Testing methods and ecological consequences of large-scale removal of common carp

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NON-TECHNICAL SUMMARY

Testing methods and ecological consequences of large scale removal of common carp

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OBJECTIVES:

1. Evaluate the effectiveness of rotenone pellet baits on carp and effects on non-target species such as small fish and crustaceans.
2. Assess the effectiveness of large-scale fishing methods for the removal of carp.
3. Assess the ecological impact of adult and juvenile carp at high and low densities.

NON TECHNICAL SUMMARY:

Common carp (*Cyprinus carpio*) are introduced pest fish that are widely distributed in South-Eastern Australia. Carp dominate many of the fish communities within their range, particularly in the Murray-Darling Basin. The successful establishment of the species is aided by their high environmental tolerances, mobility and high fecundity. Further, these characteristics make carp persistent pests that are difficult to eradicate.

There are a number of potential tools available for carp control, including biological control, habitat modification, physical control and chemical control. However, a lack of information on the relative costs, availability, social acceptance, and efficiency of different control methods makes choosing an appropriate technique difficult. Further, implementing a suitable combination of effective control techniques, following the principals of integrated pest management, is not possible without detailed assessment of the effectiveness and short-falls of alternative control strategies.

This report documents the findings of three separate studies. The first study (undertaken by Dr Gehrke) aimed to evaluate the effectiveness of rotenone pellet baits on carp eradication and impacts on non-target native species. The second (undertaken by Dr Schiller) aimed to assess different fishing gear types and provide information on the most cost-efficient and effective harvest techniques. Particularly those techniques suitable for use by community groups and other organisations wishing to remove carp from their local waterbodies. And the third (also undertaken by Dr Schiller) aimed to identify ecological differences between large and small carp in enclosed waterways in order to assess the ecological consequences of selective harvest of large adult carp. The main findings from these studies are outlined below.

Assessment of oral rotenone baits for carp control

Floating pellet baits containing a lethal dose of rotenone were tested in billabongs, hatchery ponds and aquaria to assess their potential for carp control in Australia. Application of rotenone pellets in three replicate billabongs killed only 12 carp from an estimated population of ~2,700. However a large number of Australian smelt (~3,000) were also killed in one billabong. Fine pellet dust added with the pellets in that billabong was considered to be the most likely reason for mortality of Australian smelt.

In aquarium experiments, crimson-spotted rainbowfish, western carp gudgeons and Australian smelt suffered high mortality when rotenone pellets were left in the water. However, if pellets were removed after 30 minutes, mortality of two of these non-target species was reduced. Australian smelt still suffering 95% mortality when pellets were removed. These results suggest that leaching of rotenone from uneaten pellets can impact on non-target fish species, and that effects of leaching can be reduced by removing uneaten pellets after carp have fed on the pellets.

In the pond experiment, substantial numbers of bony herring (39%) but very few carp (5%) died after application of rotenone pellets.

A palatability experiment suggested that the addition of rotenone (and other associated chemicals in the baits) significantly reduced the palatability of baits to carp. Rotenone pellets may be made more effective by improving their palatability. In addition, screening pellets to prevent fine particles from entering the water and removing uneaten pellets after thirty minutes would reduce the risk to non-target species. Based on these results, pellet baits require extensive further development before they can be considered to be effective for carp control, with an acceptably low risk to non-target species in Australia.

Effectiveness of four large scale fishing methods for the removal of carp

Information is needed on the availability of alternative and easy to use fishing gear that is cost effective, efficient and has minimal impact on native species. Current gear types being used by commercial operators and government departments require a high level of expertise, effort and expense but are not well suited for community groups and other organisations to use.

The effectiveness of four large-scale fishing methods was evaluated in the Menindee Lakes in Western New South Wales. Gear types compared were large (85mm) and small mesh (35mm) fyke nets, an electro-seine and a pound net. The four different fishing methods were assessed for catch efficiency, cost-effectiveness, ease of use, suitability for use in a range of different aquatic environments and their potential for minimising bycatch and injury to native fish.

Small mesh fyke nets caught the most carp from the widest range of size classes, were the easiest to use, caused least mortality of bycatch and were the second most cost effective gear type. Therefore, the small mesh fyke nets were regarded as the most suitable gear type for community groups and other organisations to use for harvest of carp from local waterbodies.

Assess the ecological impact of adult and juvenile carp at high and low densities

A density-dependent recruitment model has been proposed for carp which suggests that recruitment success of juvenile carp is greatest at low to intermediate densities of adult fish. Therefore, harvest techniques that target adult carp may result in improved survival of juvenile fish. It is important to understand the possible ramifications on the aquatic environment of replacing a given number of large adult carp with potentially many more smaller ones.

The experiment aimed to assess ecological changes in four billabongs, each separated into four replicate carp enclosures. The treatments consisted of high adult biomass and high juvenile biomass, high adult and low juvenile biomass, low adult and high juvenile biomass and a control replicate with no carp. In each treatment group, a number of variables including aquatic macrophyte density, suspended solids (turbidity) and nutrient levels (chlorophyll a, nitrates and phosphate) were monitored.

Unfortunately, the system of isolating the replicates in each billabong was not effective and individual carp moved among the four enclosures. This may have occurred either by carp jumping between pens, burrowing under the mesh walls or swimming over the nets during periods of high water level at one of the billabongs. Future attempts at such an experiment should take extra precautions to ensure that carp are effectively retained within assigned treatments.

General conclusions

Neither oral rotenone baits or any of the gear types tested were particularly effective at removing large numbers of carp. Therefore, the feasibility of other techniques, such as biological controls like the daughterless carp program (Thresher and Bax 2003), fishway trapping using the 'William's carp separation cages' (Stuart *et al.* 2003), excluding adult carp from spawning areas using 'fish screens' (Nichols and Gilligan 2004), pellets containing alternative active agents (Kroon *et al.* in press), or the use of pheromone attractants (Sorensen 2003) should be assessed as potential alternative carp control strategies.

1. INTRODUCTION

Dean M. Gilligan

1.1. Carp in Australia

The introduced common carp (*Cyprinus carpio*) is currently considered by fisheries biologists as the worst freshwater pest fish in both Australia and New Zealand (Chadderton *et al.* 2003). Further, there is considerable public pressure to undertake carp control (Koehn *et al.* 2000).

Common carp flourish in temperate river systems and are particularly prominent in the Murray-Darling Basin, comprising around 90% of fish biomass in many areas (Gehrke *et al.* 1995; Harris & Gehrke 1997; Gilligan 2005). Increased incidence of blue-green algal blooms (Breukelaar *et al.* 1994; Gehrke and Harris 1994; Williams *et al.* 2001), declining native fish populations (Lachner *et al.* 1970; Roberts 1978; Page and Burr 1991; Hindmarsh 1994; Koehn *et al.* 2000), increased turbidity (Crivelli 1981; Fletcher *et al.* 1985; Newcome and Macdonald 1991; Driver *et al.* 1997; King *et al.* 1997; Roberts *et al.*, 1995; Schiller and Harris 2001), damage to stream banks (Wilcox and Hornbach 1991) and loss of aquatic vegetation (McCrimmon 1968; Crivelli 1983; Hume *et al.* 1983; Fletcher *et al.* 1985; Panek 1987; Roberts *et al.* 1995; Williams *et al.* 2001) have all been attributed to carp populations. In response, common carp have been declared a noxious species in several Australian States. Furthermore, “the introduction of fish (including carp) to freshwaters within a catchment outside their natural range”, has been listed as a key threatening process to threatened and vulnerable fish in New South Wales under the Fisheries Management Act, 1994.

