Summer*	*Spring*	*Summer*		
Hypseleotris klunzingeri	Western carp gudgeon	76	7	30	1648	181	325	-	6	**2273**	70.52
Cyprinus carpio	Carp*	12 (46)	2 (45)	2 (3)	(60)	5	(2)	(11)	6 (12)	**206**	6.39
Hypseleotris spp.	Undescribed carp gudgeons	43	7	4	58	24	51	-	11	**198**	6.14
Perca fluviatilis	Redfin perch*	-	-	-	-	-	1	3	130	**134**	4.16
Gambusia holbrooki	Gambusia, Mosquito fish*	-	6 (1)	-	-	11	109	-	-	**127**	3.94
Retropinna semoni	Australian smelt	8	-	15	-	-	-	53 (9)	-	**85**	2.64
Philypnodon grandiceps	Flathead gudgeon	9	-	9	1	31	14	-	(1)	**65**	2.02
Nematolosa erebi	Bony bream	-	-	1	3	6	19	5	23	**57**	1.77
Carassius auratus	Goldfish*	32	2	1	-	9	-	-	-	**44**	1.37
Craterocephalus stercusmuscarum fulvus	Fly-specked hardyhead	-	-	-	14	-	4	-	-	**18**	0.56
Macquaria ambigua	Golden perch	-	-	6	1	4	-	-	-	**11**	0.34
Bidyanus bidyanus	Silver perch	-	-	-	(3)	(1)	-	-	-	**4**	0.12
Tandanus tandanus	Freshwater Catfish	-	-	-	1	-	-	-	-	**1**	0.03
Total individuals		**226**	**70**	**71**	**1789**	**272**	**525**	**82**	**188**	**Total individuals:**	
% contribution to total		7.01	2.17	2.20	55.51	8.44	16.29	2.54	5.83	**3223**	

Table 9. Proportional biomass of fish species in four areas of the Lake Cargelligo system across two seasons. This table excludes observed specimens. * denotes alien species

Scientific Name	Common Name	Canal 1		Lake Curlew		Canal 2		Lake Cargelligo		Total species biomass (gm)	Proportional biomass (%)
		Spring %	*Summer* %	*Spring* %	*Summer* %	*Spring* %	*Summer* %	*Spring* %	*Summer* %		
Hypseleotris klunzingeri	Western carp gudgeon	3.2	0.24	0.58	73.99	8.23	13.4	-	0.35	**1333.03**	3.6
Cyprinus carpio	Carp*	2.24	47.63	0.51	-	0.98	-	-	48.64	**15605.39**	42.16
Hypseleotris spp.	Undescribed carp gudgeons	19.21	2.91	0.96	26.88	16.16	26.83	-	7.03	**146.51**	0.4
Perca fluviatilis	Redfin perch*	-	-	-	-	-	0.12	31.97	67.92	**7201.34**	19.45
Gambusia holbrooki	Gambusia, Mosquito fish*	-	5.85	-	-	11.75	82.41	-	-	**23.16**	0.06
Retropinna semoni	Australian smelt	10.63	-	17.92	-	-	-	71.45	-	**133.06**	0.36
Philypnodon grandiceps	Flathead gudgeon	11.68	-	11.32	0.49	64.36	12.15	-	-	**177.19**	0.48
Nematolosa erebi	Bony bream	-	-	2.66	38.44	4.72	18.32	28.16	7.71	**6954.87**	18.79
Carassius auratus	Goldfish*	80.93	1.24	2.11	-	15.71	-	-	-	**1144.47**	3.09
Craterocephalus stercusmuscarum fulvus	Fly-specked hardyhead	-	-	-	79.21	-	20.79	-	-	**17.93**	0.05
Macquaria ambigua	Golden perch	-	-	69.54	4.67	25.79	-	-	-	**3536.08**	9.55
Tandanus tandanus	Freshwater Catfish	-	-	-	100	-	-	-	-	**743.73**	2.01
Total biomass (gm)		**1381.87**	**7455.59**	**2801.36**	**4622.9**	**1918.39**	**1544.75**	**4260.12**	**13031.79**	**Total biomass (gm):**	
% contribution to total		3.72	20.09	7.55	12.46	5.17	4.16	11.48	35.12	**37016.76**	

Seven fish species were sampled by bait traps, six species by fyke nets and nine species by backpack electrofishing (Table 10). Flathead gudgeon, gambusia and goldfish were captured by all three techniques utilised in the current study (Table 10). Carp, western carp gudgeons, undescribed carp gudgeons, Australian smelt, bony bream and fly-specked hardyhead were sampled by a combination of two techniques (Table 10). Golden perch, freshwater catfish and redfin perch were sampled only in fyke nets (Table 10). Silver perch were observed during the current study (Table 10).

Table 10. Fish species sampled by three sampling techniques in four areas of the Lake Cargelligo system (C1 = Canal 1, Cu = Lake Curlew, C2 = Canal 2 and Ca = Lake Cargelligo). Species observed whilst backpack electrofishing or checking fyke nets are indicated in brackets.

Species	**Backpack electrofishing**	**Fyke nets**	**Bait traps**
Western carp gudgeon	C1, Cu, C2		C1, Cu, C2, Ca
Undescribed carp gudgeons	C1, C2		C1, Cu, C2, Ca
Carp	C1, (Cu), C2, (Ca)	C1, Cu, C2, Ca	
Redfin perch		C2, Ca	
Gambusia	C2	(C1)	C1,C2
Australian smelt	C1, Cu, Ca		Ca
Flathead gudgeon	C1, C2	(Ca)	C1, Cu, C2
Bony bream	C2	Cu, C2, Ca	
Goldfish	C1, C2	C1, Cu, C2	C1
Fly-specked hardyhead	C2		Cu, C2
Golden perch		Cu, C2	
Silver perch	(Cu)	(C2)	
Freshwater catfish		Cu	

Backpack electrofishing sampled comparatively more species in the canals than in the lakes, whereas bait traps and fyke nets sampled a more consistent number of species in all areas (Table 11).

Table 11. Number of species sampled at each area and by each technique. Species observed whilst backpack electrofishing or checking fyke nets are given in brackets.

Method	**Canal 1**	**Lake Curlew**	**Canal 2**	**Lake Cargelligo**
Electrofishing	6 (1)	2 (2)	9 (1)	1 (2)
Bait traps	5	4	5	3
Fyke nets	2 (1)	5	5 (1)	3 (1)
Total number of species sampled in each area	**7**	**11**	**11**	**7**

3.4 Comparison of fish community composition between areas

Eleven fish species were recorded from Lake Curlew and Canal 2, and seven species were recorded from Canal 1 and Lake Cargelligo (Tables 8 & 11). There was a significant difference in the number of species between areas ($F = 4.408$, $p = 0.016$). Although there were more species in Canal 2 than Lake Cargelligo ($p = 0.009$), all other pairwise comparisons of areas were not significantly different.

Carp, western carp gudgeon, undescribed carp gudgeons and flathead gudgeon occurred in all four sampling areas (Table 8). Goldfish, bony bream and Australian smelt occurred in three areas, with goldfish absent from Lake Cargelligo, bony bream absent from Canal 1 and Australian smelt absent from Canal 2 (Table 8). Golden perch, silver perch and fly-specked hardyhead occurred only in Lake Curlew and Canal 2 (Table 8). Redfin occurred in Lake Cargelligo and Canal 2 and gambusia occurred in Canal 1 and Canal 2 (Table 8). A single freshwater catfish was caught in Lake Curlew (Table 8).

The fish communities in each of the four sampling areas were distinct (Figure 14) and displayed significant differences from one another in all pairwise comparisons (Table 12).

Table 12. Single factor ANOSIM comparing species composition between areas (Canal 1, Lake Curlew, Canal 2 and Lake Cargelligo).

Comparison	**R Value**	**P**
Global area comparison	0.886	<0.01
Canal 1 Vs Lake Curlew	0.593	<0.01
Canal 1 Vs Canal 2	0.815	<0.01
Canal 1 Vs Lake Cargelligo	1	<0.01
Lake Curlew Vs Canal 2	0.815	<0.01
Lake Curlew Vs Lake Cargelligo	1	<0.01
Canal 2 Vs Lake Cargelligo	1	<0.01

In the MDS plot (Figure 14), the sites from Lake Cargelligo formed a tight group that was separate from all other sites. This was mainly due to the large numbers of redfin perch and comparatively few western carp gudgeon and undescribed carp gudgeons that occurred in Lake Cargelligo (Table 13). In all other areas, redfin perch were not present (with the exception of one individual from Canal 2), and the most commonly sampled fish were western carp gudgeon (Table 8).

Carp and goldfish were most abundant in Canal 1. Bony bream were not present in Canal 1, and gambusia were present only in small numbers (Table 8). These factors, combined with the large numbers of western carp gudgeon caught in Lake Curlew and Canal 2, contributed to the separation of Canal 1 from both Lake Curlew and Canal 2 (Figure 14, Table 13).

