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The distribution, spread, ecological impacts and potential control of carp in the upper Murray River

by
Dean Gilligan and Thomas Rayner

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Authors: Dean Gilligan and Thomas Rayner

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NON-TECHNICAL SUMMARY

The distribution, spread, ecological impacts and potential control of carp in the upper Murray River

PRINCIPAL INVESTIGATOR: Dr Dean Gilligan

ADDRESS: NSW Department of Primary Industries
Narrandera Fisheries Centre
Buckingbong Road
Narrandera NSW 2700

OBJECTIVES:

- Collect and document current data on the incidence of carp in the upper Murray River.
- Review data on the spread of carp within the upper Murray River.
- Review the likely ecological consequences of carp in the upper Murray River.
- Review potential options for controlling carp in the upper Murray River.

NON TECHNICAL SUMMARY:

Common carp are a noxious pest species with potential to negatively affect water quality, habitat structure and native fish populations throughout Australia. Carp invaded the upper Murray River catchment in 1977 and have since become well established, particularly at lower elevations. This report summaries existing literature and data relating to carp in the upper Murray River, investigates their likely ecological consequences and reviews potential control options.

In order to document the current distribution and abundance of carp within the upper Murray River, an electrofishing survey was conducted along an altitudinal gradient between November 2006 and February 2007. Carp were the most common species sampled and were found at sites up to 410 m elevation. These data are consistent with a recently reported observation of carp ~10 km downstream of Tom Groggin Station, which equates to an altitude of ~450 m. The majority of carp caught during the study were very large individuals, indicating that carp recruitment has been low for a number of years.

Carp are a highly mobile species, migrating up and down rivers throughout the year. Given their ability to disperse great distances, their extended presence in the upper Murray (~27 years) and the lack of obstructions to fish passage in the system, we hypothesise that their low abundances in upstream areas are linked to unsuitable habitat and water quality conditions. For example, colder winter temperatures and a lack of suitable substrates are likely to limit spawning and recruitment in upland streams. Apart from colonisation of Khancoban pondage, it is unlikely that carp will continue to spread beyond their current distribution.

Although carp were more abundant than other fish species in the 2006/07 survey, their abundance in the upper Murray was relatively low compared to other Murray-Darling Basin catchments in NSW. Except for the impounded waters of Lake Hume itself and wetlands on the upper Murray floodplain, carp are unlikely to have a substantial impact on turbidity and sediment re-suspension given the low proportion of muddy substrates susceptible to re-suspension. Further, the generally

high flow rates in this section of the Murray river generally result in rapid flushing of the system which prevents build up of large amounts of fine sediments.

Two physical control options (Judas fish approach and the Williams' Carp Separation Cage) are currently available for implementation in the upper Murray catchment. Two biological control options (Koi Herpes Virus and Daughterless Carp Gene Technology) are potentially suitable, but the results of initial trials of these procedures will not be available for several years.

1. INTRODUCTION

Common carp (*Cyprinus carpio*) are an important food source for humans and are also a common target species for recreational anglers across their native range (Panek 1987; Lin and Peter 1991; Koehn *et al.* 2000; Splitler 1987). However, they are perceived as a significant ecological pest in many of the countries where they have been introduced (Lamarra 1975; Cooper 1987; Koehn *et al.* 2000). Carp have been implicated in the degradation of many Australian river systems, particularly those in the Murray-Darling Basin (Koehn *et al*. 2000), and have been declared a noxious species in most states and territories. In NSW, the introduction of carp (and other fish species) into new catchments is recognised as a key threatening process to threatened fish and aquatic ecosystems under the *Fisheries Management Act* (1994). The aim of this report is to review the current distribution, historical and future spread, ecological impacts and potential control options for carp in the Murray River upstream of Hume Dam. This report is a result of enquires referred to the NSW Department of Primary Industries (NSW DPI) by the Department of Environment and Water Resources (DEW).

2. THE INTRODUCTION AND SPREAD OF CARP IN THE UPPER MURRAY RIVER

The first carp introduced to waters of the Murray-Darling Basin were a bright orange strain of Asian koi carp. These fish were released into irrigation canals in the Murrumbidgee Irrigation Area in southern-central NSW sometime during the 1940s or 1950s, where they established a self-sustaining population, but did not disperse widely and had limited ecological impact (Lake 1967). It was not until the introduction of a second strain, imported from Europe and raised on a fish farm at Boolarra, Victoria (Shearer and Mulley 1978), that the species became a ‘pest’. The Victorian authorities attempted to prevent the sale and distribution of these fish, but were unsuccessful (Butcher 1962) and an intensive eradication campaign failed to prevent their spread. By 1968, the Boolarra strain was found in the lower Murray River at Mildura and by the mid-1970s had invaded the lower reaches of the Darling, Lachlan, Murray and Murrumbidgee Rivers (Reid *et al.* 1997) along with the Victorian tributaries of the Murray River itself. In 1976, carp had begun to invade the reaches between Yarrawonga and Hume Dam (Walker and Hillman 1977), but sampling of three sites in the upper Murray River suggested that the reaches above Hume Dam were free of carp (Llewelyn 1983). However, Gilligan (unpublished data: Figure 1) aged a sample of 300 carp collected from the upper Murray in 2004 and found that the oldest carp in the sample was spawned in 1977, suggesting that carp have been present in the upper Murray catchment for at least 27 years.

Carp are now present in all Australian states except the Northern Territory and their range continues to increase (Brumley, 1996). Within NSW, carp are distributed across most of the Murray-Darling Basin, occurring in 85% of the state’s inland waterways (Graham *et al*. 2005). Data collected from two sites in the upper Murray River, at Talmalmo and Tintaldra, between 1990 and 2005 suggests that the abundance of carp increased dramatically in the mid to late 1990s (up to ~54 carp per hour electrofishing in 1998, NSW DPI, unpublished data: Figure 2). No sampling was undertaken in the early 2000s, but by 2005 the abundance of carp had decreased to ~8 carp per hour (NSW DPI, unpublished data). Most recently, fish community data collected from 16 sites across the upper Murray catchment in early 2005, for the Murray-Darling Basin Commission’s Sustainable Rivers Audit (Arthur Rylah Institute for Environmental Research, unpublished data), were limited to areas below 340 m ASL. Lastly, a comparison of the abundance of carp across all the Murray-Darling Basin catchments of NSW, using data collected from 2000 - 2006, indicates that the upper Murray catchment has the lowest abundance of carp of any inland catchment in NSW (Figure 3).

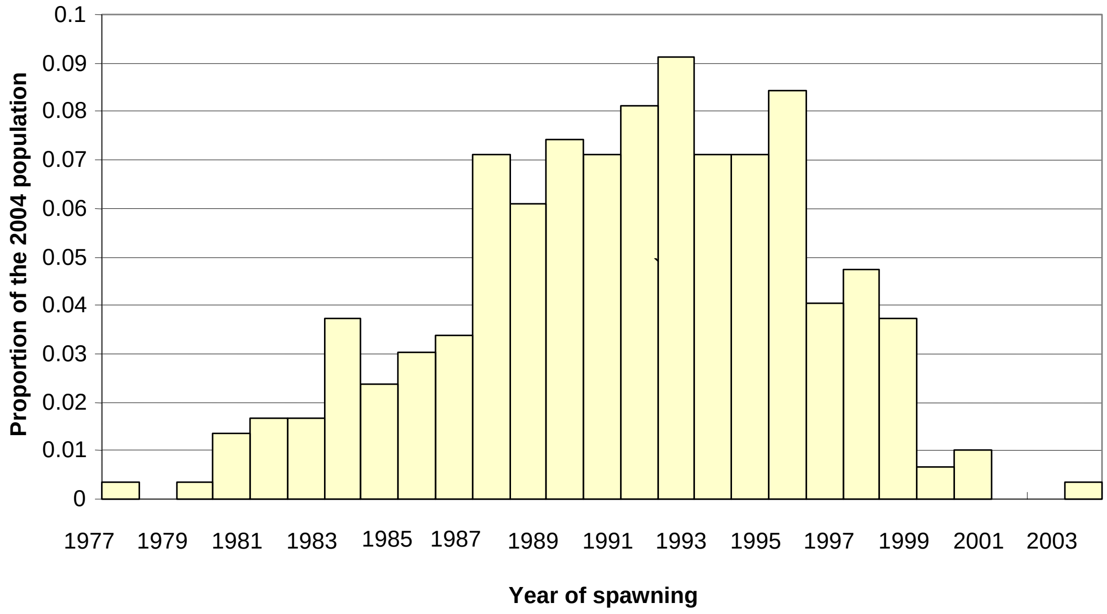

Figure 1. The age structure of the common carp population in Lake Hume in April 2004 (n = 300) (Gilligan, unpublished data).