There are a number of factors that have facilitated the spread of carp throughout South-Eastern Australia, including large floods, the use of live carp as bait fish, deliberate introductions and accidental escape of ornamental fish from fishponds. Establishment of carp populations is generally considered to be facilitated by the degraded condition of Australian river systems and fish communities, resulting from river regulation and its associated effects, as well as over harvest of the major predatory species (Cadwallader 1978; Lake 1980; Gehrke *et al.* 1995; Driver *et al.* 1997; Koehn *et al.* 2000). As carp have wide tolerances to a range of environmental variables, being able to withstand temperatures between 4 - 36^{o}C, pH between 5 – 10.5, extreme turbidity, moderate salinities, high toxicant loads and very low dissolved oxygen levels (Panek 1987; Mackenzie *et al.* 2000) they have become established under conditions unsuitable for native Australian fish species. As they now dominate the biomass of freshwater environments in which they have become established, their presence is likely to inhibit or prevent the recovery of native fish populations even after management programs remediate degraded freshwater habitats. Therefore, carp control programs are a necessary component of restoring freshwater fish communities.

1.2. Carp control options

Despite concern over the negative impacts of carp, there is currently a lack of information on the effectiveness of various alternatives for carp control (Roberts and Ebner 1997). Numerous methods and actions have been undertaken both overseas and in Australia. These control methods fall into four broad areas: biological control, habitat manipulation, physical control and chemical control (Roberts and Ebner 1997).

1.2.1. Biological control

Proposed biological controls include viral control agents such as the Spring Viraemia Virus (Fijan 1972; Jeney and Jeney 1995), bio-manipulation and other molecular approaches such as induced fatality genes (Grewe 1997; Koehn *et al.* 2000). More recently, Daughterless Carp Gene Technology, currently under development by the CSIRO Marine Research Laboratories and the CRC for Pest Animal Control, is emerging as a promising option for long-term carp control (Lapidge 2003).

However, even if the daughterless gene biotechnology is completely successful, carp populations will maintain their current densities for many decades before declines in population size are observed. As a result, concurrent control techniques are required to; 1) reduce carp abundances in the interim, and 2) enable more rapid and effective dispersal of the daughterless gene within carp populations if and when that technology is introduced.

1.2.2. Habitat manipulation

There are a number of ways that carp habitats can be manipulated to either totally remove carp or reduce carp biomass. This can occur through the removal of adult fish or through habitat manipulations which impact on spawning and recruitment (termed ‘recruitment sabotage’, Brown *et al.* 2003).

The drainage or drying of wetlands is being used in an attempt to remove carp from some wetland systems. Re-colonisation is inhibited by the construction of ‘fish screens’ preventing the re-entry of adult carp. However, assessments of carp abundance and biomass within screened and un-screened wetlands found that fish screens did not prevent the re-colonisation of carp in managed wetlands (Nicols and Gilligan 2004). Larval or juvenile carp capable of passing through the screens grow rapidly in the wetland environment. For example, larval and juvenile carp entering a wetland at $< 43 \pm 3$ mm reached sizes of 232 ± 31 mm within 6 months following a managed drying/wetting event at Lake Merriti in the Murray Riverlands (Nicols and Gilligan, unpublished data). Therefore, the biomass of carp quickly recovers following managed drying events, even when carp exclusion screens prevent the colonisation of adult fish. However, managed wetting regimes in regulated wetlands fitted with fish screens may still be useful for inhibiting carp reproduction in managed wetlands by: 1) preventing the entry of sexually mature fish, and 2) ensuring that the wetting and drying frequency is shorter than the 2-3 years it takes for young carp to reach sexual maturity. However, the negative impacts that fish screens may have on the migration of native fish between the river and floodplain wetlands may outweigh the potential benefits resulting from reduced carp reproduction.

Wetland draw-down has also been proposed and tested as a method of disrupting spawning and recruitment success (Shields 1958; Gafny *et al.* 1992; Verrill and Berry 1995; Wilson pers. comm.). Rapid reduction in water level immediately following a spawning event could be used to desiccate eggs. However, a major difficulty in applying this technique under natural conditions is that, because carp spawning activity is greatest under high flow conditions (Gilligan and Schiller 2004), the feasibility of reducing water levels in wetlands during periods of elevated river level is limited. Further, any manipulation of water levels or drainage of wetlands, will require increased knowledge of native fish species inhabiting wetlands, and assessment made of the potential impacts on native fish communities.

In addition to these difficulties, simulations of ‘recruitment-sabotage’ undertaken using an age-based population model for carp (CARPSIM: Brown *et al.* 2003) suggest that this management strategy may be counter-productive if recruitment cannot be controlled with a high probability of success over a 30 – 40 year period. If extremely effective recruitment sabotage is possible (e.g. 99 years in 100), carp populations can decline rapidly (Brown *et al.* 2003). However, simulations suggested that a significant risk of an increase in carp biomass exists if recruitment cannot be controlled with a probability of 50% (Brown *et al.* 2003), which is a much more realistic scenario. Therefore, the use of habitat manipulations with the aim of reducing recruitment success is unlikely to provide an effective means of controlling carp populations in the long term.

1.2.3. Chemical control

Chemicals such as rotenone can be used effectively to eradicate carp in small enclosed waterbodies (Crivelli 1981; Pearce 1986; Hall 1988; Sanger and Koehn 1997), although, the lack of species specificity of chemical control agents means that they are only applicable where there is a low risk to other aquatic species. To overcome the lack of species specificity, carp specific baits laced with rotenone have been developed to control grass carp (*Ctenopharyngoden idella*), another invasive carp species causing environmental impacts in New Zealand (Rowe 1999). Another bait formulation developed for control of carp uses the piscicide, antimycin (Marking 1992).

Control options capable of resulting in non-selective mortality, such as the use of piscicides, have been simulated using CARPSIM (Brown *et al.* 2003). Using population parameters based on a carp population in the Barmah area of the Murray River, simulations representing the regular use of a non-selective piscicide resulted in effective carp control even if only 50% of the carp biomass was removed (Brown *et al.* 2003). Using parameters from the carp population in the Campaspe Irrigation Area, effective control was possible if over 75% of carp biomass was removed. If only 50% of the carp biomass was removed from this waterway, biomass of the carp population would be reduced to < 30% (Brown *et al.* 2003).

1.2.4. Physical control

Carp can be harvested from large waterbodies with methods such as boat electrofishing, seine and gill nets (Knapp and Mathews 1988; Thresher 1997). These methods are used by commercial operators in Victoria and New South Wales (Charlie Carp and K&C Fisheries) (Koehn *et al.* 2000).