The fish communities in Canal 2 and Lake Curlew included both the greatest number of species (11) and species sampled in low numbers such as golden perch, silver perch and fly-specked hardyhead (Table 8). The large numbers of carp from Lake Curlew and the large numbers of gambusia from Canal 2 (but absent from Lake Curlew), contributed to the differences between these two areas (Table 13). Like the sites in Lake Cargelligo, the sites in Canal 2 form a tight group in the MDS plot due to the presence of most species at all sites (Figure 14). These species include all carp gudgeons, gambusia, flathead gudgeon and bony bream (Table 8).

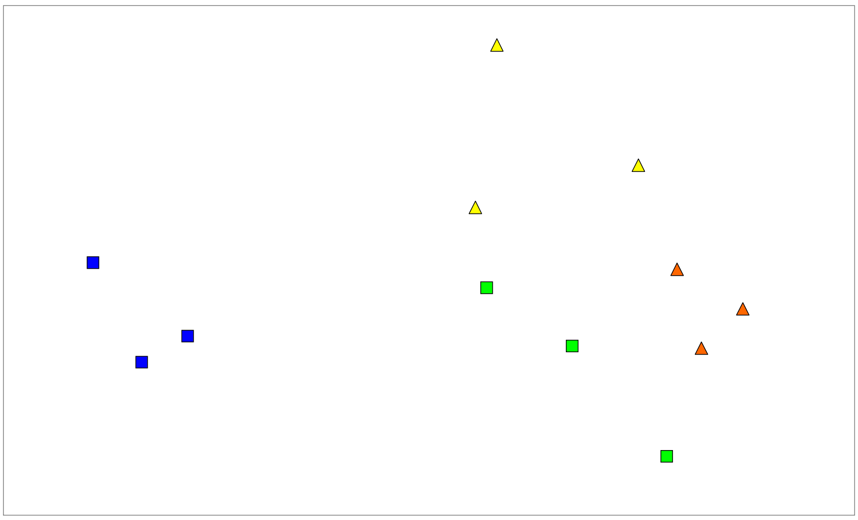

Figure 14. MDS ordination of species composition at Canal 1 (yellow triangles), Lake Curlew (green squares), Canal 2 (orange triangles) and Lake Cargelligo (blue squares) (Stress = 0.08).

Table 13. SIMPER analysis comparing species composition between Canal 1 (C1), Lake Curlew (Cu), Canal 2 (C2) and Lake Cargelligo (Ca).

	Average abundance per sample				**Percent contribution to observed differences (>5%)**					
Species	C1	Cu	C2	Ca	C1 - Cu	C1 -C2	Cu - C2	C1 - Ca	Cu - Ca	C2 - Ca
Western carp gudgeon	27.67	559.33	168.67	2.00	26.29	15.61	6.99	11.48	28.31	18.59
Other carp gudgeon	16.67	20.67	25.00	3.67	-	-	-	8.40	7.94	8.17
Redfin	0.00	0.00	0.00	44.33	-	-	-	22.39	19.24	15.13
Gambusia	2.33	0.00	40.00	0.00	6.78	16.92	23.07	-	-	16.57
Australian smelt	2.67	5.00	0.00	20.67	6.44	6.43	11.13	9.71	6.42	9.98
Flathead gudgeon	3.00	3.33	15.00	0.00	6.71	9.6	10.05	6.74	5.49	11.22
Bony bream	0.00	1.33	8.33	9.33	-	13.89	10.01	13.70	8.35	-
Goldfish	11.33	0.00	3.00	0.00	13.93	8.12	6.53	13.74	-	5.09
Carp	35.00	21.67	2.33	9.67	11.64	13.40	12.34	7.98	8.75	-
Fly-specked hardyhead	0.00	4.67	1.33	0.00	8.02	5.17	6.07	-	5.96	-
Golden perch	0.00	2.33	1.33	0.00	6.90	-	-	-	-	-

3.5 Comparison of fish abundance between seasons

There were more fish caught in summer than in spring ($F = 6.737$, $p = 0.017$), but there was no difference in biomass ($F = 0.313$, $p = 0.582$). Western carp gudgeon, undescribed carp gudgeons and bony bream were more abundant in summer than in spring in all areas combined (Table 14). Within areas, western carp gudgeon and undescribed carp gudgeon were more abundant in summer than in spring in both lakes (Table 14). Western carp gudgeon were also more abundant in summer than in spring in Canal 2 (Table 14).

Table 14. Summary of ANOVA results from comparisons of fish abundance between seasons (* = p<0.05, ** = p<0.01, ns = not significant).

Area	Species	df	Mean Square	F value	*p* value	sig.
All areas	Western carp gudgeon	1	9.267	4.555	0.045	*
	Undescribed carp gudgeons	1	0.873	4.397	0.048	*
	Flathead gudgeon	1	0.478	2.975	0.099	ns
	Bony bream	1	0.845	6.187	0.021	*
	Carp	1	0.222	0.704	0.411	ns
Canal 1	Western carp gudgeon	1	0.501	0.771	0.444	ns
	Undescribed carp gudgeons	1	0.227	2.617	0.204	ns
	Bony bream		(Not caught in Canal 1)			
Lake Curlew	Western carp gudgeon	1	6.761	21.073	0.010	*
	Undescribed carp gudgeons	1	1.291	12.259	0.025	*
	Bony bream	1	0.038	0.858	0.407	ns
Canal 2	Western carp gudgeon	1	0.092	7.830	0.049	*
	Undescribed carp gudgeons	1	0.154	5.779	0.074	ns
	Bony bream	1	0.488	3.808	0.123	ns
Lake Cargelligo	Western carp gudgeon	1	0.317	27.762	0.006	**
	Undescribed carp gudgeons	1	0.617	35.251	0.004	**
	Bony bream	1	0.585	4.236	0.109	ns

3.6 Length frequency and distribution of species

Mature and immature western carp gudgeon, carp, redfin perch, gambusia, flathead gudgeon, bony bream, goldfish and golden perch were sampled during the current study (Table 15). The sample of undescribed carp gudgeons included fish that were smaller than the adult size of *Hypseleotris* sp. 1 (Pusey *et al.* 2004), however this sample may have contained multiple species for which the length at maturity is not known. Mature Australian smelt, fly-specked hardyhead, and freshwater catfish were sampled during the current study (Table 15). Silver perch were observed but not caught during the study, and all observed silver perch were estimated to be less than 200mm TL. This suggests that they were probably immature fish, however they may have been small adults as silver perch have been demonstrated to have highly variable growth rates (Mallen-Cooper *et al*. 1995; NSW DPI 2005).

Table 15. Size range and maturity of caught species sampled during the current study.

Species	Season(s) sampled	Size range (mm)	Maturity composition of sampled fish
Western carp gudgeon (n = 2273)	Both seasons	13 – 49	Mature and immature fish
Carp (n = 27)	Both seasons	87 – 640	Mature and immature fish
Undescribed carp gudgeon (n = 198)	Both seasons	19 – 47	Mature and immature fish*
Redfin perch (n = 134)	Both seasons	62 – 398	Mature and immature fish
Gambusia (n = 126)	Both seasons	8 – 52	Mature and immature fish
Australian smelt (n = 76)	Spring only	42 – 62	Mature fish only
Flathead gudgeon (n = 64)	Both seasons	31 - 90	Mature and immature fish
Bony bream (n = 57)	Both seasons	34 - 387	Mature and immature fish
Goldfish (n = 44)	Both seasons	52 – 115	Mature and immature fish
Fly-specked hardyhead (n = 18)	Summer only	31 – 55	Mature fish only
Golden perch (n = 11)	Both seasons	225 – 348	Mature and immature fish
Freshwater catfish (n = 1)	Summer only	395	Mature fish only

* It is probable that some of the undescribed carp gudgeons in the size range 19 – 30mm were *Hypseleotris* sp. 1 (Pusey *et al.* 2004).

Western carp gudgeon were abundant in Canal 1 in spring (Figure 15a), Lake Curlew in summer (Figure 15b), and in Canal 2 in both seasons (Figure 15c). Immature western carp gudgeon (<20mm in total length) were sampled in Canal 2 and Lake Curlew in both seasons and in Canal 1 in spring only (Figure 15). Western carp gudgeon were rare in Lake Cargelligo, and were sampled only in summer (Figure 15d). Western carp gudgeon were also rare in Canal 1 in summer (Figure 15a).