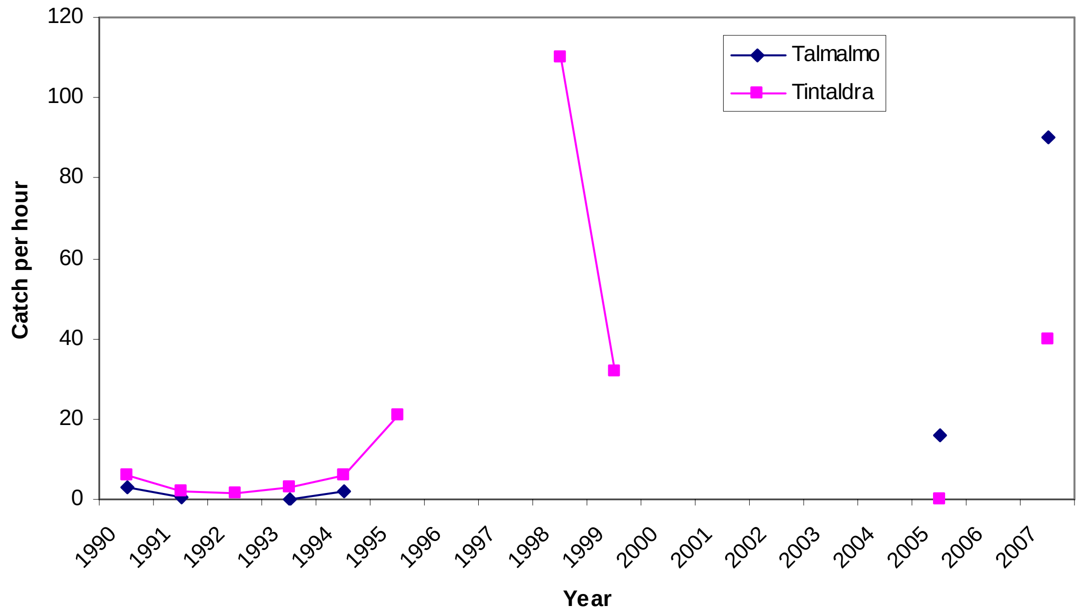

Figure 2. The abundance of common carp (catch per hour of electrofishing) at two sites in the Upper Murray River catchment between 1990 and 2005 (Harris and Gerhke 1997; NSW DPI, Freshwater Fish Research database), with additional sampling conducted during 2006/07 as part of the present study.

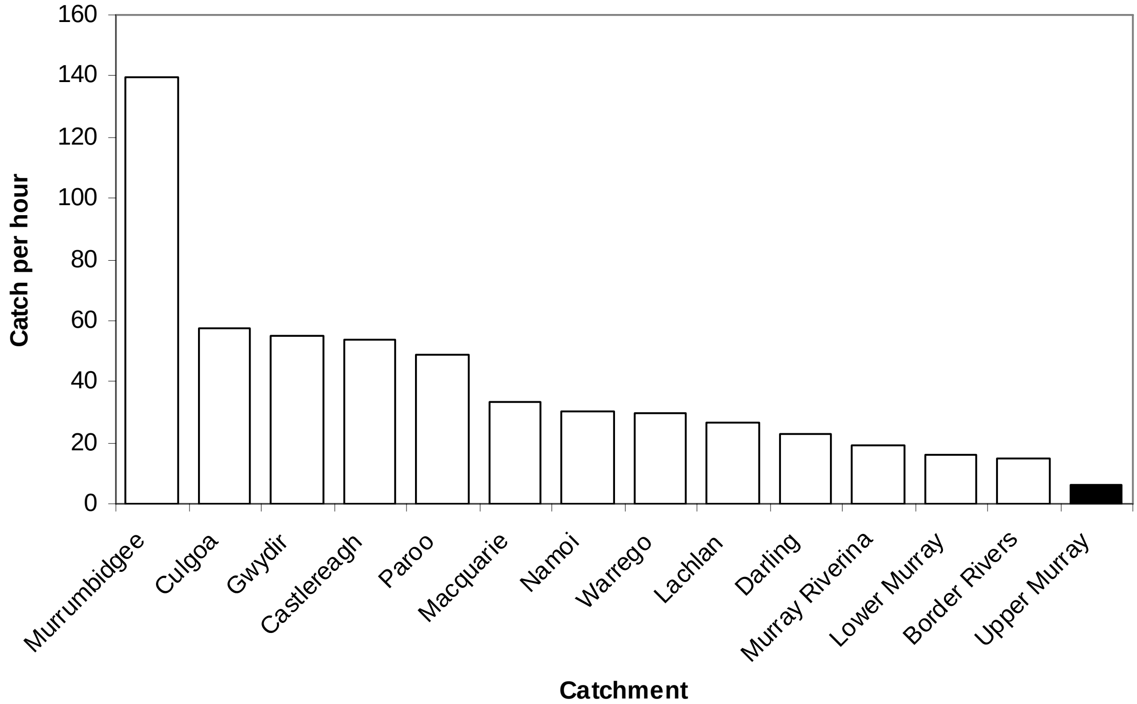

Figure 3. The abundance of common carp (catch per hour of electrofishing) within each of the inland catchments of NSW. Data collected between 1 July 2000 and 30 June 2006 (NSW DPI, Freshwater Fish Research database).

3. PRESENT DISTRIBUTION OF CARP IN THE UPPER MURRAY RIVER

3.1. Aims and methods

In order to document the current distribution and abundance of carp within the upper Murray River, an electrofishing survey was conducted between November 2006 and February 2007. Ten sites were sampled along an altitudinal gradient (Table 1), with the aim of further investigating the altitudinal limit of carp. The most downstream site was at Talmalmo (180 m altitude), being relatively close to upstream limit of the Hume weir-pool (at full capacity), while the most upstream site was the Tom Groggin rest area (580 m), above the previously reported upper altitude limit of carp in the Murray River (~ 450 m).

Each site was sampled using the standard sampling protocol developed for the Murray-Darling Basin Commission’s Sustainable River Audit – Fish theme. This sampling protocol is based on standardised boat or backpack electrofishing, in addition to 10 un-baited concertina-type shrimp traps (MDBC, 2006). A boat electrofishing system (7.5 kW Smith-Root model GPP 7.5 H/L) was used at the four most downstream sites. Twelve boat electrofishing operations, each consisting of 90 seconds of electrofishing (power on), were done at each of these sampling sites. A backpack electrofishing system (Smith-Root model 12 POW backpack unit) was used at the remaining six sites which were too small and/or shallow to be navigated by boat. Eight backpack operations, each consisting of 150 seconds of electrofishing (power on) were done at these sites.

During each operation, a dip-netter removed electrofished individuals and placed them in an aerated live-well (boat fishing) or bucket (backpack fishing). All individuals that could not be dip-netted but could be positively identified were recorded as ‘observed’. All electrofishing was undertaken during daylight hours. The 10 shrimp traps were set in an attempt to sample smaller fish which are sometimes under-represented in electrofishing samples. Traps were set for a minimum period of two hours whilst electrofishing was being undertaken. At the completion of each operation (electrofishing or shrimp traps), captured individuals were identified, counted, measured and observed for health conditions such as externally visible parasites, wounds or diseases. Measurements to the nearest millimetre were taken as fork length for species with forked tails or total length for other species.