To encourage commercial carp fishing and establish markets for carp products, the New South Wales Government implemented an incentive scheme in 1998 (Kick, 2001). 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, 2001). Three licences were issued under the scheme. One of these was taken by Charlie Carp who produce fertilisers from approximately 180 to 200 tonnes of carp per year, caught mostly from Lake Boga in Victoria (R. Kopanica pers. comm. 2003). Another licence was taken by K&C Fisheries who harvest up to 1000 tonnes of carp per year, caught mostly from the Gippsland Lakes in Victoria (K. Bell pers. comm. 2003). Their product is sold to a range of markets, both domestic and export, including fresh fish, rock lobster bait, stock feed, fertilizer and dried and smoked products. Exports are shipped to Poland, Fiji, Israel, Germany and Malaysia (Bell 2003). 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 its closure and are now entitled to harvest yabbies and carp. Poor quality controls, lack of suitable supply, poor market perception and limited financial returns hamper the success of the commercial carp fishery (Kick 2001).

Recreational fishing clubs and local communities have also been involved with promotion of carp control by holding regular carp fishing competitions such as the Carpathon in Narrandera, the Carp round-up in Lake Cargelligo, Moree and Brewarrina, the Harvey Norman sponsored event in Hume Weir and Carp Busters in South-East Queensland.

Traps have been used to harvest adult carp moving onto and out of floodplain wetlands when suitable wetland regulation structures exist. For example, in New South Wales, K&C Fisheries trapped the entrances of Moira Lake in the Barmah-Millewa Forest and harvested approximately 76 tonnes of carp within a six week period (Stuart and Jones 2002).

Similarly, migrating carp commonly use fishways designed to allow fish passage for native species (Mallen-Cooper *et al.* 1995; Mallen-Cooper, 1999). Stuart *et al.* (2003) have tested a 'carp drafting device' designed to separate carp from native fish using fishways. As carp jump and native fish generally do not (Stuart *et al.* 2003), the device separates carp from the native fish using a baffle within the trap which stimulates carp to jump. As carp leap over the baffle, they fall through a trap-door into a holding pen. This was demonstrated in an initial assessment where 100% (16 individuals) of carp jumped over the baffle and fell through the trap door. No native fish (silver perch, golden perch, bony herring, and Murray cod) jumped over the baffle when it was set at 200 mm above the water surface (Stuart *et al.* 2002). This trap has considerable potential for capture of carp migrating through fishways and further assessment is being undertaken by the Arthur Rylah Institute, Victoria.

Unlike chemical control options, physical control techniques such as harvest and trapping are typically selective for specific size classes of fish, usually being more effective at harvesting larger individuals. Simulations of size-selective mortality using CARPSIM (Brown *et al.* 2003) suggest that even at high capture efficiencies, size-selective harvesting is unlikely to result in effective carp control through compensatory enhanced recruitment. However, using physical harvest techniques could result in significant reductions in carp biomass (< 60%) by reducing the abundance of large size classes (Brown *et al.* 2003). Therefore, to increase the effectiveness of physical control options, the gear types used must be effective in sampling as broad a range of size classes as is possible.

1.3. Objectives

A lack of information on the relative costs, availability, social acceptance, and efficiency of different control methods make choosing an appropriate technique difficult. Further, implementing a suitable combination of effective control techniques, following the principals of integrated pest management, is not possible without detailed assessment of the effectiveness and short-comings of alternative control strategies. To help fill these knowledge gaps, three separate studies were undertaken. The first study aimed to evaluate the effectiveness of a chemical control, rotenone pellet baits, on carp eradication and impacts on non-target native species. The second aimed to assess a number of physical control options and provide information on the most cost-efficient and effective harvest techniques. In particular, those techniques suitable for use by community groups and other organisations wishing to remove carp from their local waterways. And the third study aimed to identify the ecological consequences of either chemical or physical control options that selectively remove only large adult fish, with the potential consequence of improving recruitment of carp juveniles.

2. ASSESSMENT OF ORAL ROTENONE BAITS FOR CARP CONTROL IN NSW

Peter C. Gehrke

Note - Parts of this assessment have previously been published as:

Gehrke P.C. 2003. Preliminary assessment of oral rotenone baits for carp control in New South Wales. Pages 143-154 in Department of Conservation, Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10-12 May 2001, Hamilton.

2.1. Introduction

Biocides are a potential way of eradicating pest fish and have been used extensively around the world (Crivelli 1981; Pearce 1986; Hall 1988; Wiley and Wydoski 1993; Shaw and Studholme 2001). Ichthyocides such as rotenone can be applied directly to the water to remove carp, but their lack of species specificity means that these chemicals can only be used where there is a low risk to other species. The recent development by Prentiss Inc. of a pellet bait system (Prentox® Prenfish™ Common Carp Management Baits) represents the first commercial scale attempt at manufacturing a product to control carp. In contrast to direct application of rotenone to water, floating baits require far less rotenone to kill fish, and can be tailored to suite the feeding behaviour and 'tastes' of the target species. Further, as the pellets are designed to float, uneaten baits can be removed, resulting in reduced leaching of rotenone into the water.

Common carp trainer pellets contain vegetable meal products flavoured with corn to attract carp. These trainer pellets are used to habituate carp before poisoned pellets are introduced. Carp management baits have the same basic ingredients, but also contain rotenone (2.64% wet weight), related compounds (3.36%) and piperonyl butoxide (0.50%) as a synergist. Both pellet formulations are extruded as a 10 mm diameter pellet. Oral toxicity of rotenone to carp is 8.1 mg kg^{-1} (LD50) at around 25°C (Fajt & Grizzle 1993). Each management pellet contains the lethal oral dose for a 1 kg carp. The pellets are formulated to float, reducing the risk to non-target species that do not feed from the surface. The relatively large size of the pellet also reduces the risk of ingestion by smaller non-target species.

The objectives of this study were:

- To evaluate whether the pellet method of delivery is effective to reduce carp populations under Australian conditions.
- To assess the effects of application on non-target species such as native fish and crustaceans.
- To determine whether the size of the pellet provides secondary protection for non-target species.
- To establish the duration of baiting required to get an effective kill of carp.
- To test the palatability of rotenone pellets against trainer pellets.

These objectives serve specific requirements to evaluate the potential for rotenone pellets in Australia. It is not sufficient just to establish whether the pellets kill carp because the toxic effects of rotenone on fish are already well-known (Wiley & Wydoski 1993). Rather, the first objective focuses on whether the pellet method allows existing carp populations to be significantly reduced. Irrespective of the number of carp killed, if the number of fish removed does not represent a significant proportion of the carp population, then prospects for reducing the environmental impacts of carp will be limited. The second and third objectives consider whether undesirable effects on non-target species will limit the habitats in which the product may be used. Objectives 4 and 5 are intended to optimise application to obtain the greatest reduction in carp populations with the minimum application of product.

2.2. Methods

2.2.1. Billabong experiment

The effectiveness of rotenone bait pellets at controlling carp amongst natural fish communities was tested in three replicate billabongs (Kurrajong, Sheepwash and Bulgari) near Narrandera in south-western New South Wales. Billabongs were selected if they were at least 1 m deep and contained established carp populations. The minimum size for suitable billabongs required that three feeding stations could be located in each billabong at a distance of 100 m apart. Potential sites were sampled with fyke nets, gill nets and electrofishing to confirm the abundance of carp.