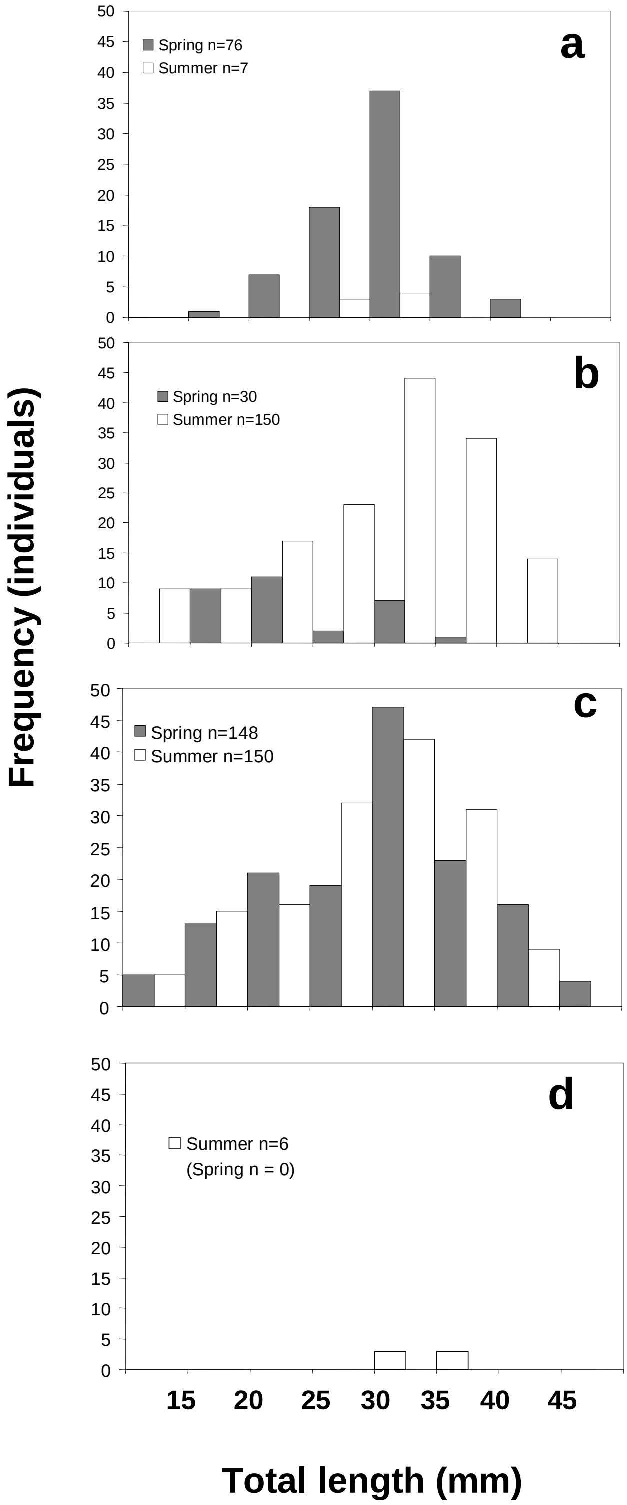

Figure 15. Length frequency of all western carp gudgeon caught during spring (grey bars) and summer (white bars) in Canal 1 (a), Lake Curlew (b), Canal 2 (c) and Lake Cargelligo (d).

Western carp gudgeon were present in numbers of 25 or more in both seasons in Lake Curlew and Canal 2 which allowed a statistical comparison of length frequency to be made (Table 16). Western carp gudgeon from Lake Curlew were smaller in spring than in summer, but this pattern was not evident in Canal 2, where there was no difference in the size of western carp gudgeon between spring and summer (Figure 16).

Table 16. Summary table of results from Kolmogorov-Smirnov two-sample tests on western carp gudgeon from Lake Curlew and Canal 2. (*** = p<0.001, ns = not significant).

Comparison	**Kolmogorov-Smirnov Z**	**Asymp. Sig. (2 – tailed)**	**Sig.**
Curlew spring Vs Curlew summer	2.200	0.000	***
Canal 2 spring Vs Canal 2 summer	0.649	0.749	ns

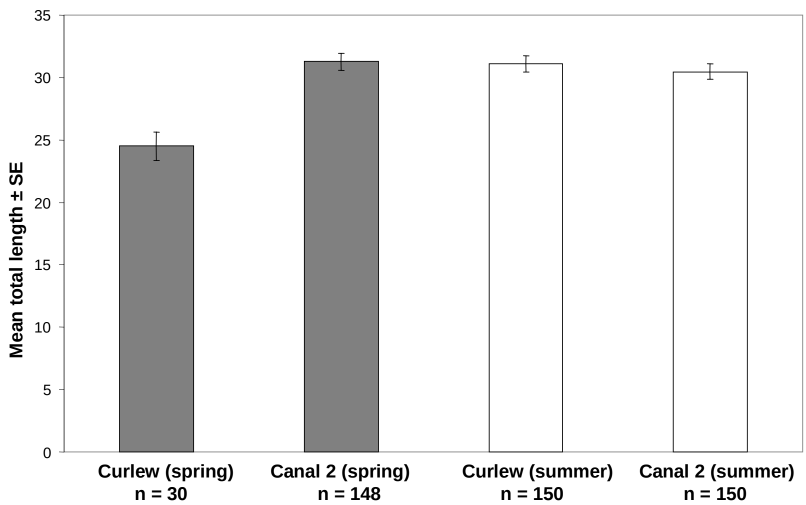

Figure 16. Mean total length ± standard error of western carp gudgeon in Lake Curlew and Canal 2 in spring (grey bars) and summer (white bars).

Bony bream were commonly sampled from Canal 2 and Lake Cargelligo during the current study. Immature bony bream with a total length of less than 150mm were more abundant in the summer samples than in the spring samples (Figure 17). Small bony bream less than 50mm in total length were sampled only from Lake Cargelligo in summer. Bony bream were not sampled in Canal 1, and only four individuals were sampled in Lake Curlew (Table 8).

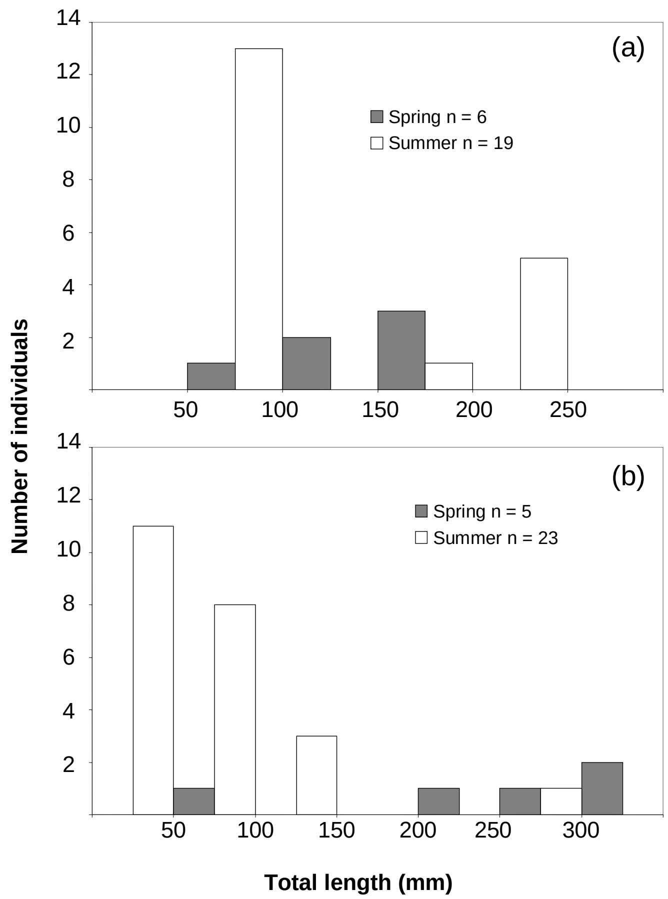

Figure 17. Length frequency of bony bream caught during the current study in Canal 2 (a) and Lake Cargelligo (b).

Flathead gudgeon were sampled in all areas, however 69.2% of all flathead gudgeon sampled were caught in Canal 2 (Table 8). Immature flathead gudgeon with a standard length of less than 50mm were sampled from Canal 2 in both spring and summer, and individuals less than 30mm in standard length were sampled from Canal 2 only in summer (Figure 18).

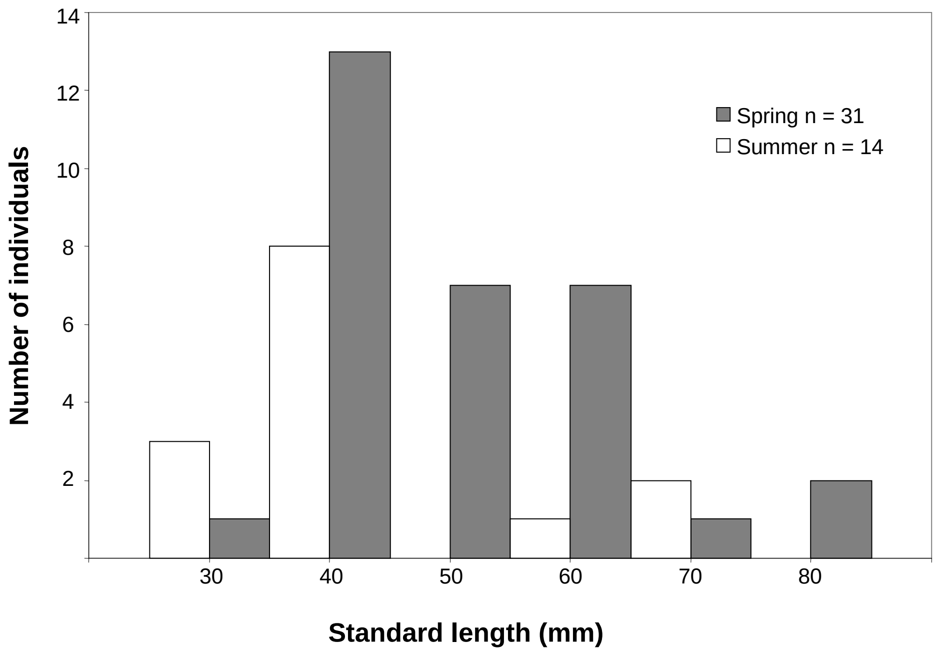

Figure 18. Length frequency of flathead gudgeon caught in Canal 2 during the current study.