Table 1. Details of sites in the upper Murray River catchment surveyed between November 2006 and February 2007.

Site name	Date sampled	Altitude (m)	Latitude	Longitude
Talmalmo	01/02/07	180	-35.9688	147.5467
Illawong (Jingellic)	01/02/07	200	-35.9572	147.6389
Tintaldra	31/01/07	230	-36.0457	147.9316
Towong	31/01/07	260	-36.1246	147.9933
Indi Bridge	6/11/2006	310	-36.2350	148.0351
Hogs Retreat	7/11/2006	348	-36.3551	148.0495
Surveyors Creek Track	7/11/2006	430	-36.4329	148.0875
Murray Gates	8/11/2006	470	-36.4636	148.1242
Tom Groggin Station	8/11/2006	520	-36.5060	148.1279
Tom Groggin Rest Area	9/11/2006	580	-36.5518	148.1244

3.2. Results and discussion

Carp were the most common species sampled in the Upper Murray River (Table 2). They were collected at all sites below 310 m altitude, and were observed (but not captured) at 430 m altitude. They were not sampled at the three sites above 470 m. These data are consistent with the recently reported observation of carp ~ 10km downstream of Tom Groggin Station (Trevor Davis, per comm.), which equates to an altitude of ~ 450 m. The majority of carp were very large individuals (Figure 4), the smallest being 321 mm in length, corresponding to an age of approximately three years. There were no juvenile carp collected in the sample and the absence of any carp < 321 mm indicates a lack of recruitment in the upper Murray catchment carp population for several years. Based on the age data presented in Figure 1, 1998 was probably the most recent large/moderate carp recruitment event in the upper Murray catchment.

The catch per unit effort at the two sites with long term monitoring data were 90 and 40 carp per hour of electrofishing at Talmalmo and Tintaldra, respectively. This represents a substantial increase in abundance since the previous sample in 2005 (Figure 2). However, given that the increase since 2005 was not a result of the recruitment of juvenile carp into the population, it can only be assumed that the increases observed at Talmalmo and Tintaldra are a direct result of the low water levels in Lake Hume (< 10% capacity at the time of sampling), which is likely to have forced carp from Lake Hume upstream into the Murray River itself.

In addition to carp, four other species of introduced fish were collected during the present study. Redfin perch (*Perca fluviatilis*) were common, being found at all sites below 260 m (Table 2).

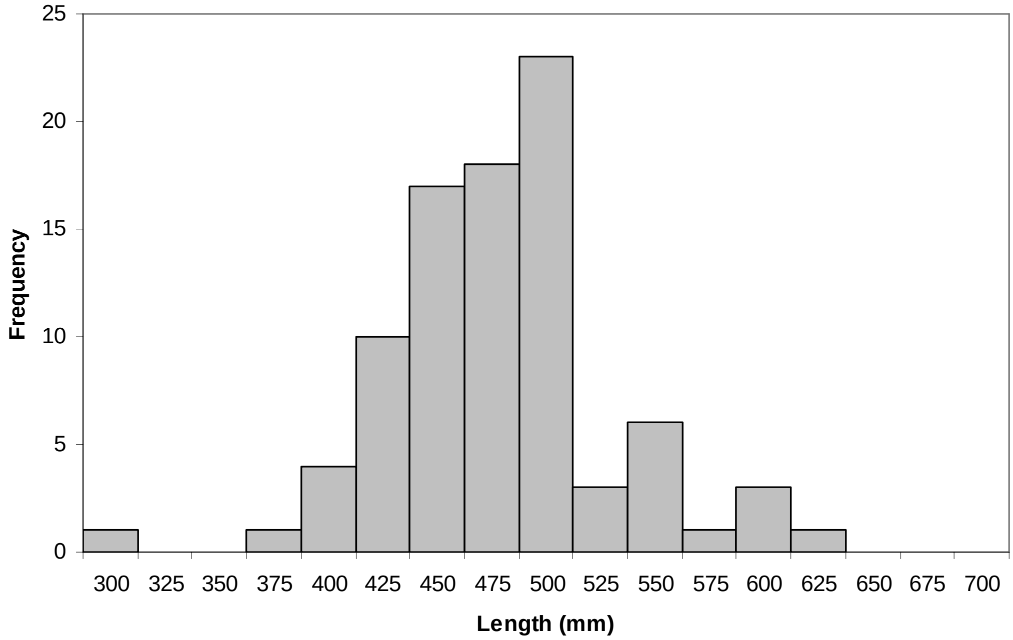

Figure 4. The length-frequency distribution of carp sampled in the Upper Murray River in 2006/07.

Previous sampling in the upper Murray suggests that redfin extend up to elevations of at least 571 m (Arthur Rylah Institute for Environmental Research, unpublished data). Introduced brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) were only sampled at a single site (Towong) during this survey (Table 2). Previous sampling suggests that these two species are more widespread than these data suggest, being found up to altitudes of at least 1,290 m (Arthur Rylah

Institute for Environmental Research, unpublished data). The only other introduced species collected was a single mosquito fish (*Gambusia holbrooki*) at Towong (Table 2). No goldfish (*Carassius auratus*) were captured. Although uncommon in the upper Murray, they are known to occur, with a single individual collected in a tributary stream, Walwa Creek, in 2005 (Arthur Rylah Institute for Environmental Research, T. Raadik, pers. comm.).

Only four native fish species were collected, two of these being threatened species. The endangered trout cod (*Maccullochella macquariensis*) was only sampled at a single site (Talmalmo): both individuals sampled were very large, and are likely to be individuals stocked by the NSW DPI conservation stocking program. Only a single vulnerable Murray cod (*Maccullochella peelii*) was sampled at Tintaldra: this individual was also very large. As no small trout cod or Murray cod were sampled, it is suggested that these two species are not breeding effectively in the upper Murray River. It is likely that the populations of both species will decline in the future. Two-spined blackfish (*Gadopsis bispinosus*) were more widespread, being present at five of the eight sites below an altitude of 470 m, but were not very common at any individual site. Previous sampling in the Upper Murray catchment indicates that this species did occur up to elevations of at least 850 m (Arthur Rylah Institute for Environmental Research, unpublished data). Finally, Australian smelt (*Retropinna semoni*) were only collected at sites below 230 m. Previous sampling has collected them as far upstream as 280 m (NSW DPI, unpublished data).

Several other native species known to inhabit the upper Murray catchment were not collected during this survey. Native carp-gudgeons (*Hypseotris* spp.) are known to occur in the lower reaches of the upper Murray. A second species of blackfish, river blackfish (*Gadopsis marmoratus*) is known to exist in the catchment up to elevations of at least 570 m (Arthur Rylah Institute for Environmental Research, unpublished data). Mountain galaxias (*Galaxias olidus*) occur at altitudes up to at least 1,290 m, but are not common below altitudes of 400 m (Arthur Rylah Institute for Environmental Research, unpublished data). Both silver perch (*Bidyanus bidyanus*) and golden perch (*Macquaria ambigua*) formerly existed is the upper Murray River, but are reported to have declined or disappeared in the 1930s (Trueman, pers comm. 2007). Neither species has been sampled during any scientific fish surveys since 1990, despite being stocked in large numbers in Lake Hume for many years.

Table 2. Abundance of fish species caught at sites in the Upper Murray River in 2006/07.