Intensive mark-recapture assessments were undertaken to allow the population of carp in each billabong to be estimated using the Petersen method (Seber 1982). Carp collected by electrofishing were fin-clipped and returned to the water. One week later, each billabong was sampled a second time. On this occasion, only carp caught were examined to identify whether they had been marked in the previous sample, and then were again returned to the water. Simple estimates of the total carp population in each billabong were obtained by applying the Chapman formula:

$$N = \frac{(M+1)(C+1)}{(R+1)}$$

where M is the number of fish marked during the initial sample, C is the total number of fish caught in the second sample, and R is the number of marked fish in the second sample (Seber 1982). The variance of this estimate is obtained as:

$$S^2 = \frac{N^2(C-R)}{(C+1)(R+2)}$$

A second population estimate was obtained in one billabong after the bait treatment to estimate the population reduction achieved independently of the number of dead fish observed and removed. Non-target species were also recorded during sampling, to determine the composition of the fish communities in each billabong.

Within each billabong, three circular feeding stations were established by bending a length of flexible polyethylene pipe to form a circle enclosing 36 m^2 (Figure 1). The floating pipes were secured in position with star pickets driven into the substratum. A 1 m^2 mesh tray was placed on the bottom below the centre of each feeding station to sample any benthic non-target organisms that may have died at each station.

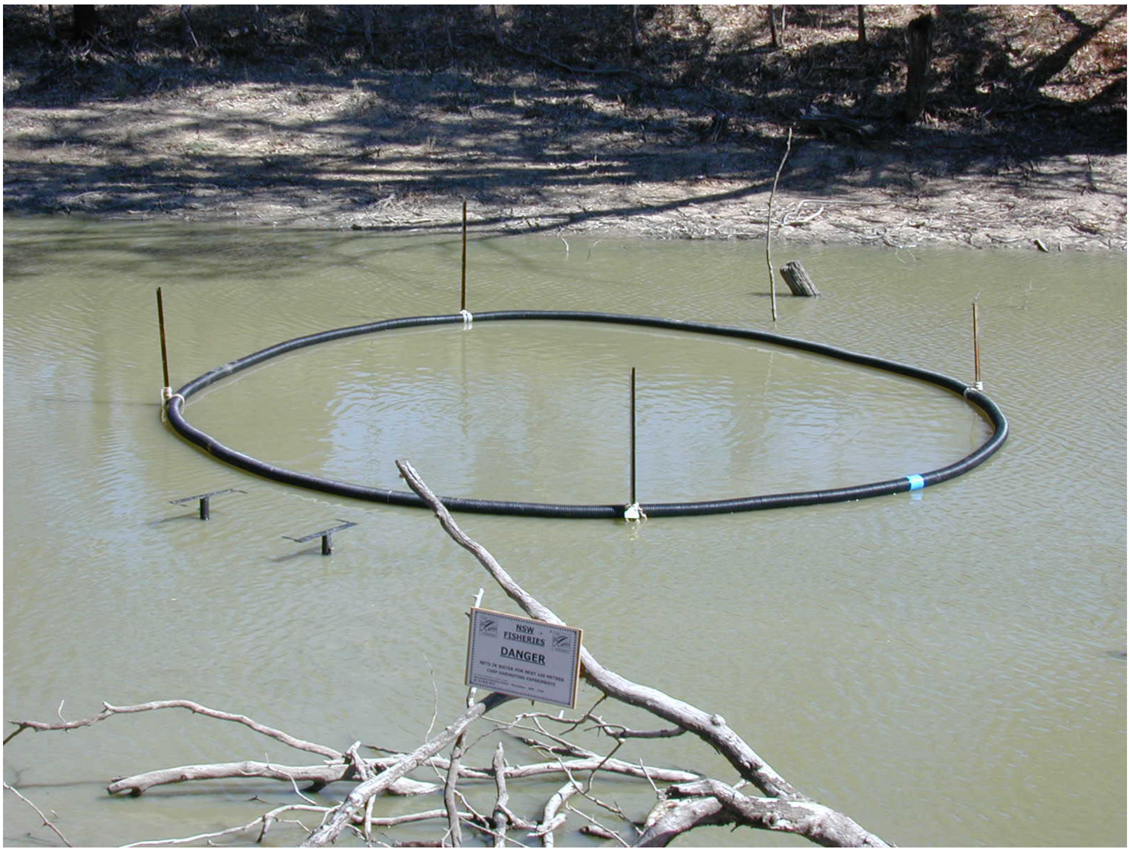

Figure 1. A feeding station established in a billabong to undertake bait trials.

Non-toxic trainer pellets were applied once daily within each feeding station. The initial application rate of 600g pellets per day was altered daily according to the amount of pellets consumed by carp within 20 minutes. Pellets were spread by hand into the floating feeding stations in two consecutive 10 minute periods. An indicator of carp feeding intensity was obtained by counting the number of times carp were observed to feed from the surface during the 20 minute feeding period. Trainer pellets were applied for nine days, and management pellets (containing rotenone) were substituted on the tenth day.

Management pellets were applied in an identical manner in a single application. Rotenone bait pellets in all experiments contained glitter to enable positive identification, by inspecting gut contents, of fish that had fed on pellets.

2.2.2. Aquarium experiment

Aquarium studies were conducted to assess the susceptibility of small non-target fish and invertebrates to rotenone applied in pellet form. Three species of fish: crimson-spotted rainbowfish (*Melanotaenia fluviatilis*), Australian smelt (*Retropinna semoni*) and western carp gudgeon (*Hypseleotris klunzingeri*), and three species of decapod crustaceans: freshwater prawn (*Macrobrachium australiense*), freshwater shrimps (*Paratya australiensis*) and yabbies (*Cherax destructor*) were collected from nearby creeks and ponds.

The experiment consisted of three treatments: (i) control; (ii) pellets removed after 30 minutes; and (iii) pellets not removed. Two replicates of each treatment were established for each species in 60 L glass aquaria fitted with aerators and undergravel filters. Ten individuals of each species were used in each replicate for Australian smelt (mean length = 44 mm), western carp gudgeons (28 mm) and freshwater shrimps (mean carapace length = 9 mm). Only five individuals were used for yabbies (20 mm), freshwater prawns (27 mm) and crimson-spotted rainbowfish (67 mm) due to the limited availability of these species.

Animals in control aquaria were fed daily on natural plankton collected from nearby ponds and on pieces of carrot. Animals in the second treatment were fed daily on five trainer pellets, which were removed after 20 minutes. In the third treatment, five pellets were added daily and not removed until feeding time on the following day. On the ninth day, management pellets containing rotenone were applied to the two experimental treatments, with pellets removed or not as for the trainer pellets. Only one management pellet was applied in each replicate because the leaching rate of rotenone from a single pellet was calculated to produce concentrations in water that would exceed the lethal limit for fish (J. Fajt, Prentiss Inc. pers. comm.).