Redfin perch were generally restricted to Lake Cargelligo, and only one individual was sampled from another area (Canal 2 in summer) (Table 8). Redfin perch with a total length of less than 100mm were sampled in summer only, whereas mature redfin perch were sampled in both seasons (Figure 19).

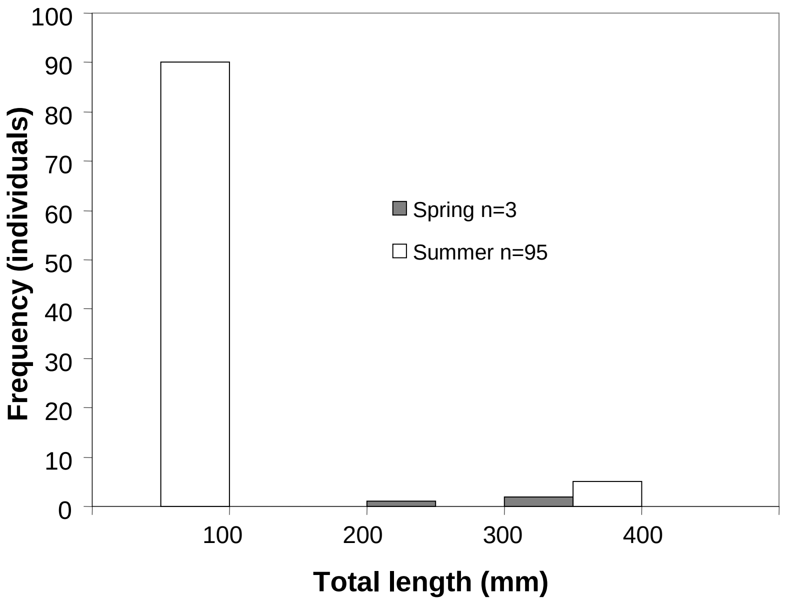

Figure19. Length frequency of redfin perch from Lake Cargelligo during both sampling periods.

Gambusia were absent from both Lake Curlew and Lake Cargelligo, and 94.5% of all gambusia were sampled in Canal 2 (Table 8). Immature gambusia with a total length of less than 20mm were sampled only from Canal 2 in summer (Figure 20). Although larger gambusia were sampled in both seasons, comparatively few gambusia (11) were sampled in spring (Table 8).

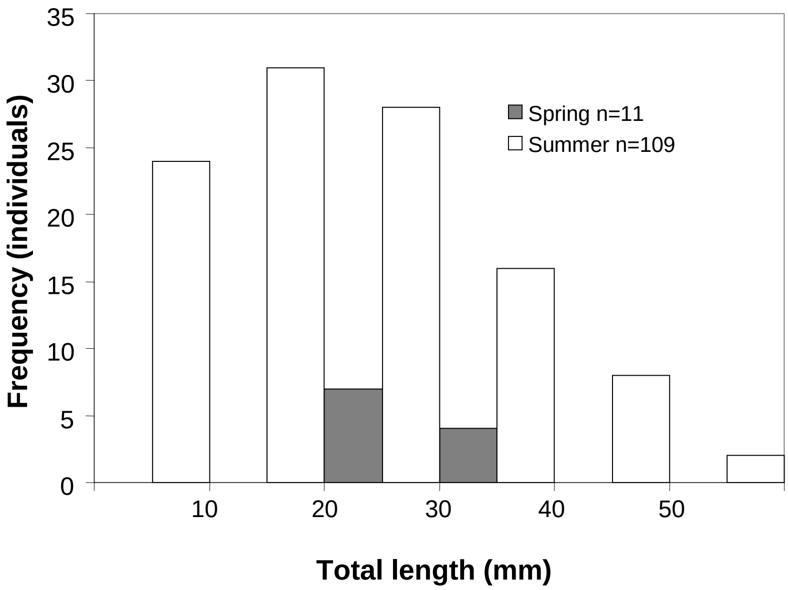

Figure 20. Length frequency of gambusia from Canal 2 during both sampling periods.

4. Discussion

4.1 Comparison of the current survey with previous surveys in the Lachlan catchment

The results from the current survey of the Lake Cargelligo system include a greater number of species than all previous surveys in the lower Lachlan catchment, with the exception of the study by Llewellyn (1983)(Table 17).

Table 17. Fish species recorded in surveys within the Lachlan catchment 1983 – present, but excluding species only found at higher altitudes. All *Hypseleotris* gudgeons are grouped together as 'all carp gudgeons'.

Species	**1983 (Llewellyn)**	**1997 (Harris & Gehrke)**	**2001 (Growns)**	**2004 (MDBC – SRA Pilot)**	**2004/05 Lake Cargelligo system**
Australian smelt	●	●	●	●	●
Goldfish	●	●	●	●	●
Carp	●	●	●	●	●
Freshwater catfish	●		●		●
Gambusia	●	●	●	●	●
Fly-specked hardyhead	●				●
Agassiz's glassfish	●				
Murray cod	●		●	●	
Golden perch	●	●	●	●	●
Bony bream		●	●	●	●
Silver perch	●	●			●
Redfin	●	●	●	●	●
All carp gudgeons	●	●	●	●	●
Flathead gudgeon	●	●	●	●	●
Total number of species	**13**	**10**	**11**	**10**	**12**

Determining the exact number of species sampled during the current study was difficult due to the presence of three undescribed species of carp gudgeons in the samples. While most authors have avoided dealing with this taxonomically complex group of species (Harris & Gehrke 1997; Growns 2001; MDBC 2004), an attempt was made during this study to differentiate between western carp gudgeon and these undescribed species.

The current study is the first fish survey of the Lake Cargelligo system. All other surveys were undertaken in either the main channel of the Lachlan River and/or at effluent creek sites (Harris & Gehrke 1997; Growns 2001; MDBC 2004). Results from this study suggest that the Lake Cargelligo system currently contains a larger number of Murray-Darling Basin fish species than the main channel or effluent creeks of the lowland Lachlan River.

Analysis of the fishing methods used in *The NSW Rivers Survey* (Harris & Gehrke 1997) concluded that boat electrofishing is the most suitable fish sampling method for fresh waters in south-eastern Australia and that electrofishing (by both boat and backpack), generally provides a more accurate representation of fish communities than passive fish sampling methods (Faragher & Rodgers 1997). The current study supports this finding, as more species were sampled using backpack electrofishing (9) than by fyke nets (6) or bait traps (7). Additionally, the use of backpack electrofishing facilitated the observation and positive identification of fish, particularly carp and silver perch, in instances where they could not be netted.

During the current study, golden perch, redfin perch and freshwater catfish were not sampled by backpack electrofishing, despite the fact that these species have been sampled by electrofishing in past surveys within the Lachlan catchment (Growns 2001) and within the Lake Cargelligo system (Andrew Bruce NSW DPI pers. comm.). Backpack electrofishing sampled more fish in canal habitats than lake habitats during the current survey, and when staff from NSW DPI used boat electrofishing in July 2004, approximately 900 fish were sampled from Canal 2, but exploratory electrofishing in Lake Curlew produced no samples (Andrew Bruce NSW DPI pers. comm.). Thus, although electrofishing has generally been suggested to be the most effective and efficient sampling method (Faragher & Rodgers 1997), results from both the current survey and the NSW DPI sampling (July 2004) suggest that electrofishing may be an ineffective sampling technique in large areas of open water such as Lake Cargelligo and Lake Curlew.

4.2 Species absent from the Lake Cargelligo system

Species not recorded in the current study of the Lake Cargelligo system but recorded in past surveys within the Lachlan catchment include Agassiz's glassfish, which were recorded by Llewellyn (1983), and Murray cod, which were recorded by Llewellyn (1983), Growns (2001) and MDBC (2004).