	Talmalmo	Illawong	Tintaldra	Towong	Indi Bridge	Hogs Retreat	Surveyors Creek Track	Murray Gates	Tom Groggin Station	Tom Groggin Rest Area
Native species										
Australian smelt (*Retropinna semoni*)	1	0	146	0	0	0	0	0	0	0
Murray cod (*Maccullochella peelii*)	0	0	1	0	0	0	0	0	0	0
Trout cod (*Maccullochella macquariensis*)	2	0	0	0	0	0	0	0	0	0
Two-spined blackfish (*Gadopsis bispinosus*)	1	2	0	3	0	1	0	1	0	0
Alien species										
Brown trout (*Salmo trutta*)	0	0	0	12	0	0	0	0	0	0
Common carp (*Cyprinus carpio*)	70	29	32	50	1	0	1	0	0	0
Eastern gambusia (*Gambusia holbrooki*)	0	0	0	1	0	0	0	0	0	0
Rainbow trout (*Oncorhynchus mykiss*)	0	0	0	4	0	0	0	0	0	0
Redfin perch (*Perca fluviatilis*)	26	4	3	20	0	0	0	0	0	0

4. THE SPREAD OF CARP WITHIN THE UPPER MURRAY RIVER

Carp are a highly mobile species, capable of migrating up and down rivers throughout the year (Stuart and Jones 2002). Consequently, it is likely that all areas suitable for colonisation were invaded shortly after carp first appeared in the upper Murray catchment. Koehn (2004) noted that carp have ecological tolerances which would allow them to establish populations in any Australian river system and that the further expansion of carp across most of the remainder of Australia should be expected. Carp are capable of withstanding water temperatures of 4 – 35 ^{o}C, pH of 5 – 10.5, high turbidity, moderate salinities, high toxicant loads and very low dissolved oxygen levels (Panek 1987; Mackenzie *et al.* 2000; Smith 2005). However, carp prefer mid-latitude, low-altitude, slow flowing or still water, with a silty substrate and access to shallow vegetated areas for spawning (McCrimmon 1968; Crivelli 1981; Panek 1987; Brown 1998). These types of habitat are found commonly in off-stream wetlands, billabongs, in large rivers, irrigation canals and large water storages (such as Lake Hume) in south-eastern Australia (McDowall 1996; Brown 1998; Stuart and Jones 2002).

Given that Hume Dam prevents colonisation of the upper Murray River by carp from downstream, their existence in the upper Murray River must have resulted from one or more of the following: their use as live bait, their deliberate introduction by humans, the transport of their sticky eggs on waterbirds. When carp were introduced into the neighbouring Murrumbidgee catchment in 1976 (Lintermans 2002), they spread rapidly through the low gradient waterways above Burrinjuck Dam, but did not reach an elevation of 710 m until 1992 (16 years later). Their present upper elevation of 760 m was not reached until sometime between 1992 and 2003 (16 to 27 years). Fish community data collected from 16 sites across the upper Murray catchment in early 2005 indicated that carp were present at all sites sampled below an altitude of 340 m ASL, but were absent from all sites at higher altitudes (Arthur Rylah Institute for Environmental Research, unpublished data). Samples collected during this study have increased this altitudinal limit to at least 430 m, with the added possibility that they exist as far upstream as 450 m ASL (Trevor Davis, pers comm., 2006).

Given their presence up to 760 m elevation in the Murrumbidgee catchment, carp have the ability to survive at much higher altitudes than they currently exist at in the upper Murray River. We hypothesise that further colonisation upstream is most probably limited by a natural fish passage barrier. Apart from colonisation of Khancoban pondage, it is unlikely that carp will continue to spread beyond their existing distribution in the Murray River. Even if individual carp do manage to migrate up to, or above, Tom Groggin Station, the shallower depths, faster flow velocities, coarser riverbed sediments and cooler winter temperatures are likely to inhibit the establishment of a permanent population. Further, the lack of any suitable spawning and recruitment areas anywhere in the upper reaches precludes the establishment of an abundant recruiting population. Any carp observed in the upper Murray River above 450 m altitude are likely to be vagrant individuals migrating temporarily from further downstream.

5. THE ECOLOGICAL IMPACTS OF CARP IN THE UPPER MURRAY

The impacts of carp are estimated to cost ~$15.8 million dollars annually (McLeod 2004), $2 million of which is spent on carp management, $2 million on research and $11.8 million on remediation of environmental impacts. However, it is still unclear if carp invasion represents a symptom or a cause of degraded aquatic systems. Increased incidence of blue-green algae blooms, declining native fish populations, increased turbidity in major rivers, damage to stream banks and loss of aquatic vegetation have all been attributed to carp populations (Lachner *et al*. 1970; Crivelli 1983; Hume *et al*. 1983; Fletcher *et al*. 1985; Page and Burr 1991; Wilcox and Hornbach 1991; Breukelaret *et al*. 1994; Faragher and Harris 1994; Gehrke and Harris 1994; Hindmarsh 1994; Roberts and Ebner 1997; Koehn *et al*. 2000; Schiller and Harris 2001; Williams *et al.*. 2001), backed by differing levels of credible scientific evidence. In most cases, the specific impacts of carp are complex and difficult to isolate from other inter-related anthropogenic changes to ecosystems (Hume *et al*. 1983).

5.1. Impacts on sediment re-suspension, turbidity and algal blooms

Research efforts have generally been unable to pinpoint the specific effects that carp have had on turbidity at a catchment scale (Driver *et al.* 1997; Fletcher *et al.* 1985). Despite this, turbidity is potentially one of the most significant impacts of carp on aquatic systems (Schiller and Harris, 2001). Increased turbidity suppresses biofilm production, disrupts zooplankton grazing, limits the growth of macrophytes and algae by reducing light penetration, reduces survival of eggs and larvae of various fish species, alters breeding behaviour and limits the foraging behaviour of visually-cued fish (Schiller and Harris 2001; Newcome and Macdonald 1991). The benthic foraging behaviour of carp, known as 'mumbling', re-suspends sediments and increases turbidity (Crivelli 1981).

In Australia, the results of research examining the relationship between carp and turbidity have varied between study systems. Fletcher *et al.* (1985) reported no increases in turbidity at carp densities of 140 – 1,500 kg per hectare, while King *et al.* (1997) reported turbidity increases at densities of 510 kg per hectare and 118 kg per hectare. Overall, the relationship between carp and turbidity is complex, with sediment type, water depth, presence of water plants, and variation in wind velocity and water temperature all being important factors (Fletcher *et al.* 1985; Dieter 1990; Robertson *et al.* 1995). The foraging behaviour of carp can also negatively affect the benthic community structure and dynamics, as well as the physical condition of the substratum (Wilcox and Hornbach 1991). These disturbances may also influence algal blooms by the re-suspension of sediment (Gehrke and Harris 1994) and release nutrients such as phosphorus (Breukelaret *et al*. 1994; Williams *et al*. 2002). In addition, carp feeding may promote algal blooms by reducing zooplankton that feed on the algae (Gehrke and Harris, 1994).

Except for the impounded waters of Lake Hume itself and wetlands on the upper Murray floodplain, carp are unlikely to have a significant impact on the turbidity and sediment re-suspension in the upper Murray River, given the low proportion of muddy substrata susceptible to re-suspension and the generally rapid flushing of the system by the generally high flow rates.

5.2. Impacts on macrophytes

There are many accounts of carp destroying aquatic macrophyte beds either directly through grazing or uprooting (e.g., during spawning activity) or indirectly by increasing turbidity, altering nutrient concentrations and reducing photosynthesis by sediment smothering (Crivelli 1983; Hume *et al.*. 1983; Schiller and Harris 2001). However, it is generally accepted that herbivory by carp is rare and only occurs when preferred food items are unavailable (Fletcher *et al*. 1985). It is thought that damage to macrophytes may occur during benthic feeding, with soft leaved and shallow rooted plants such as *Potamogeton*, *Vallisneria* and *Chara* species being most susceptible to damage (Hume *et al*. 1983; Crivelli 1983 Fletcher *et al*. 1985).