Small numbers of other species (Murray cod *Maccullochella peelii*; trout cod *Maccullochella macquariensis*; golden perch *Macquaria ambigua*; silver perch *Bidyanus bidyanus*; Macquarie perch *Macquaria australasica*; and freshwater catfish *Tandanus tandanus*) in aquaria were also fed daily on trainer pellets to assess whether these species were attracted to the pellets, and therefore at risk of feeding on management baits during field applications.

2.2.3. Pond experiment

One hundred carp (112 – 539 mm fork length) and 102 bony herring (*Nematalosa erebi*) (32 – 346 mm) were collected from nearby waterbodies and stocked into an earthen pond (400 m^2) at the Narrandera Fisheries Centre. Bony herring were considered to be the native species most at risk from ingesting pellets intended for carp because of their feeding habits (Gehrke & Harris 1994). A single floating feeding ring (36 m^2) was placed in the centre of the pond to contain pellets. Trainer pellets were fed daily at the rate of 250 g per day. Uneaten pellets were removed after 30 minutes to estimate the quantity of pellets eaten. The quantity of trainer pellets consumed stabilised by day 8, so management pellets containing rotenone were applied on day 9. In an attempt to maximise effects on the fish, 500 g of management pellets were applied. The pond was then monitored for three consecutive days, and affected fish were collected and dissected for traces of glitter from management pellets in the digestive tract. On the fourth day the pond was drained to count all surviving fish and dead fish not collected previously.

2.2.4. Palatability and bait toxicity for carp

Twelve carp weighing from 1,211 g to 4,068 g were collected from local water bodies near Narrandera, New South Wales, and acclimated in individual 1800 L aerated hatchery tanks at 21^{o}C in a hatchery building. Flow through the tanks was kept to the minimum possible because the heating system could not support higher flow-through rates. Ten carp were initially presented with trainer pellets at the rate of 20 per day. Uneaten pellets were removed after a 30 minute feeding period. The weight of pellets consumed by each fish could then be expressed as a percentage of body weight. As carp became accustomed to feeding on pellets, the amount offered was doubled when each fish consumed 75% of the offered ration. The training period lasted for 22 days, with rotenone pellets substituted on day 23. Rotenone pellets were presented, to each individual fish, at the same rate as trainer pellets on the previous day, with uneaten pellets again removed after 30 minutes to assess consumption. Control fish were not offered pellets (trainer or rotenone), and were fed on natural zooplankton collected from outdoor ponds. Rotenone pellets were offered to control fish on the final day to assess ingestion by untrained fish and to assess any potential mortality from rotenone leachate. Fish were inspected hourly for symptoms of rotenone poisoning for the first eight hours following rotenone bait application, and then daily to remove dead or moribund fish. One carp contracted a fungal disease and died on day nine of the trial. Results from this fish were not used in subsequent analyses.

2.3. Results

2.3.1. Billabong experiment

Carp were the dominant species in Kurrajong and Sheepwash Lagoons (Table 1). Bulgari Lagoon contained relatively large numbers of Australian smelt and bony herring as well as carp (Table 1). Nine species were recorded in total from the three billabongs. Mark-recapture estimates of carp populations from the three billabongs before treatment were 768 ± 368 carp in Bulgari Lagoon, 852 ± 152 carp in Kurrajong Lagoon and 1054 ± 163 carp in Sheepwash Lagoon (Table 2).

Table 1. Summary of fish catches before pellet application from three billabongs. Numbers with asterisks include estimates of fish observed but not caught during electrofishing.

Species	Common name	Kurrajong	Sheepwash	Bulgari
Carassius auratus	Goldfish	23	29	13
Cyprinus carpio	Carp	199	218	63
Gambusia holbrooki	Gambusia	5*	5*	5*
Hypseleotris klunzingeri	Western carp gudgeon	5*	5*	5*
Maccullochella peelii	Murray cod	1	0	0
Macquaria ambigua	Golden perch	0	1	0
Nematalosa erebi	Bony herring	0	8	250*
Perca fluviatilis	Redfin perch	4	20	0
Retropinna semoni	Australian smelt	0	0	1000*
Number of species		6	7	6

Table 2. Carp population estimates before and after treatment: *M* represents the number of carp fin-clipped and returned to the water during the initial sample; *C* indicates the number of fish caught in the second sample; *R* is the number of fin-clipped fish in the second sample; and *N* is the population estimate.

Site	*M*	*C*	*R*	*N*	± SD
Before Treatment					
Bulgari	63	35	2	768	368
Sheepwash	218	153	31	1054	163
Kurrajong	199	97	22	852	152
After Treatment					
Kurrajong	153	146	16	1332	296

Feeding intensity of carp in the three billabongs appeared to stabilise on days 8 and 9 of trainer pellet application (Figure 2). Water temperature declined gradually during the training period from 23°C at the start of training to 20°C on the final day. Management pellets containing rotenone were applied on day 10. The weight of rotenone pellets applied at each feeding station was identical to the weight of trainer pellets consumed at the end of the training period (Table 3).

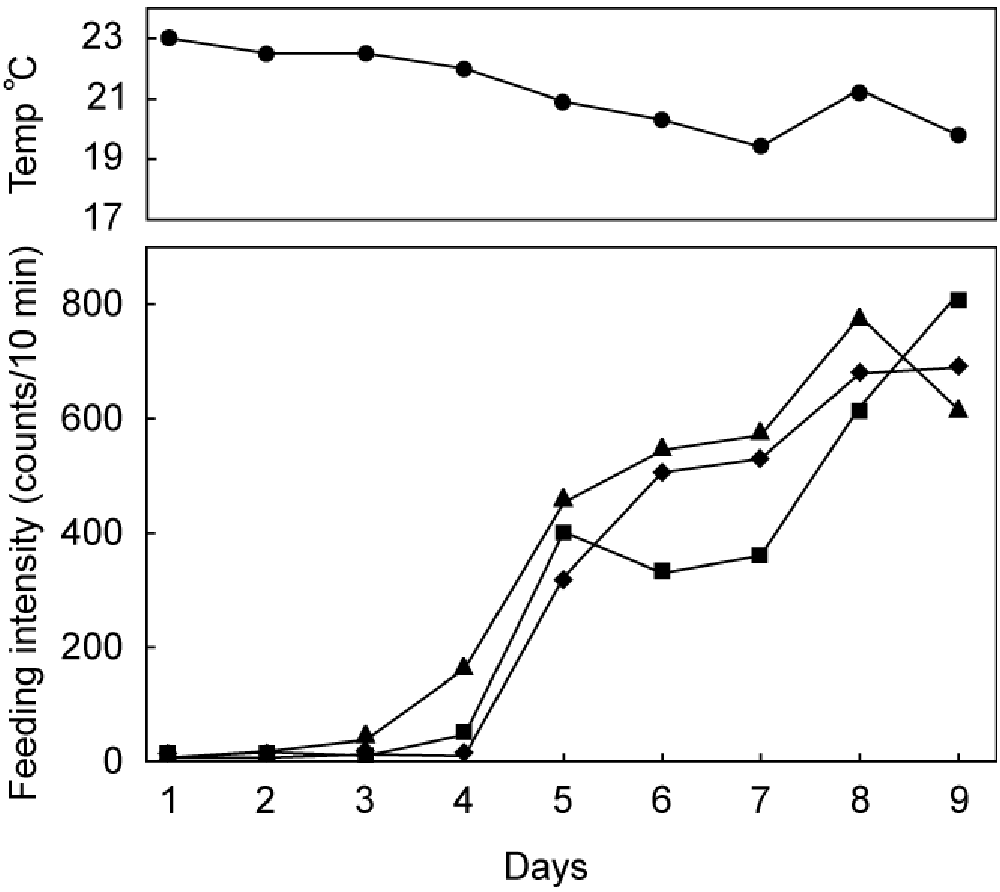

Figure 2. Standardised feeding intensity of carp and water temperature during training period at three feeding stations in Bulgari Lagoon. Feeding was measured as counts of the number of times carp were observed to ingest pellets at the surface.