The western population of Agassiz's glassfish is listed as endangered (NSW Fisheries 2005a) and this species has not been recorded from the Lachlan catchment since Llewellyn's survey (1983). Additionally, only a single specimen of Agassiz's glassfish was recorded from western New South Wales in the Macquarie River during the *NSW Rivers Survey* (Harris & Gehrke 1997). Agassiz's glassfish were recorded during the *Sustainable Rivers Audit Pilot* (MDBC 2004), but only in the Condamine River in the northern Murray-Darling Basin. The scarcity of Agassiz's glassfish in the Murray-Darling Basin may be linked to the absence (or decline) of suitable habitat, as studies in south-east Queensland have demonstrated that this species prefers areas containing aquatic macrophytes (Pusey *et al.* 2004). Additionally, although Agassiz's glassfish is tolerant of a wide range of variation in temperature, dissolved oxygen, pH and conductivity, this species may be disadvantaged by high turbidity, as Agassiz's glassfish have not been recorded from Queensland in waters with turbidity exceeding 144 NTU (Pusey *et al*. 2004). This turbidity figure was exceeded in all areas of the Lake Cargelligo system during the current study except Canal 2. It is likely that a combination of turbid water and the comparative absence of aquatic macrophytes are contributing factors to the status of Agassiz's glassfish within the southern Murray-Darling Basin generally, and specifically within the Lachlan catchment and the Lake Cargelligo system.

Murray cod are considered to be declining throughout the Murray-Darling Basin (NSW Fisheries 2005a). The decrease in their abundance is commonly attributed to the impact of commercial fishing and alterations to the riverine environment (Allen *et al.* 2002). Murray cod inhabit deeper sections of rivers and streams, and prefer areas with cover provided by in-stream debris and overhanging vegetation (Allen *et al.* 2002). Although Murray cod have exhibited migratory behaviour (Reynolds 1983), research indicates that they return to a specific home range (Koehn 1996). An unknown number of Murray cod were sampled in the Lachlan catchment by Llewellyn (1983), and the fishing method used is absent from the data. Murray cod were not sampled in the Lachlan catchment by Harris and Gehrke (1997), three Murray cod were sampled by electrofishing in the Lachlan catchment by Growns (2001), and four were sampled by electrofishing in the Lachlan catchment by MDBC (2004). These observations suggest that Murray cod occur in the Lachlan catchment in relatively small numbers and that electrofishing is the most successful method for sampling this species.

The shallow lakes and interconnecting canals of the Lake Cargelligo system, and especially the deeper sections of Lake Curlew and Canal 2, provide habitat which could be considered suitable for Murray cod. Historical anecdotal evidence from the 1930s and 1940s suggests that Murray cod were previously more abundant within the Lake Cargelligo system (Roberts & Sainty 1996), however more recent anecdotal evidence from an ex-commercial fisher indicates that Murray cod have been an uncommon species within the Lake Cargelligo system for at least the last 30 years (Colin Sibraa pers. comm.). Although this local decline may be linked with the population spread of carp (1970s) and subsequent reduction in aquatic vegetation, the decline in Murray cod numbers appears to pre-date this period. The commercial catch data for Murray cod in the Lachlan catchment was highest in the decade 1955 – 64 with a catch of 2.74 tonnes and was lowest in the decade 1974 – 84, when only 0.35 tonnes were caught (Reid *et al.* 1997). As commercial fishing in the Lachlan catchment was limited to Lakes Cowal, Brewster and Cargelligo from 1959, all Murray cod caught from the Lachlan catchment from 1959 onwards were caught from these three lake systems. From 1965 – 1994 the total recorded catch of Murray cod in the Lachlan catchment was only 2.31 tonnes (Reid *et al.* 1997), which suggests that Murray cod have not been common in either Lake Cargelligo or the other lakes since the 1950s. It is likely that a combination of recreational, illegal and commercial fishing (in the period before catch reporting was introduced in 1947), has had a large impact on the numbers of Murray cod in the Lachlan catchment.

4.3 Species present in the Lake Cargelligo system

Species recorded during the current study of the Lake Cargelligo system include freshwater catfish, silver perch, golden perch, fly-specked hardyhead, goldfish, bony bream, flathead gudgeon, Australian smelt, gambusia, redfin perch, carp, western carp gudgeon and up to three species of undescribed carp gudgeons.

Freshwater catfish, which are considered to be in decline (NSW Fisheries 2005a), have been sampled previously in the Lachlan catchment by both Llewellyn (1983) and Growns (2001). Freshwater catfish are found in a wide variety of habitat types within the Murray-Darling Basin and within other drainage divides, and also appear to be capable of tolerating a wide range of variance in temperature, dissolved oxygen, pH and conductivity (Pusey *et al.* 2004). One adult freshwater catfish was sampled during the current study in a heavily snagged area of Lake Curlew with a turbidity of 376 NTU. This is far in excess of the highest turbidity reading recorded from studies of freshwater catfish in the north-east coast drainage division (250 NTU) (Pusey *et al.* 2004), indicating that freshwater catfish are tolerant of high turbidity in the southern Murray-Darling Basin. Two freshwater catfish were also sampled by NSW DPI staff in July 2004 in Canal 2 (Andrew Bruce NSW DPI pers. comm.). Both anecdotal accounts (Roberts & Sainty 1996) and commercial fishing records (Reid *et al.* 1997) indicate that the population of freshwater catfish has declined since the 1970s in both the Lake Cargelligo system and the Lachlan River generally, and this is most often attributed to the population spread of the Boolara strain of carp, the removal of aquatic macrophytes and increasing turbidity (Roberts & Sainty 1996). Freshwater catfish are a non-migratory species (Reynolds 1983; Pusey *et al*. 2004). Therefore, it is likely that commercial fishing may have had a substantial impact on their population within the Lake Cargelligo system. Additionally, freshwater catfish are a nest-building fish (Merrick & Schmida 1984), and both the degradation of breeding areas and the feeding habits of carp have been suggested as possible limiting factors to their reproductive success (Allen *et al.* 2002). Although immature freshwater catfish were not sampled during the current study, it is likely that freshwater catfish breed within the Lake Cargelligo system, as depressions matching the description of freshwater catfish nests have been observed close to Site 9 in Canal 2 (pers. obs.).

Silver perch, which are listed as vulnerable (NSW Fisheries 2005a), have been recorded previously in the Lachlan catchment by Llewellyn (1983) and Harris and Gehrke (1997) and were observed during the current study in small numbers (4) in both the open-water environment of Lake Curlew and close to woody debris in Canal 2. Silver perch occur in a wide range of habitat types within the Murray-Darling Basin, including impoundments, headwater streams and lowland rivers (NSW DPI 2005). Commercial fishing records from the Lachlan catchment suggest that, like Murray cod, silver perch have not been an abundant species during the last 60 years (Reid *et al.* 1997). Anecdotal information from an ex-commercial fisher indicates that silver perch have been noticeably rare in the Lake Cargelligo system since the 1980s (Colin Sibraa pers. comm.). Silver perch are an omnivorous species (Warburton 1998) and consequently their diet overlaps with that of carp. Given that large numbers of carp were also caught and observed during the current study, it is possible that carp may compete with silver perch and therefore affect the population of silver perch within the Lake Cargelligo system. However, this does not adequately explain the apparent scarcity of silver perch that appears to pre-date the arrival of the Boolara strain of carp in the early 1970s (Roberts & Sainty 1996). Research has suggested that silver perch undertake migration for either spawning (Reynolds 1983) or dispersal (Mallen-Cooper *et al.* 1995). It is possible that the limited opportunities to access migration pathways may affect the success of this species within the Lake Cargelligo system. Silver perch are known to be susceptible to the EHN virus (Rowland & Ingram 1991), and the presence of redfin perch in the Lake Cargelligo system suggests there is a possibility that the silver perch population may have been exposed to this virus.

Golden perch have been sampled frequently in the Lachlan catchment (Llewellyn 1983; Harris & Gehrke 1997; Growns 2001; MDBC 2004), and golden perch were sampled in both Lake Curlew and Canal 2 in the current study. Golden perch were exclusively sampled in the vicinity of snags, stumps and standing dead trees. Golden perch are a piscivorous species which has been demonstrated to utilise a 'sit and wait' ambush approach to catch prey in an experimental study (Shirley 2002). It is likely that the sites in Lake Curlew and Canal 2 provide the most appropriate habitat for golden perch within the Lake Cargelligo system due to the presence of cover and the large number of small (prey) species that were also sampled at these sites. Golden perch in the Murray-Darling Basin are known to inhabit water with a Secchi disk reading of 12 cm (Pusey *et al.* 2004), which corresponds to approximately 400 NTU (King 1995). The current survey confirms that golden perch are tolerant of turbidity in this range, as a single specimen from Lake Curlew in summer was sampled in water with a turbidity of 376 NTU. Movement studies of this species suggest that migration may be associated with either spawning of mature fish (Reynolds 1983) or dispersal of juveniles (Mallen-Cooper *et al.* 1995), however subsequent studies indicate that golden perch may also utilise low flows for recruitment (Humphries *et al.* 1999). There is general consensus within the most current literature that golden perch are a highly adaptive species that is capable of spawning and recruiting in a variety of flow and habitat conditions (Pusey *et al.* 2004). As a combination of mature and immature golden perch were sampled during the current study, it is possible that recruitment of this species occurs within the Lake Cargelligo system. Alternatively, recruitment may occur elsewhere within the Lachlan River, and the sampled fish may have entered the Lake Cargelligo system during earlier periods of connectivity before December 2003.