Despite some debate in the literature over the direct effects of carp on macrophytes, it is generally accepted that carp do have some impact. The implications for aquatic ecosystems are potentially large, as macrophytes perform several important functions, which are analogous to those performed by sea-grass beds in estuarine systems. For example, macrophytes contribute to the aquatic carbon cycle, modify flow and create velocity shelters (Newell 1995), provide habitat for bacteria, fungi and algal epiphytes (Burns *et al.* 1994), aid sedimentation, stabilise the stream bed, provide habitat and shelter for invertebrates and act as nursery areas for small and juvenile fish.

Research conducted in England by Williams *et al*. (2002) suggested that carp indirectly decreased the abundance of macrophytes by increasing nitrogen concentrations. Nitrogen released from fish excreta led to an increase in epiphytic (algae) load and reduced available light and carbon dioxide available to the macrophytes. Such studies may explain macrophyte losses in some Australian systems and in carp experiments that had low levels of available nitrogen. In the present study, aquatic macrophyte beds were only present at three of the ten sites sampled for this study (Indi Bridge, Murray Gates and Tom Groggin Station); two of the three sites above the altitude limit of carp, and only one of the seven sites below. Whether the general absence of macrophyte beds where there are carp is a direct result of carp presence cannot be determined, as we have no data on macrophytes at any sites in the upper Murray prior to the appearance of carp.

5.3. Impacts of carp on native fish

Populations of native freshwater fish species have declined markedly in distribution and abundance during the last 100 years. While the causes of these declines have been discussed at length (Cadwallader 1978; Cadwallader 1986; Cadwallader and Lawrence 1990; Faragher and Harris 1994; Harris and Gehrke 1997), it is still unclear what impacts carp have had on native fish, when compared to other environmental impacts, such as the modification of flow regimes, overfishing, habitat loss, habitat degradation, and the impact of other exotic fish and their diseases. A diet study of Australian carp populations suggested limited predation on native fishes (Khan 2003). However, some accounts from America suggest that carp may feed on fish eggs and larvae (Lachner *et al*. 1970; Page and Burr 1991). There is no information on the significance of competition between native fish and carp, although larval, juvenile and adult carp consume zooplankton (Hume *et al*. 1983; Khan 2003) and may compete with native juvenile or small fish. In addition, habitat changes caused by carp (e.g., increased turbidity and loss of macrophytes) may influence small native species, such as southern pygmy perch and flat-headed galaxias, which are reliant on aquatic macrophytes for spawning and cover (Llewellyn 1974; Llewellyn 2005). Similarly, substrate disturbance by carp may also impact upon catfish nests (Schiller and Harris 2001), although catfish were probably locally extinct in the upper Murray before carp arrived (Trueman, pers. comm.). Lastly, carp have been implicated in the spread of fish diseases, such as the exotic bacteria *Aeromanas salmonicida* (Hindmarsh, 1994) and parasites such as *Lernaea* spp. (Rowland and Ingram 1991). The impacts of other introduced species, redfin perch, brown trout and rainbow trout on native fish communities are also important.

6. OPTIONS FOR CONTROLLING CARP IN THE UPPER MURRAY RIVER

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

1. Forum on European carp (Murrumbidgee Catchment Management Committee 1994).
2. National Carp Summit (Broster 1996).
3. Controlling carp – Exploring options in Australia (Roberts and Tilzey 1997).
4. Carp Control Reference Group
    a. National Management Strategy for carp control (2000 – 2005) (Murray-Darling Basin Commission 2000a).
    b. Future directions for research into carp (Murray-Darling Basin Commission 2000b).
    c. Ranking areas for action: A guide for carp management groups (Murray-Darling Basin Commission 2000c).
5. Managing invasive freshwater fish in New Zealand (New Zealand Department of Conservation 2001).
6. National Carp Workshop (Lapidge 2003).

A number of control strategies have been proposed, developed, modelled and/or tested. These are: physical removal, biological control, habitat modification and chemical control (Roberts and Tilzey 1997). Those with potential for implementation in the upper Murray catchment are outlined below.

6.1. Physical removal

To stimulate commercial carp fishing and markets for carp products, the NSW Government implemented an incentive scheme in 1998 (Kick 2002). This scheme offered commercial fishing licences to parties who could demonstrate their ability to catch and sell carp. The scheme also offered set payments for carp caught in 1999, 2000 and 2001 to offset development and transport costs (Kick 2002). Under the scheme a total of three licences were issued. A company called "Charlie Carp" produces fertilisers out of approximately 180 to 200 tonnes of carp per year caught mostly from Lake Boga in Victoria (R. Kopanica pers. comm. 2003). Another company, K & C Fisheries, harvest up to 1000 tonnes of carp from the Gippsland Lakes, Victoria (K. Bell pers. comm. 2003). The carp are sold to a variety of markets including: export to Poland, rock lobster bait, fertiliser and smoked products (Koehn *et al*. 2000). There are a further 21 commercially licensed fisherman who hold Class A licences in the inland restricted fishery. These fishermen previously held inland fin-fish licences prior to the closure of the fishery and are now entitled to catch yabbies and carp. Subsidised commercial harvest may be a potential means of achieving rapid population reduction, particularly given the very low water levels currently in Lake Hume.

Thresher (1997) and Brown and Walker (2004) modelled the feasibility of physical removal as a control strategy and concluded that potential for broad-scale control of carp populations in open river systems in the long-term were limited. Apart from the fact that the Upper Murray is not an 'open' river system, two recent advances in targeted physical removal would substantially improve the efficiency of physical removal in the Upper Murray, the 'Judas fish' approach, as used in the Tasmania carp Management Program (Diggle *et al*. 2004; Inland Fisheries Service 2004), and Williams' Carp Separation Cage technology for fishways (Stuart *et al*. 2003; Stuart *et al.* 2006).

The Tasmanian Carp Management Program

Following the discovery of established carp populations in Lakes Crescent and Sorell in Tasmania in 1995, the Tasmanian Inland Fisheries Service undertook a campaign of containment and eradication (Diggle *et al*. 2004). Screens were installed in the channel linking the two lakes and at the outlet of Lake Crescent (the downstream lake), using a mesh small enough to prevent eggs and larvae leaving the lakes. This strategy was successful in preventing the colonisation of the Derwent catchment downstream. Had this occurred, it would have significantly reduced the potential for eradication. Both lakes were closed to recreational angling in order to minimise the risk of further translocations, with the waters of Lake Crescent closed to all forms of access.

Water levels in Lake Crescent were manipulated to exclude carp from spawning areas (shallow marshy areas) during the spawning season. This could not be achieved at Lake Sorell. As an alternative, marsh areas were fenced off with carp-proof mesh to exclude spawning fish. Although these approaches have undoubtedly assisted in limiting recruitment, they have not been entirely successful, with some recruitment detected in 1995/96, 1997/98, 2000 and 2003 (Diggle *et al*. 2004; Inland Fisheries Service 2004).

To physically remove adults, a variety of fishing methods were used, including fyke nets, seine nets, gill nets, traps and electrofishing. Since 1997, fishing effort was enhanced by incorporation of a ‘Judas fish’ strategy into the control program, where a number of males were radio tagged in order to identify spawning aggregations, and help understand habitat preferences and behaviours (Diggle *et al.* 2004). From 1999, the Carp Management Program routinely tagged (double dart-tagged) and returned all male carp to in order to enable estimation of population size using mark – recapture models. In November 2003, the carp population in Lake Crescent was estimated to consist of just 32 individual fish (Diggle *et al.* 2004). The number of tagged male fish returned is now being limited to the minimum number required to assist in the collection of the remaining females. Lake Crescent was re-opened to recreational fishing in August 2004 (Inland Fisheries Service, 2004).

In Lake Sorell, continued improvements in fishing efficiency are required in order to achieve eradication (Diggle *et al.* 2004) as the small population in this Lake (originally less than 200 fish) is hard to target (Inland Fisheries Service 2004). As of 2004, only 16 adult females had been removed from the Sorell population (Inland Fisheries Service 2004). Modelling of the recruitment event in 2000 suggested that a maximum of 3,000 juveniles were recruited, of which 2,070 have been so far been removed. This suggests that around 930 carp remain in Lake Sorell (Inland Fisheries Service 2004).