Table 3. Daily rate of trainer and management pellet application at feeding stations in each billabong. Application rate was determined by the consumption rate by carp at each station on previous days, and modified daily in accordance with actual consumption. Low application rates for management pellets at one station in each of Kurrajong and Sheepwash lagoons reflect the low feeding rates on trainer pellets at those stations.

Billabong	Trainer (g)	Management (g)
Kurrajong	600-1400	50-900
Sheepwash	600-1400	100-900
Bulgari	600-1800	1100-1400

At Bulgari Lagoon, dead and dying Australian smelt were observed near the downwind shore of the billabong within two hours of applying management pellets. Over the next two hours, Australian smelt were collected over 150 m of shoreline at an estimated density of 20 fish m^{-1} giving a total estimate of 3,000 dead smelt in this billabong. No non-target mortality was observed from the other two billabongs. All benthic animals collected on trays beneath the feeding rings were alive and appeared to be unaffected by rotenone.

Over the next three days, only two carp were recovered from Kurrajong Lagoon, one from Sheepwash Lagoon, and nine from Bulgari Lagoon. Dead carp collected ranged from 473 – 651 mm in length, and weighed from 1.9 – 4.9 kg.

The final mark-recapture population estimate for Kurrajong Lagoon (1332 ± 296) was larger than the pre-treatment estimate (852 ± 152), indicating that it was unlikely that other carp had been killed without being observed. Consequently, further population estimates were not conducted at Sheepwash or Bulgari lagoons.

2.3.2. Aquarium experiment

Percentage survival in aquarium experiments was high for all species in the control treatment (Table 4), with only Australian smelt suffering any mortality. In the 'pellets removed' treatment all species except Australian smelt showed 100% survival. In the treatment where pellets were not removed, Australian smelt and crimson-spotted rainbowfish suffered 100% mortality, with 95% mortality of western carp gudgeons. In contrast, of the three crustacean species, only one freshwater prawn died in all three treatments.

Table 4. Percentage survival of non-target species among control and rotenone pellet treatments in aquarium trials (replicates = 2) over 24 h.

Species	Individuals per replicate	Control	Pellets removed	Pellets not removed
Fish				
Hypseleotris klunzingeri	10	100	100	5
Melanotaenia fluviatilis	5	100	100	0
Retropinna semoni	10	85	5	0
Decapod crustaceans				
Cherax destructor	5	100	100	100
Paratya australiensis	10	100	100	100
Macrobrachium australiense	5	100	100	95

Fish were not observed actively feeding on trainer or management pellets, suggesting that mortality may have resulted from leaching, rather than ingestion, of rotenone. In contrast, some of the crustaceans were observed clinging to the pellets, and apparently feeding on them without obvious effects.

Six large non-target species (Macquarie perch, silver perch, golden perch, freshwater catfish, trout cod and Murray cod) did not accept trainer pellets offered daily but continued to feed on natural foods, suggesting that the risk of these species taking management baits is low.

2.3.3. Pond experiment

The weight of trainer pellets ingested increased daily, from 114 g on day 1 to a maximum of 227 g on day 7 before declining slightly on day 8 (Figure 3). One carp and eight bony herring died and were removed from the pond before management pellets were applied. On day 9, 248 g (348 pellets) of management pellets were consumed. After bait application, five dead carp (112 – 530 mm) and 37 dead bony herring (107 – 346 mm) were collected over the next three days (Table 5). All dead carp had glitter in their digestive tracts, confirming that they had eaten management pellets. In contrast, the guts of 27 dead bony herring contained no glitter, suggesting that they died from causes unrelated to the treatment. This could potentially have been a result of leachate from the management baits. When the pond was drained, 21 bony herring and three carp could not be accounted for, and were presumed to have been eaten by piscivorous birds observed near the pond.

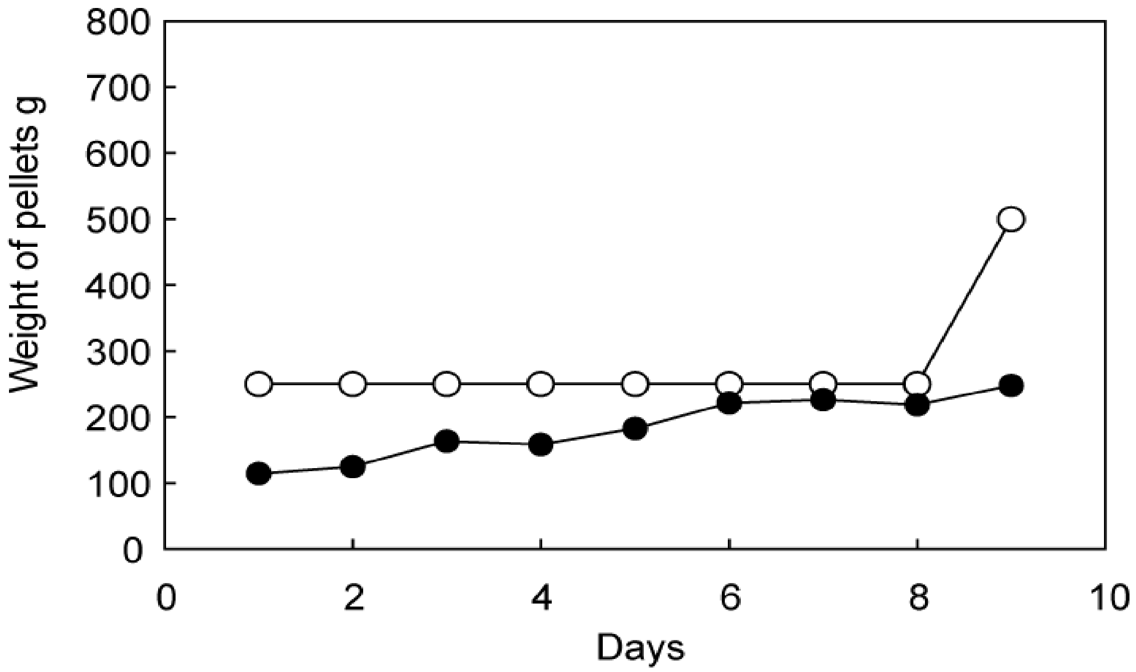

Figure 3. Number of pellets fed (hollow symbols) and eaten (solid symbols) per day during training (days 1 – 8) and application of management baits (day 9) in the pond experiment.