The current study has confirmed the presence of fly-specked hardyhead in the Lake Cargelligo system. A species of hardyhead was previously sampled in the main channel of the Lachlan River by Llewellyn (1983), and recorded as *Craterocephalus fluviatilis* (not *Craterocephalus stercusmuscarum*) (see Appendix 1). Records held at the Australian Museum indicate that earlier samples of fly-specked hardyhead (recorded as *Craterocephalus stercusmuscarum fulvus*) were taken in Lake Cargelligo in 1972 (Australian Museum Fish Database 2005). Fly-specked hardyhead were not sampled in the Lachlan catchment during the *NSW Rivers Survey* (Harris & Gehrke 1997), by Growns (2001) or by the MDBC (2004). This indicates that fly-specked hardyhead may have a limited range within the Lachlan catchment and that this range may be confined to the Lake Cargelligo system. Fly-specked hardyhead are a pelagic schooling species and demonstrate a preference for areas of low flow (Pusey *et al.*

2004). The Lake Cargelligo system, which includes large areas of open water with very little flow may be a highly suitable habitat for this species within the southern Murray-Darling Basin. Fly-specked hardyhead are thought to mature quickly (<1 year) and be short-lived (2+ years) (Milton & Arthington 1983 cited in Pusey *et al.* 2004). It seems likely that this species breeds within the Lake Cargelligo system, especially given the intermittent nature of the system's connectivity with the Lachlan River, however immature fly-specked hardyhead were not sampled during the current study.

Goldfish were sampled in all areas except Lake Cargelligo during the current study. Of the 44 goldfish sampled, only 2 were sampled in summer. Despite the presence of goldfish in the Murray-Darling Basin over an extended period, a paucity of information exists regarding their ecological significance (Faragher & Harris 1994). The current study indicates that within the Lake Cargelligo system, goldfish are more abundant in areas such as Canal 1 which do not contain large amounts of riparian and in-stream cover and which are not favoured by the majority of other species. Both mature and immature goldfish were sampled during the current study, suggesting that goldfish breed within the Lake Cargelligo system. Explaining the scarcity of goldfish in the summer samples is problematic, for goldfish were sampled by all three sampling techniques in spring and are thought to be tolerant of a wide range of water quality and habitat variables (Allen *et al.* 2002). Estimating the possible impacts goldfish may have on native fish populations within the Lake Cargelligo system (and within the Murray-Darling Basin generally) is limited by a lack of research data (Faragher & Lintermans 1997).

Bony bream were sampled in all areas except Canal 1 during the current study, and this species has been sampled regularly within the Lachlan catchment (Harris & Gehrke 1997; Growns 2001; MDBC 2004). Bony bream are the most widely distributed freshwater fish in Australia and, as detritivores and algivores, their presence is thought to play an important role in the functioning of aquatic ecosystems (Pusey *et al.* 2004). The presence of immature bony bream (<150mm TL) in both Canal 2 and Lake Cargelligo, and juvenile bony bream (<50mm TL) in Lake Cargelligo during the current study supports the findings of Puckridge and Walker (1990) which demonstrated that bony bream spawn in open-water environments within the southern Murray-Darling Basin.

Flathead gudgeon were sampled in all areas of the Lake Cargelligo system, and the total number sampled (65) was far higher than previous recorded totals from sites within the Lachlan catchment. A single flathead gudgeon was recorded by Growns (1991), and four were recorded during the *Sustainable Rivers Audit Pilot Study* (MDBC 2004). As Harris and Gehrke (1997) recorded a total of 46 flathead gudgeon from all sites in western New South Wales, the population of flathead gudgeon within the Murray-Darling Basin appears to be localised and fragmented, and the Lake Cargelligo system in the Lachlan catchment may provide highly suitable habitat for this species. Flathead gudgeon were most common in slow-flowing or still-water canal habitats during the current study and were most-often sampled in the vicinity of fallen timber, stumps and aquatic macrophytes. The presence of immature flathead gudgeon, ranging in size from 30 – 50mm SL, supports previous studies (Humphries *et al.* 1999) that suggest that this species has an extended spawning season.

Australian smelt have been sampled within the Lachlan catchment during all recent surveys (Llewellyn 1983; Harris & Gehrke 1997; Growns 2001; MDBC 2004), and were sampled during the current study in spring only in all areas except Canal 2. Australian smelt are a pelagic schooling species (Pusey *et al.* 2004), and the majority (73%) were sampled in the open-water habitat of Lake Cargelligo in the current study. It has been suggested that Australian smelt may be intolerant of increased suspended sediment concentrations (Pusey *et al.* 2004), and as the mean turbidity of Lake Cargelligo increased from 119 NTU in spring to 419 NTU in summer, this may explain their lack of abundance in this area during summer. Australian smelt appear to spawn in a range of habitats and often over an extended period (Pusey *et al.* 2004). Although immature Australian smelt were not sampled during the current study, it is likely that Australian smelt complete their life-cycle within the Lake Cargelligo system, especially given their life expectancy (2 - 3 years) and their age at maturity (6 – 9 months) (Milton & Arthington 1985, cited in Pusey *et al.* 2004).

Gambusia were absent from both lakes during the current study, but common in Canal 2 in the vicinity of in-stream and riparian cover. Gambusia have a widespread distribution within the Murray-Darling Basin, show a preference for slow-flowing habitats with overhead and in-stream cover and are tolerant of a wide variety of water quality parameters and habitat characteristics (Faragher & Lintermans 1997). Gambusia are the only live-bearing fish occurring in the Lake Cargelligo system. Gravid females and juveniles (<10mm TL) were sampled from all Canal 2 sites in summer. This supports the conclusion of King *et al.* (2003), that gambusia only spawn in low-flow conditions. Gambusia are efficient and opportunistic predators, and dietary overlaps between gambusia and small native species have been demonstrated in Queensland studies (Arthington 1991).

Redfin perch were almost exclusively found in the open-water habitat of Lake Cargelligo, with the exception of one individual from Canal 2. The current study suggests that habitat requirements for redfin perch recruitment may include shallow, unsheltered lakes with a minimum of cover, as immature redfin perch were sampled from Lake Cargelligo in summer. This finding is in contrast with some authors (Merrick & Schmida 1984; Allen *et al.* 2002), who state that redfin perch require sheltered areas with vegetation and/or submerged debris in order to spawn.

European studies suggest that redfin perch are more likely to favour open habitats in water with high turbidity due to a decreased need for cover (Snickars *et al*. 2004), and that they are able to compensate for increasing turbidity in their feeding behaviour (Granqvist & Mattila 2004). Although the turbidity figures used in the European experiments (up to 30 NTU) were extremely low in comparison with the turbidity of the southern Murray-Darling Basin, it is possible that redfin perch exhibit similar (and increased) adaptive behaviour in highly turbid Australian environments. Within the Lake Cargelligo system, redfin perch were most numerous at the most turbid site, and several redfin perch were observed to have small bony bream (<50mm TL) in their mouths. The feeding efficiency of redfin perch has been demonstrated to be compromised in highly turbid water in an Australian experimental study, and this has been suggested as a limiting factor for their growth, survival and recruitment in the presence of large numbers of carp (Shirley 2002). During the current study, immature and adult redfin perch were caught at the same sites as carp, and in water which far exceeded the maximum turbidity (125 NTU) tested by Shirley (2002). This suggests that redfin perch are an adaptable species and that high turbidity may not necessarily impact negatively on their behaviour within the Lake Cargelligo system. Redfin perch comprised 19.5% of the total biomass of fish in this study. Redfin perch are active and efficient piscivores. Their high contribution to total fish biomass in this study suggests that they have the potential to contribute to a decline in the numbers of prey species in the Lake Cargelligo system. In Western Australian experiments Molony *et al.* (2004) introduced 50 – 80mm rainbow trout into ponds containing redfin perch. Within 60 hours the small fish appeared to have suffered up to 100% mortality. In the current study, although bony bream and Australian smelt were sampled where redfin perch also occurred, western carp gudgeon, undescribed carp gudgeons and flathead gudgeon were sampled in only very small numbers, and fly-specked hardyhead were not found. As these species are all likely to be preyed upon by redfin perch, it is possible that the large numbers of redfin perch within Lake Cargelligo contribute to the low populations of some or all of these prey species. Experimental removal of redfin perch from waterways in New Zealand has demonstrated a resultant increase in the populations of smaller native species (Ludgate & Closs 2003), indicating that redfin perch are likely to deplete the populations of smaller native fish in habitats where they are the dominant piscivores.