William’s Carp Separation Cages

Carp are highly mobile and regularly pass through fishways designed to enable the migration of native fish. As migrating fish must pass through these structures in order to move within regulated waterways, fishways create a migration bottleneck, with all fish passing through the ~25cm fishway ‘slots’. These bottlenecks have potential as locations for the removal of migrating carp. Within the Murray-Darling Basin, there are many observations of carp jumping, whilst native fish rarely jump. Further, carp are known to escape easily from fish traps not fitted with a secure roof (Stuart *et al.* 2003). Mr Alan Williams, a lock master (Goulburn-Murray Water) at Torrumbarry Weir (Murray River) conceived a carp drafting device that capitalised on the jumping behaviour of carp and the fact that they regularly pass through fishway bottlenecks.

The Williams’ Carp Separation Cage (Stuart *et al.* 2006) is a low cost automated trap/drafting device suitable for installation in vertical slot fishways (see Stuart *et al*. (2006) for a diagram). Trials of prototype traps have been undertaken at the Torrumbarry fishway and 83% of all carp jumped into the containment area, where they are held until the trap is emptied. In contrast, 99.9% of native fish passed successfully through the fishway (Stuart *et al.* 2006). These fishway traps currently provide the most cost-effective and efficient means of removing carp from river systems. As a result, the Murray-Darling Basin Commission is undertaking to build a Williams' cage on each fishway it constructs as part of its Lake Hume to the Sea Program in the lower reaches of the Murray River (Barrett and Mallen-Cooper 2006).

The only requirements for the device are the existence of a functional vertical-slot fishway and a means of harvesting the contained carp on a regular basis. These requirements are significant in regards to the upper Murray River given that no weirs or fishways exist on the main channel upstream of Hume Dam. In order to be implemented, a purpose built 'leaky weir' fitted with a vertical slot fishway would need to be constructed.

With funding from the Invasive Animals CRC, NSW Department of Primary Industries has been sampling carp larvae in order to locate carp recruitment 'hot-spots' throughout the Murray-Darling Basin. A 250 km length of the Upper Murray River was sampled during a minor flow peak in 2005. No carp larvae were collected at any site upstream of Lake Hume (Gilligan, unpublished data). This suggests by default that the primary carp recruitment area in the Upper Murray catchment is Lake Hume itself. As a result, the carp population in the upper Murray catchment can be divided into the source population in Lake Hume and the sink population in all other reaches upstream. A site in the lower reaches, as close to the upper pool level of Lake Hume, would be the optimal location to construct a Williams' cage, as it would limit the dispersal of juvenile carp from the source, effectively controlling the population of carp in all reaches upstream of the separation cage.

6.2. Biological control

The Invasive Animals Cooperative Research Centre (CRC) is currently funding the development and assessment of two biological control options that may be suitable for implementation in the upper Murray catchment; koi herpes virus and Daughterless Carp Gene Technology. Unfortunately, both methods are in early stages of development and may not be available for implementation for some time, if ever.

Koi Herpes Virus

Koi herpes virus (KHV) is a highly contagious viral disease causing significant morbidity (sickness or disease) and mortality in common carp (Hedrick *et al*. 2000). The virus is reported to be specific to common carp, with other related cyprinid species such as the goldfish and grass carp (*Ctenopharyngodon idella*) unaffected by the virus and not acting as carriers (Perelberg *et al*. 2003; Ronen *et al*. 2003). KHV disease may cause 80 – 100% mortality in affected populations, with outbreaks reported from Israel, the USA, the UK, Netherlands, Japan and Indonesia (Hedrick *et al*. 2000; Hartman *et al.* 2004). Onset of mortality may occur very rapidly in affected populations, with deaths starting within 24 – 48 hours after the onset of clinical signs (Hartman *et al.* 2004). In experimental studies, 82% of fish exposed to the virus at a water temperature of 22°C died within 15 days (Ronen *et al*. 2003). KHV infection may produce severe gill lesions and affected fish often remain near the surface, swim lethargically, and exhibit respiratory distress and uncoordinated swimming (Hartman *et al.* 2004). Susceptibility is greatest at water temperatures of 22 – 27°C, with no mortality reported below 18°C (Goodwin, 2003). This viral disease affects fish of various ages, but fry are more susceptible than mature fish (Perelberg *et al*. 2003). With funding from the Invasive Animals CRC, the CSIRO Livestock Industries' Australian Animal Health Laboratory (AAHL) is currently assessing KHV's potential as a bio-control agent in Australia.

Carp pox disease, or cyprinid herpesvirus (CHV-1), is caused by a different herpes virus (*Herpesvirus cyprini*) that has a wide geographic distribution and affects common carp and koi (Hartman *et al.* 2004). CHV typically causes wart-like masses on skin and fins of older fish, but may be associated with high mortality in fish less than two months of age (Hedrick *et al.* 2000). In mature fish, CHV-1 is typically a non-lethal, self-limiting disease (Hartman *et al.* 2004), but it may be of use in limiting carp recruitment in Australian rivers. Carp pox disease is not currently being considered for carp control in Australia, but it may be an alternative bio-control agent that should be considered.

Daughterless Carp Gene Technology

Dr Thresher and his team from CSIRO Marine Laboratories (Hobart) have been considering the applicability of molecular control techniques for carp for almost a decade (see Grewe 1997). In 2003, CSIRO obtained funding from the Murray-Darling Basin Commission to commence development of ‘Daughterless Carp Gene Technology’. The daughterless concept arose from the widespread use of chemical aromatase inhibitors to create single-sex lines of fish for aquaculture. Aromatase is the enzyme responsible for female development. If aromatase is inhibited, all embryos develop as fully functional phenotypic males irrespective of their genotypic sex (XX or XY) (Piferrer *et al.* 1994). The ‘daughterless’ gene proposed by Thresher (Lapidge 2003) is an inheritable modified sequence of carp DNA that inhibits the expression of the aromatase gene (Thresher and Bax 2003). Thresher and Bax (2003) proposed that the release of a sufficient density of artificially-reared daughterless gene carriers, each carrying a sufficient number of copies of the daughterless gene, and with stocking continued for a sufficient number of years, the sex ratio of the wild carp population will be skewed to the extent that the viability of the population will decline.

Apart from potential fitness affects arising from the gene insertion process, the proposed ‘daughterless’ gene is not predicted to have negative affects on the fecundity or fitness of the neo-males (XX daughterless gene carriers), and consequently the gene could potentially escape natural selection (Thresher and Bax 2003). Further, despite the fact that each copy of the daughterless gene has a 50% chance of being lost during meiosis in every generation (hence the requirement for numerous copies in each individual fish released), the number of ‘daughterless’ carriers in the population is predicted to “snowball” each generation (Thresher and Bax 2003). These hypotheses have been tested in population models (Thresher and Bax 2003) which predict that carp populations could decline significantly within 20 years and reach pseudo-extinction within 30 years. CSIRO are in the process of developing daughterless gene constructs and integrating them into the genomes of a model organism (medaka: Japanese rice fish) in order to demonstrate proof-of-concept. Once achieved, laboratory-based population studies of medaka will be used to test population responses. From there, carp-specific daughterless constructs will be created and field trials are proposed. Funding for further development of the technology is being provided by the Murray-Darling Basin Commission and the Invasive Animals CRC for the next two years (at least).

Numerous concerns regarding the field application of daughterless technology exist. The principal concerns are: i) it is not known whether the reproductive fitness of hatchery-produced neo-males will be equivalent to true males; ii) the infrastructure to produce sufficient numbers of daughterless fish in hatcheries does not exist; and iii) that declines in carp abundance could take much longer than modelled, with carp populations potentially remaining at carrying capacity for many decades. Despite these concerns, if the technology is proven feasible, daughterless technology may provide a generic means of controlling pest fish (and perhaps other animal groups) across the world. Consequently, development and testing of this high-risk/great benefit solution to pest fish control warrants current levels of financial support for further development and testing of the technology.