Table 5. Mortality of fish before and after applying management pellets in pond experiment.

Species	No. Stocked	Died Before	Died After	Surviving	Missing
Bony Herring	102	8	37*	36	21
Carp	100	1	5	91	3

*Only ten of these bony herring had glitter from pellets in their digestive tracts, confirming they had consumed pellet material.

2.3.4. Palatability and management bait toxicity for carp

One carp took trainer pellets on the first day, but 15 days training were required before all carp were consistently consuming pellets. The maximum daily rate of pellet consumption varied between fish from 3.2 to 9.0 g kg^{-1}. The mean weight of pellets consumed per day reached a maximum of 5.0 ± 0.8 g kg^{-1} (27 ± 7 pellets per fish) on day 19, and remained at or near this level. When pellets containing rotenone were applied on day 23, the consumption rate fell to 1.9 ± 0.6 g kg^{-1}, or 7 - 8 pellets per fish (Figure 4). Consumption of pellets containing rotenone was only 37% of the weight-standardised intake, and 26% of the maximum daily pellet intake per fish. Two carp refused to take the rotenone pellets. One of these fish, plus another carp that had eaten only one rotenone pellet, displayed no adverse symptoms after 24 h and fed readily on trainer pellets the following day (Table 6).

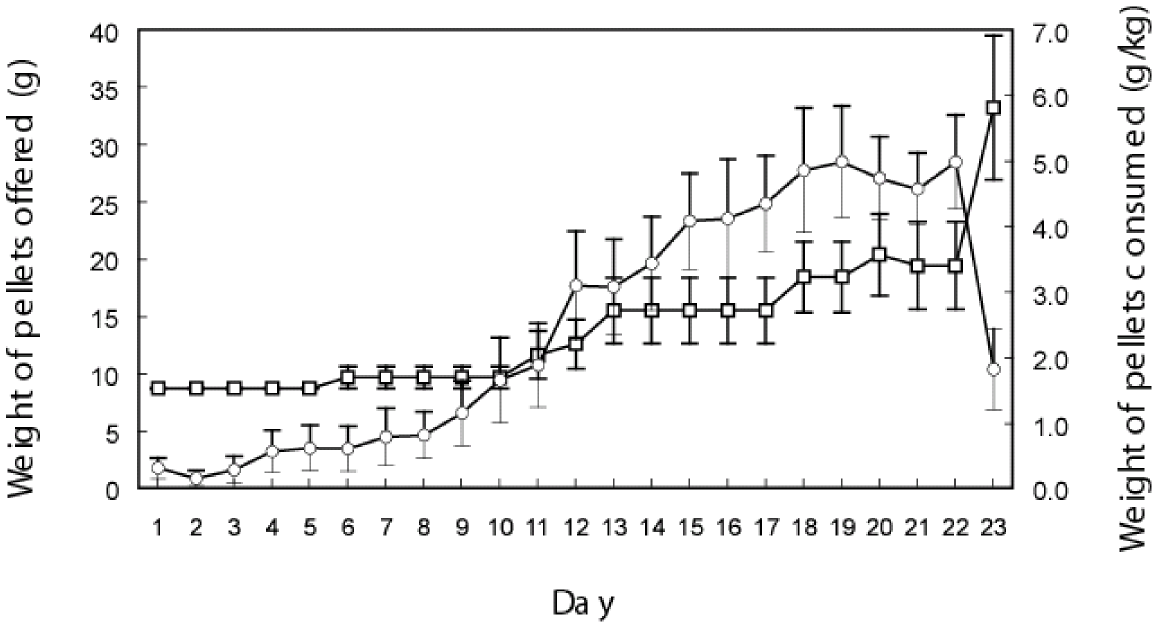

Figure 4. Rate of consumption of trainer pellets (days 1-22) and management pellets containing rotenone (day 23). Squares indicate mean ± SE weight of pellets offered to each fish; Circles indicate mean ± SE weight of pellets actually consumed. n=9.

Table 6. Oral dose of rotenone administered to carp and time for onset of symptoms.

Initial length	Initial weight (kg)	Sex	Maximum trainer pellets eaten	Rotenone pellets eaten	Weight rotenone pellets (g kg^{-1})	Oral rotenone dose (mg kg^{-1})	Time to loss of equilibrium (h)	Time to death (h)
Treatment								
454	1.867	Male	18	7	2.67	66.8	3	24
481	1.884	Male	21	5	1.89	47.3	6	48
587	2.588	Female	53	17	4.68	117.0	24	48
467	1.685	Male	15	0	0.00	0.0	-	-
464	1.862	Male	26	0	0.00	0.0	3	60
483	2.455	Female	41	3	0.87	21.8	3	60
412	1.121	Male	17	2	1.27	31.8	24	72
480	1.25*	Male	9	1	0.57	14.3	-	-
569	4.068	Female	80	27	4.73	118.3	1	24
Control								
278*	0.324*	Female	-	0	0	0	5	72
439*	1.496*	Male	-	0	0	0	4	48

2.4. Discussion

Pellet baits laced with rotenone were found to be ineffective for control of pest carp populations. Only small numbers of carp were killed during pond and billabong experiments. In contrast, high non-target mortality was observed under laboratory, pond and field conditions. However, mortality of bony herring in the pond experiment was in contrast to the billabong experiment where no mortality of this species was observed despite the presence of large numbers in Bulgari Lagoon. Bony herring are fragile and are sensitive to stress during handling and transport. Consequently, some of the mortality observed in the pond experiment is likely to have resulted from capture and handling. Alternatively, a sufficient concentration of rotenone may have leached from the baits to affect this species. Only small numbers of large native species were available for pellet feeding experiments, and more rigorous evaluation would be necessary to extend the preliminary results presented here. However, the refusal of these species to take trainer pellets suggests that the risk of them taking pellets containing rotenone is low. It is clear from this experiment that small fish are susceptible to rotenone leached from pellets, although the concentration of leached rotenone in aquaria would be many times higher than in large systems under field conditions. The risk to non-target fish species was significantly reduced by removing uneaten pellets within 30 minutes of application. Crustaceans appear to have low susceptibility to rotenone in pellet form as few died after exposure to rotenone baits despite having fed on them.

Results from these assessments differ from experiences in North America and New Zealand. Application of rotenone bait pellets to Lake Montery, Florida, resulted in 68% of the population of grass carp (*Ctenopharyngodon idella*) being removed. In this lake, grass carp accounted for only 1.9% of the total fish community (Fajt 1996). In addition, 109 field applications of rotenone bait pellets to control grass carp killed only 10 non-target fish (Fajt 1996). Seven applications of rotenone baits to water bodies containing common carp removed a total of 4,288 carp, and 130 non-target fish from four species, for an average non-target mortality of 1.3% (Prentiss Inc. unpublished data). In New Zealand, Rowe (1999) removed 22 grass carp from a small dune lake following one application of rotenone pellets, without observing any effects on non-target fish or birds. Based on North American experience, Rowe (1999) assumed that 60 – 70% of grass carp affected by rotenone were killed, but the number of grass carp surviving in the lake was not estimated.