Carp were caught and observed in all areas of the Lake Cargelligo system during the current study. Carp have been most commonly found in slow-flowing turbid waterways within western New South Wales (Faragher & Lintermans 1997; Driver *et al.* 1997). The Lake Cargelligo system therefore represents highly suitable habitat for this species. Although caught carp made up 42% of total biomass, a much larger number of carp were observed, suggesting that the total biomass of carp within the Lake Cargelligo system may be extremely high. During the spring sampling period, carp were observed forming large spawning aggregations in Canal 1. The presence of both mature and immature carp within the samples indicates that this species reproduces within the Lake Cargelligo system. Carp have been classified as both macrophagic omnivores (Harris 1995) and macro carnivores (MDBC 2004). Under either classification, but particularly if they are considered carnivores, it seems likely that carp may have a direct impact upon the populations of all potential prey species within the Lake Cargelligo system given their high biomass and wide distribution.

Western carp gudgeon and undescribed carp gudgeon were common in all areas sampled in this study with the exception of Lake Cargelligo, where in-stream cover was minimal and predators (redfin perch) were abundant. Immature (<20mm) western carp gudgeon and undescribed carp gudgeons were present in both the spring and summer samples. The presence of large congregations of both adult and juvenile western carp gudgeons in Lake Curlew in summer may provide evidence of localised migration within the Lake Cargelligo system. It is possible that such localised migrations are linked to recruitment, as gravid females were common within the Lake Curlew samples. Migratory behaviour has been suggested for larger species such as golden perch and silver perch, both as adults (Reynolds 1983) and juveniles (Mallen-Cooper *et al.* 1995). More recently, migratory behaviour on a smaller scale has been found to characterise the life cycles of smaller species such as carp gudgeons (all species), Australian smelt and fly-specked hardyhead (Baumgartner 2004).

The possibility that certain areas within the Lake Cargelligo system may be utilised as breeding areas by western carp gudgeon is supported by the abundance of this species within Lake Curlew. During spring, a comparatively small number of western carp gudgeon was sampled in Lake Curlew and most were less than 25mm in total length. In summer, 1,648 western carp gudgeon were sampled in Lake Curlew with a mean total length of over 30mm. It is therefore possible that during spring a small resident population of western carp gudgeon inhabit Lake Curlew, but in summer large numbers of adult western carp gudgeon migrate to the area. Although the reproductive biology of carp gudgeons (all species) is poorly understood (Pusey *et al.* 2004), various species have been spawned in aquaria when water temperatures were between 20° and 30°C (Unmack 2000). The current study indicates that recruitment within wild populations may be associated with large aggregations of western carp gudgeon in particular areas in summer. However, the presence of juvenile and immature western carp gudgeon in both sampling periods also suggests that these species may spawn over an extended period or may spawn more than once during a breeding season. The current study also indicates that carp gudgeon recruitment is not contingent upon elevated flows or water levels, since no water entered the Lake Cargelligo system during (or between) both sampling periods. This supports the finding of King *et al.* (2003), that *Hypseleotris* gudgeons prefer low flow periods for spawning.

4.4 Seasonal abundance of fish within the Lake Cargelligo system

More fish were sampled in summer (2572) than spring (653) in this study, supporting previous observations that summer is the most opportune season to sample freshwater fish in south-eastern Australia (Faragher & Rodgers 1997). However, the species composition of the samples changed at most sites between spring and summer, suggesting that sampling in different seasons is likely to give a more accurate representation of resident fish communities. Athough most species were more abundant in the summer samples, goldfish, flathead gudgeon and golden perch were sampled in higher numbers in spring, indicating that multi-season sampling is necessary in order to accurately investigate fish distribution and abundance within a localised system such as Lake Cargelligo. In general, the large difference between the number of individuals sampled in spring and summer can be attributed to 1,648 western carp gudgeon caught in Lake Curlew in summer.

The area that demonstrated the largest seasonal change in fish abundance was Lake Curlew, with only 71 individuals sampled in spring and 1,789 sampled in summer. The species most commonly caught in Lake Curlew in summer was western carp gudgeon. Piscivorous species such as golden perch and freshwater catfish, and 104 common snake-neck turtles and 184 Macquarie turtles were also caught in Lake Curlew in summer. This suggests that aggregations of western carp gudgeon may be opportunistically preyed upon by larger species. This seems especially likely for turtles, as recent studies indicate that the diet of freshwater turtles in south-eastern Australia, although dominated by vegetable debris, is also largely made up of fish (Meathrel *et al*. 2004). As turtles are considered to be opportunistic omnivores (Cann 1978), it is highly likely they would take advantage of aggregations of small fish such as western carp gudgeon, and as turtles of two species were sampled in high numbers, it is possible that common fish such as western carp gudgeon may form a significant part of their diet within the Lake Cargelligo system.

4.5 Implications for management and future research

Breeding populations of native fish species such as western carp gudgeon, undescribed carp gudgeons, flathead gudgeon and bony bream were recorded during the current study. Comparatively low numbers of golden perch, silver perch, fly-specked hardyhead and freshwater catfish were found. Vulnerable and declining species (silver perch, freshwater catfish, fly-specked hardyhead) were limited in their ranges to Lake Curlew and Canal 2, and it is these areas which therefore have higher conservation value within the Lake Cargelligo system. Inclusion of the Lake Cargelligo system in future large-scale audits of the Lachlan catchment is recommended in order to monitor the populations of these species.

Fly-specked hardyhead are present in the Lake Cargelligo system, but may be absent from the main channel of the Lachlan River and effluent creeks (Harris & Gehrke 1997; Growns 2001; MDBC 2004). Additionally, fly-specked hardyhead appear to be uncommon in other parts of the southern Murray-Darling Basin (Ivantsoff & Crowley 1996; Harris & Gehrke 1997). Further research on the population of all hardyheads within the Lachlan, Murrumbidgee and Murray catchments is necessary in order to confirm their current status. Further research on the Lake Cargelligo population of fly-specked hardyheads is recommended in order to ensure it remains viable. The current management of the Lake Cargelligo system should aim to ensure that the population of fly-specked hardyheads is not exposed to threatening processes.

The current study indicates that both silver perch and freshwater catfish are present in the Lake Cargelligo system in resident (but possibly small) populations. Management of the Lake Cargelligo system should aim to protect and enhance the habitats afforded by Lake Curlew and Canal 2 with a view to conserving these species, and future studies of the populations of these species within the Lake Cargelligo system are encouraged.

The results of the current study suggest that the *Hypseleotris* gudgeon complex is well-represented within the Lake Cargelligo system, and highlight the difficulties associated with identifying these fishes to a species level due to the lack of taxonomic work completed to date. Research aimed at describing the *Hypseleotris* gudgeons of the Murray-Darling Basin should be prioritised, and the inclusion of samples from the Lake Cargelligo system may be beneficial to such work.

Carp, redfin perch, gambusia and goldfish were all found to occur in breeding populations within the Lake Cargelligo system. Research aimed at quantifying the impacts alien species have on both habitat and native species could be undertaken within the areas surveyed during the current study. Addressing the lack of information regarding the impacts of redfin perch on native fish populations and the ecological significance of goldfish would be highly beneficial to all future studies of fish communities in the southern Murray-Darling Basin. Additionally, as the Lake Cargelligo system is physically isolated from the Lachlan River (and linked only by regulated channels), it represents one of the few areas in the Murray-Darling Basin where a program aimed at excluding alien fish may be successful.

5. Conclusion

Both the fish fauna and the riverine environment of the Lachlan catchment are considered to be in a degraded condition (NSW EPA 1999a; NSW EPA 1999b; Growns 2001). The current study has found that the Lake Cargelligo system includes populations of all fish species that may occur in the lowland Lachlan River with the exception of Murray cod and Agassiz's glassfish. The assemblage of fish species found includes silver perch, freshwater catfish and fly-specked hardyhead, all of which are thought to be declining in the southern Murray-Darling Basin (Allen *et al.* 2002), and significant numbers of flathead gudgeon, which appear to have a patchy distribution in western New South Wales. The Lake Cargelligo system therefore represents a faunally significant wetland of the lower Lachlan River.

The combined areas of Lake Curlew and Canal 2 contributed 82.5% of all fish sampled during the current survey. The larger amount of in-stream cover available in Lake Curlew and Canal 2 appears to be the most likely reason for the greater number of species and the greater number of individuals recorded from these areas. Lake Curlew and Canal 2 also remained deeper than either Canal 1 or Lake Cargelligo, and Lake Curlew and Canal 2 were the only areas that remained connected throughout the entire sampling period. It is unlikely that the variations in temperature, dissolved oxygen, pH and conductivity recorded during the current study contributed substantially to the variation in fish distribution and abundance. However, it is possible that increasing turbidity, combined with decreasing depth, may have affected populations of native species (such as Australian smelt) during summer. Fish were far more abundant in summer than spring in all areas except Canal 1 (which had become very shallow). Increases in fish abundance in summer can be directly linked with the recruitment of species such as redfin perch and gambusia. The largest species increase (western carp gudgeon in Lake Curlew) may represent a localised migration event which could also be associated with recruitment.