7. REFERENCES

Barrett, J. and Mallen-Cooper, M. (2006). The Murray River's 'Sea to Hume Dam' fish passage program: progress to date and lessons learned. *Ecological Management and Restoration* **7**, 173 – 183.

Broster, L. (ed.) (1996). Proceedings of the National Carp Summit, Renmark, South Australia, October 6 – 7, 1995. Murray-Darling Basin Association, Adelaide.

Brown, P. (1998). Carp in Australia. NSW Fisheries. Fish fact, No 4.

Brown, P. and Walker, T. (2004). CARPSIM: stochastic simulation modelling of wild carp (*Cyprinus carpio* L.) population dynamics, with applications to pest control. *Ecological Modelling* **176**, 83 – 97.

Breukelaret, A.W., Lammens, E.H. and Breteler, K. (1994). Effects of benthivorous bream (*Aramis brama*) and carp (*Cyprinus carpio*) on sediment re-suspension and concentrations of nutrients and chlorophyll a. *Freshwater Biology* **32**, 113 – 121.

Brumley, A.R. (1996). Family Cyprinidae: Carps, minnows, etc. Pages 99 – 106 in R. McDowall (ed.). *Freshwater Fishes of South-Eastern Australia.* Reed Books, Sydney.

Burns, A., Sheldon, F. and Walker, K.F. (1994). Managing rivers from the bottom up – the importance of littoral biofilms. Pages 52 – 58 in Proceedings of the Environmental Flows Seminar, Canberra, 25 – 26 August 1994. Australian Water and Wastewater Association, Artarmon.

Butcher, D. (1962). The implications of the introduction of carp into Victorian waters. Fisheries and Wildlife Department, Victoria.

Cadwallader, P.L. (1978). Some causes of the decline in range and abundance of native fish in the Murray-Darling River system. *Proceedings of the Royal Society of Victoria* **90**, 211 – 224.

Cadwallader, P.L. (1986) Fish of the Murray-Darling system. Pages 679 – 694 in B. R. Davies and K. F. Walker (eds). *The Ecology of River Systems.* Dr W. Junk Publishers, Dordrecht.

Cadwallader, P. and Lawrence, B. (1990). Fish. Pages 317 – 335 in N. McKay & D. Eastburn (eds). *The Murray*. Murray-Darling Basin Commission, Canberra.

Cooper, E. L. (ed) (1987). *Carp in North America*. American Fisheries Society. Maryland, USA

Crivelli, A.J. (1981). The biology of the common carp, *Cyprinus carpio* Linneaus in the Cammargue, southern France. *Journal of fish Biology* **18**, 271 – 290.

Crivelli, A.J. (1983). The destruction of aquatic vegetation by carp, a comparison between Southern France and the United States. *Hydrobiologia* **106**, 37 – 41.

Davis, K.M., Dixon, P.I. and Harris, J.H. (1999). Allozyme and mitochondrial DNA analysis of carp, *Cyprinus carpio* L. from south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **50**, 253 – 261.

Dieter, C.D. (1990). The importance of Emergent Vegetation in Reducing Sediment Resuspension in Wetlands. *Journal of Freshwater Ecology* **4**, 467 – 73.

Diggle, J., Day, J. and Bax, N. (2004). Eradicating European carp from Tasmania and implications for national European carp eradication. Inland Fisheries Service, Hobart, Tasmania.

Driver, P.D., Harris, J.H., Closs, G.P. and Koen, T.B. (2005). Effects of flow regulation on carp (*Cyprinus carpio* L.) recruitment in the Murray-Darling Basin, Australia. *River Research and Applications* **21**, 327 – 335.

Faragher, R.A. and Harris, J.H. (1994). The historical and current status of freshwater fish in New South Wales. *Australian Zoologist* **29,** 166 – 176.

Fletcher, R.F., Morison, A.K., and Hume, D.J. (1985). Effects of Carp *Cyprinus carpio* L. on Communities of Aquatic Vegetation and Turbidity of waterbodies in the Lower Goulbourn River Basin. *Australian Journal of Marine and Freshwater Research* **36**, 311 – 27.

Gehrke, P.C., Brown, P., Schiller. C.B. and Bruce, A.M. (1995). River regulation and fish communities in the Murray River system, Australia. *Regulated Rivers: Research and Management* **11**, 363 – 375.

Gehrke, P.C. and Harris, J.H. (1994). The role of Fish in Cyanobacterial Blooms in Australia. *Australian Journal of Marine and Freshwater Research* **45**, 905 – 15.

Goodwin, A. (2003). Differential Diagnosis: SVC vs. KHV in Koi. *Fish Health Newsletter* **31**, 9 – 13.

Graham, K.J., Lowry, M.B. and Walford, T.R. (2005). Carp in NSW: assessment of distribution, fishery and fishing methods. NSW Department of Primary Industries, Cronulla, Fisheries Final Report Series No. 72.

Grewe, P. (1997). Potential of molecular approaches for the environmentally benign management of carp. Pages 119 – 127 in J. Roberts and R. Tilzey (eds). *Controlling Carp: Exploring the Options for Australia*. CSIRO Land and Water, Griffith.

Harris, J.H. and Gehrke, P.C. (1997). Rivers and fish in stress: the NSW rivers survey. NSW Fisheries Office of Conservation and Cooperative Research Centre for Freshwater Ecology, Cronulla and Canberra.

Hartman, K.H., Yanong, R.P.E., Petty, B.D., Francis-Floyd, R. and Riggs, A.C. (2004). Koi Herpes Virus (KHV) disease. Fact Sheet VM-149, Department of Large Animal Clinical Sciences (College of Veterinary Medicine), Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Hedrick, R.P., Gilad, O., Yun, S., Spangenberg, J.V., Marty, G.D., Nordhausen, R.W. Kebus, M.J., Bercovier, H. and Eldar, A. (2000). A herpesvirus associated with mass mortality of juvenile and adult koi, a strain of common carp. *Journal of Aquatic Animal Health* **12**, 44 – 57.

Hindmarsh, M. (1994). Carp: a noxious fish or a resource? In: Proceedings of the Forum on European Carp, Wagga Wagga. Murrumbidgee Catchment Management Committee.

Hume, D.H., Fletcher, A.R. and Morison, A.K. (1983). Final report. Carp program report No. 10. Fisheries and Wildlife Division, Victorian Ministry for Conservation.

Inland Fisheries Service (2004). Carp Management Program Report: Lakes Crescent and Sorell 1995 – June 2004. Inland Fisheries Service, Hobart, Tasmania.

Khan, T.A. (2003). Dietary studies on exotic carp (*Cyprinus carpio* L.) from two lakes of western Victoria, Australia. *Aquatic Sciences* **65**, 272 – 286.

Kick, M. (2001). Commercial Carp Fishing: A Guide. NSW Fisheries Report.

King A.J., Robertson A.I. and Healey M.R. (1997). Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in billabongs. I. Impacts on water-column properties. *Marine and Freshwater Research* **48**, 435 – 443.

Koehn, J.D. (2004). Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. *Freshwater Biology* **49**, 882 – 894.

Koehn, J., Brumley, A. and Gehrke, P.C. (2000). *Managing the impacts of carp*. Bureau of Resource Sciences, Canberra.

Lachner, E.A., Robins, C.R. and Courtenay, Jr. (1970). Exotic fishes and other aquatic organisms introduced into North America. *Smithsonian Contributions to Zoology* **59**, 29pp.

Lake J.S. (1967). Freshwater fish of the Murray-Darling River System. State Fisheries Research Bulletin Number 7. NSW Fisheries.

Lamarra, V.A. (1975). Digestive activities of carp as a major contributor to the nutrient loading of lakes. *Verhandlungen Internationale Vereinigung fur theoretische und Angewandte Limnologie* **19**, 2461 – 2468.