It is highly likely that the majority of fish species sampled are able to complete their life cycles within Lake Cargelligo and that recruitment is not dependent upon connectivity with the Lachlan River. Immature goldfish, gambusia, redfin, flathead gudgeon, bony bream, western carp gudgeon and undescribed carp gudgeon were sampled during the current study, and no flows or interaction with the Lachlan River had occurred in the Lake Cargelligo system since December 15, 2003 (inlet) and January 8, 2004 (outlet) (Nachi Nachiappan State Water pers comm.). Immature golden perch and silver perch (with an approximate total length of less than 200mm) were also present. Whether these fish were recruits from the Lake Cargelligo system or the Lachlan River is difficult to ascertain due to their longevity and age at sexual maturity (Mallen-Cooper *et al.* 1995; Pusey *et al.* 2004). The short life-spans and early maturity of Australian smelt and fly-specked hardyhead suggest that recruitment of these species is highly likely to be non-dependent on connectivity with the Lachlan River, despite the fact that immature fish were not sampled. It is probable that freshwater catfish also recruit within the Lake Cargelligo system, as this species is non-migratory and depressions resembling catfish nests have been observed (pers. obs.)

The current study indicates that areas of low-flow which offer a variety of habitats may be important nursery areas for many fish species within lowland rivers of western New South Wales and that recruitment may be concentrated in these areas for some species. The results from this study also indicate that the presence or absence of in-stream cover strongly influences fish distribution and abundance in specific areas of the lowland Murray-Darling Basin and that a large number of predicted or expected species may be present in waterways where a diversity of habitat exists.

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Appendix 1: Classification and nomenclature anomalies

Three families of fishes mentioned in this paper continue to cause a degree of taxonomic confusion due to their identification and nomenclature. These families are discussed below.

The Atherinidae

During Llewellyn's (1983) report reference is made to *Craterocephalus fluviatilis* occurring in the Lachlan River. Commonly referred to as the Murray hardyhead, *Craterocephalus fluviatilis* appears to have suffered a drastic reduction in distribution during the period 1986 – 1996 (Ivantsoff & Crowley 1996) and was not recorded from either the Murrumbidgee or Murray Rivers during this time. As the various *Craterocephalus* species are similar, it is likely that confusion between *Craterocephalus fluviatilis*, *Craterocephalus amniculus* (Darling River hardyhead) and *Craterocephalus stercusmuscarum* (Fly-specked hardyhead) has occurred, both in the field and in the relevant literature. Currently, two sub-species of *C. stercusmuscarum* are separated by colouration and the number of vertebrae, with *C. stercusmuscarum fulvus* lacking the lateral black spots and having fewer vertebrae than *C. s. stercusmuscarum* (Pusey *et al*. 2004). *Craterocephalus stercusmuscarum fulvus*, which is commonly referred to as the Mitchellian hardyhead or un-specked hardyhead is the most likely species to be found in the Lachlan River and Lake Cargelligo, and is the only species referred to in this study.

The Chandidae/Ambassidae

This family has undergone several re-classifications. The family was originally referred to as *Ambassidae* and two species were described from south-eastern Australia; *Ambassis castelnaui*, the western chanda perch, and *Ambassis nigripinnis*, the olive perchlet (McDowall 1980). Of these two species, *A. castelnaui* was said to inhabit the inland waters of the Murray-Darling Basin and *A. nigripinnis* was afforded a coastal distribution. Thus, when Llewellyn completed *The Distribution of Fish in New South Wales* in 1983, *A. castelnaui* were found in four catchments within the Murray-Darling Basin, including the Lachlan. When *Fishes of South-Eastern Australia* (McDowall 1996) was re-written, the family name was altered from *Chandidae* to *Ambassidae* and the inland species from *A. castelnaui* to *A. agassizii*. Additionally, the common name 'olive perchlet' was substituted for western chanda perch. In 2002, Allen reverted to the family name Ambassidae, retained the species name of *A. agassizii* and gave the species the common name of 'Agassiz's glassfish' (Allen *et al.* 2002). For the purposes of this study this most recent interpretation will be used.

The Eleotridae

Recent research suggests that the Eleotridae may not be a distinct family and that the Eleotrinae may be a subfamily of the Gobioidei (Pusey *et al.* 2004) or Gobiidae (Allen *et al*. 2002). Confusion surrounds the taxonomy of the *Hypseleotris* gudgeons, especially the differences between three (or four) species, all of which inhabit the Murray-Darling Basin. *Hypseleotris klunzingeri*, commonly known as the western carp gudgeon, has been described by Ogilby in 1898 (Merrick & Schmida 1984; McDowall 1996; Allen *et al.* 2002). *Hypseleotris* sp. 4 (Midgley's Carp Gudgeon) and sp. 5 (Lake's Carp Gudgeon)(Larson & Hoese 1996), which have also been referred to as sp. 1 and sp. 2 (Merrick & Schmida 1984; Allen *et al*. 2002) have not been described. In addition, a further species, the Murray-Darling carp gudgeon (Hypseleotris sp 3) is mentioned by both Unmack (2000) and Allen *et al*. (2002), and hybridization between members of the *Hypseleotris* complex is suggested by Bertozzi *et al*. (2000), Thacker and Unmack (2005), Unmack (pers. comm.) and Hammer (pers. comm.). In the surveys cited in this paper, only Llewellyn (1983) distinguishes between *Hypseleotris klunzingeri* and *Hypseleotris* sp. 4 and sp. 5, whereas the subsequent studies by Harris and Gehrke (1997), Growns (2001) and the MDBC (2004) group all carp gudgeons together as *Hypseleotris* spp. In this study a compromise approach was taken given that it is highly likely that there may be several species of carp gudgeons awaiting description. Fish not matching the description of *H. klunzingeri* were identified as *Hypseleotris* spp. and referred to as 'undescribed carp gudgeons', whereas all specimens matching the description of *H. klunzingeri* were referred to as 'western carp gudgeons'.

Appendix 2: Biomass equations

Length: weight equations (MDBC 2004).

Species	Equation
Hypseleotris spp.	Weight (grams) = $10^{[-5.7476 + 3.6294 * LOG(total\ length)]}$
Perca fluviatilis	Weight (grams) = $10^{[-5.3735 + 3.2617 * LOG(total\ length)]}$
Gambusia holbrooki	Weight (grams) = $10^{[-5.4443 + 3.2335 * LOG(total\ length)]}$
Retropinna semoni	Weight (grams) = $10^{[-5.6923 + 3.4186 * LOG(total\ length)]}$
Philypnodon grandiceps	Weight (grams) = $10^{[-5.12 + 3.228 * LOG(standard\ length)]}$
Nematalosa erebi	Weight (grams) = $10^{[-5.2317 + 3.1961 * LOG(total\ length)]}$
Carassius auratus	Weight (grams) = $10^{[-4.3294 + 2.9457 * LOG(total\ length)]}$
Cyprinus carpio	Weight (grams) = $10^{[-4.632 + 2.9489 * LOG(total\ length)]}$
Macquaria ambigua	Weight (grams) = $10^{[-5.3226 + 3.2058 * LOG(total\ length)]}$
Craterocephalus stercusmuscarum fulvus	Weight (grams) = $10^{[-5.2183 + 3.1462 * LOG(total\ length)]}$
Tandanus tandanus	Weight (grams) = $10^{[-5.1879 + 3.1038 * LOG(total\ length)]}$

Appendix 3: Distribution and abundance of turtles caught during the current study.

Two species of freshwater turtles[2], the common snake-neck turtle, *Chelodina longicollis* and the Macquarie turtle, *Emydura macquaria*, were sampled in both seasons in fyke nets (Table 18). The highest abundance of both species was in Lake Curlew in summer. Common snake-neck turtles were sampled in all areas. Macquarie turtles were abundant in Lake Curlew and Lake Cargelligo but were not captured in Canal 1.

Table 18. Total numbers of all turtles caught during the spring and summer sampling periods in each area in the Lake Cargelligo system.

Scientific and Common Name	**Canal 1**		**Lake Curlew**		**Canal 2**		**Lake Cargelligo**		**Total**
	Spring	*Summer*	*Spring*	*Summer*	*Spring*	*Summer*	*Spring*	*Summer*	
Chelodina longicollis Common Snake-neck turtle	3	4	9	104	7	16	-	3	**146**
Emydura macquaria. Macquarie turtle	-	-	1	184	-	1	2	34	**222**
TOTALS	**3**	**4**	**10**	**288**	**7**	**17**	**2**	**37**	**368**

[2] Until recently, Australian freshwater chelonians were often referred to as 'tortoises' (Cann 1978). Although the two terms appear to be interchangeable (P. Suter pers. comm.) recent scientific literature tends to favour the word 'turtle' when referring to these animals (Meathrel *et al.* 2004). The term 'turtle' is used in this study.