Lapidge, K.L. (ed) (2003). Proceedings of the National Carp Control Workshop, March 2003, Canberra. Cooperative Research Centre for Pest Animal Control, Canberra.

Lin, H.R. and Peter, R.E. (1991). Aquaculture. Pages 590 – 617 in I.J. Winfield and J.S. Nelson (eds). *Cyprinid fishes: Systematics, Biology and Exploitation*. Chapman Hall, London.

Lintermans, M. (2002). Fish in the Murrumbidgee catchment: A review of current knowledge. Environment ACT, Canberra.

Llewellyn, L.C. (1974). Spawning development and distribution of the southern pygmy perch (*Nannoperca australis*) Gunther from inland waters of south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **25**, 125 – 149.

Llewellyn, L.C. (1983). The distribution of fish in New South Wales. Australian Society for Limnology, Special Publication No. 7.

Llewellyn, L.C. (2005). Breeding biology, and egg and larval development of *Galaxias rostratus* Klunzinger, the Murray jollytail from inland New South Wales. *Australian Zoologist* **33**, 141 – 165.

Mackenzie, R., Jackson, P. and Cotterall, E. (2000). Control of exotic pest fishes – an operational strategy for Queenslands freshwaters. Department of Primary Industries, Queensland.

McLeod, R. (2004). Counting the cost: Impact of invasive animals in Australia, 2004. Cooperative Research Centre for Pest Animal Control, Canberra.

McCrimmon, H.R. (1968). Carp in Canada. Bulletin 165, Fisheries Research Board of Canada, Ottawa.

McDowall, R.M. (ed) (1996). *The freshwater fishes of south-eastern Australia* (2nd edn). Reed Books, Sydney.

Murrumbidgee Catchment Management Committee (1994). Proceedings of the forum on European carp. Wagga Wagga, NSW 20/06/1994. Murrumbidgee Catchment Management Committee, Wagga Wagga.

Murray-Darling Basin Commission (2000a). National Management Strategy for carp control (2000 – 2005). Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission (2000b). Future directions for research into carp. Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission (2000c). Ranking areas for action: A guide for carp management groups. Murray-Darling Basin Commission, Canberra.

Murray-Darling Basin Commission (2006). SRA Combined Protocols: Approved Manual for IP3 2006 – 07. Murray-Darling Basin Commission, Canberra.

Newcome, C.P. and MacDonald, D.D. (1991). Effects of Suspended Sediments on Aquatic Ecosystems. *North American Journal of Fisheries Management* **11**, 72 – 82.

Newall, A.N. (1995). The microflow environment of aquatic plants – an ecological perspective. In: D.M. Harper and A.J.D. Ferguson (eds). *The Ecological basis for river management.* John Wiley and Sons, Chichester.

New Zealand Department of Conservation (2001). Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10 – 12 May 2001, Hamilton.

Panek, F.M. (1987). Biology and Ecology of carp. Pages 1 – 16 in E.L. Cooper (ed). *Carp in North America*. American Fisheries Society. Maryland, USA.

Page, L.M. and Burr, B.M. (1991). *A field guide to freshwater fishes North America North of Mexico*. Peterson Field Guide Series. Houghton Miffin Company. Boston. 432pp.

Perelberg, A., Smirnov, M., Hutoran, M., Diamant, A., Bejerano, Y. and Kotler, M. (2003). Epidemiological description of a new viral disease afflicting cultured *Cyprinus carpio* in Israel. *The Israeli Journal of Aquaculture* **55**, 5 – 12.

Piferrer, F., Zanuv, S., Carrillo, M., Solar, I. L., Devlin, R.I.L. and Donaldson, E.M. (1994). Brief treatment with a Aromatase inhibitor during sex differentiation causes chromosomally female salmon to develop as normal, functional males. *Journal of Experimental Zoology* **270**, 255 – 262.

Reid, D.D., Harris, J.H. and Chapman, D.J. (1997). NSW Inland Commercial Fishery data analysis. FRDC Project No. 94/027, NSW Fisheries, Cronulla.

Roberts, J. and Ebner, B. (1997). An overview of carp *Cyprinus carpio* L. in Australia. Part 1. CSIRO, Land and Water. Griffith.

Roberts J. and Tilzey R. (eds) (1997). Controlling Carp: Exploring the Options for Australia. CSIRO Land and Water, Griffith.

Robertson, A.I., Healy, M.R. and King, A.J. (1997). Experimental manipulations of the biomass of introduced carp (*Cyprinus carpio*) in Billabongs. II. Impacts on benthic properties and processes. *Australian Journal of Marine and Freshwater Research* **48**, 445 – 54.

Ronen, A., Perelberg, A., Abramovitz, J., Hutoran, M., Tinman, S., Bejerano, I., Steinitz, M. and Kotler, M. (2003). Efficient vaccine against the virus causing a lethal disease in cultured *Cyprinus carpio*. *Vaccine* **21**, 4625 – 4743.

Rowland S.J. and Ingram, B.A. (1991). Diseases of Australian native freshwater fishes. NSW Fisheries, Cronulla.

Schiller, C. and Harris, J.H. (2001). Native and Alien fish. Pages 229 – 258 in W.J. Young (ed). *Rivers as Ecological Systems: the Murray Darling Basin*. Murray Darling Basin Commission. Canberra.

Shearer, K.D. and Mulley, J.C. (1978). The introduction and Distribution of Carp, *Cyprinus carpio* Linnaeus, in Australia. *Australian Journal of Marine and Freshwater Research* **29**, 551 – 63.

Smith, B. (2005). The state of the art: a synopsis of information on common carp (*Cyprinus carpio*) in Australia. Final Technical Report, SARDI Aquatic Sciences Publication No. RDO4/0064-2; SARDI Research Report Series No. 77, Adelaide.

Splitler, R.J. (1987). Sport fishing for carp. Pages 31 – 48 in E. L. Cooper (Ed.). *Carp in North America*. American Fisheries Society. Maryland, USA.

Stuart, I. and Jones, M. (2002). Ecology and management of common carp in the Barmah-Millewa forest. Arthur Rylah Institute for Environmental Research, Heidelberg, Victoria.

Stuart, I., McKenzie, J., Williams, A. and Holt, T. (2003). Separation cages for the removal of carp from Murray-Darling Basin fishways. Final report on preliminary trials of the William’s Carp Separation Cage. Murray Darling Basin Commission. Project R2104.

Stuart, I., Williams, A., McKenzie, J. and Holt, T. (2006). The Williams’ cage: a key tool for carp management in Murray-Darling Basin fishways. Final report on the Williams’ Carp Separation Cage to the Murray Darling Basin Commission Project R3018SPD, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Thresher, R.E. (1997). Physical removal as an option for the control of feral carp populations. Pages 58 – 73 in J. Roberts and R. Tilzey (eds). *Controlling Carp: Exploring the Options for Australia*. CSIRO Land and Water, Griffith.

Thresher, R. and Bax, N. (2003). The science of producing daughterless technology; Possibilities for population control using daughterless technology; maximising the impact of carp control. Pages 19 – 24 in K.L. Lapidge (ed). *Proceedings of the National Carp Control Workshop, March 2003, Canberra*. Cooperative Research Centre for Pest Animal Control, Canberra.

Walker, K.F. and Hillman, T.J. (1977). Limnological survey of the River Murray in relation to Albury-Wodonga, 1973 – 1976. Albury-Wodonga Development Corporation and Gutteridge, Haskins & Davey, Albury, Australia.

Williams, A.E., Moss, W. and Eaton, J. (2002). Fish induced macrophyte loss in shallow lakes: top-down and bottom-up processes in mesocosm experiments. *Freshwater Biology* **47**, 2216 – 2232.

Wilcox, T.P. and Hornbach, D.J. (1991). Macrobenthic Community Response to Carp (*Cyprinus carpio* L.) Foraging. *Journal of Freshwater Ecology* **6**, 170 – 183.

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