Feeding intensity on management baits (containing rotenone) was noticeably lower than on trainer baits. For example at Sheepwash Lagoon, feeding intensity on management baits was 5% of what it had been the previous day following application of trainer baits. Feeding intensity on management baits in Kurrajong and Bulgari lagoons was estimated at 23% and 50% of the value from previous days. The reportedly bitter taste of rotenone and its synergist, piperonyl butoxide, are likely to be responsible for the observed reduction in feeding upon management baits. This observation was supported by the results of the palatability experiment where the ratio of pellets consumed per kilogram of body weight significantly decreased when management baits were introduced.

Carp mortality following application of rotenone pellets in the palatability experiment was initially lower than expected, with only two carp dying in the first 24 h. These two fish consumed seven and 27 pellets respectively, equivalent to a rotenone dose of 66.7 and 118.3 mg kg^{-1}. In contrast, Fajt and Grizzle (1993) reported that all carp which died after receiving an oral dose of up to 10 mg kg^{-1} rotenone did so within 16 h. In this study, one carp ate a single pellet, equivalent to 1.2 times the 48 h lethal dose to kill 99% of carp (11.6 mg kg^{-1} at 25°C; Fajt and Grizzle 1993) and survived to the end of the experiment with no sign of rotenone toxicity. These results suggest that the potency of rotenone in the commercially manufactured pellets was lower than that used by Fajt and Grizzle (1993). Low oral toxicity of rotenone administered to carp has been reported previously (Loeb, 1960; Rach *et al.* 1994). However, Fajt and Grizzle (1993) postulated that low oral toxicity was caused by crystallisation of the rotenone, reducing absorption from the intestine. The inclusion of a surfactant, polysorbate 80, in proprietary rotenone baits is intended to prevent crystallisation (Fajt and Grizzle 1993), so the low oral toxicity in the present experiment is not easily explained.

The high mortality of Australian smelt in the billabong experiment may be attributable to rotenone leached from pellets, ingestion of fine pellet particles, or to the fish feeding on softened pellets on the bottom. Removal of uneaten pellets after 30 min was insufficient to prevent mortality in static holding tanks. Consequently, application under field conditions where mixing of the water column is poor may pose a risk to non-target species. Potential toxic effects of leachates from pellets warrant further investigation. The most likely cause of Australian smelt mortality in Bulgari Lagoon is ingestion of pellet dust. During application of rotenone pellets at Bulgari Lagoon, pellet containers were turned upside down, allowing fine pellet dust to enter the water. Australian smelt are omnivorous planktivores which feed in the water column (McDowall 1996). The release of rotenone-laced baits in a particle size Australian smelt could readily ingest is a significant risk.

The presence of glitter in the guts of ten dead bony herring in the pond experiment suggests that the pellet size and corn flavour intended to attract carp only, do not provide adequate protection for some non-target species.

Risks to non-target species are ecologically significant. These risks can, however, be reduced by only using intact pellets, removing uneaten pellets after 30 minutes to minimise leachate, and disposing of fine pellet particles away from the water. Flotation certification by the manufacturer would help reduce the concentration of rotenone leached into the water column from sinking pellets.

2.5. Conclusions

The trainer pellets were effective in attracting carp following several weeks of training, but substitution of rotenone pellets did not result in a significant reduction of carp numbers, possibly due to the avoidance of the bitter tasting management baits. In contrast, the baits which were specifically designed to target carp (through size and flavour) were also palatable to at least two species of native fish, bony herring and Australian smelt. As a result, carp control programs using the current bait design could result in substantial non-target mortality of these native fish.

The standard 10 mm diameter pellet targets a wide size range of carp from 112 mm long and larger. The size of the pellets provides secondary protection for some non-target species, but the main risks to non-target species are leaching of rotenone from the pellets and entry of fine pellet dust into the water.

Although the rotenone pellet method has potential for carp control, further development is needed to refine the formulation of pellets, with acceptable levels of risk to non-target species. The pellet method could also be investigated for delivery of other control agents, including alternative ichthyocides such as antimycin (Rach *et al.* 1994), reproductive inhibitors (Hinds and Pech 1997), or molecular controls (Grewe 1997).

3. EFFECTIVENESS OF LARGE-SCALE FISHING METHODS FOR THE REMOVAL OF CARP

Craig Schiller

3.1. Introduction

A number of methods have been proposed as possible control measures for common carp in Australia, including the use of habitat manipulation, chemicals, biological control technologies, carp exclusion devices, capture and removal using traps, commercial fishing gears and angling (Koehn *et al.* 2000; also see chapter 1). There are a number of standard techniques that can be used to harvest carp from waterbodies, including boat electrofishing, seine (haul) netting and gill netting, which are currently used by government departments and commercial carp fishers. However, these techniques require specialised training, skills and equipment or present a risk to native fish and other aquatic animals. Therefore, they are unsuitable for widespread use by community groups and organisations who may wish to undertake large scale carp removal from local waterbodies (under relevant NSW Fisheries permits).

This study was a rapid one-off comparison of four alternative large-scale harvest techniques: small mesh fyke nets, large mesh fyke nets, pound nets and electro-seining. Primarily, each gear type was compared for the number of carp harvested per day however capture efficiency, cost of purchase and operation, ease of use, suitability for use in a range of different aquatic environments, and incidence of bycatch and injury to native fish were taken into consideration.

3.2. Methods

3.2.1. Sites

Assessments were made in the Menindee Lakes between 29 November and 8 December 1999. Trials were conducted in the same lake over a relatively short period to reduce any confounding effects of variation in habitat, water quality, carp density and temporal variation in fishing effectiveness that may have arisen if a number of different waterbodies were sampled over a longer time period. Lakes in the Menindee system are large and have high carp densities. It was anticipated that trials of each gear type would result in a minimal reduction in carp abundance within the lake, maintaining the independence of each trial.

3.2.2. Sampling methods

3.2.2.1. Electro-seining

Electro-seines had not previously been used by fisheries agencies or by commercial fishers for the capture of carp or any another other freshwater fish in Australia. However, electro-seines have been used overseas to sample fish in small streams in America (Bayley *et al.* 1989), for commercial applications in China (Cowx 1990) and for harvest of salmon from holding ponds (Cave 1990).

Electro-seining involves using a modified electrofishing system consisting of two arms that extend out from the port and starboard side of the vessel (Reynolds 1996). The electro-seine unit was fitted to FRV ACDC, a 5 m electrofishing boat. Each arm has anode and cathode droppers which are 50cm long which are arranged alternately, with a 2 m section of cathode droppers followed by a 4 m section of anode droppers. There are four banks of cathode and anode droppers on each arm, with the total length of each arm being 31 metres. The arms have floats attached along their length to support them in the water. The end of each arm is supported by a motorised punt which is manoeuvred to ensure the arms of the electro-seine maintained correct positions relative to the electrofishing boat. An on-board petrol powered 7.5 kW generator produces an electric current which passes through a rectifying unit, producing a pulsed DC waveform (Cowx 1990; Cowx and Lamarque 1990). An electric field is produced in the water through the electrodes along each arm. A control box fitted to the boat controls the sequential firing of the electrodes. A small charge of 120 Volts, 20% of range and a frequency of 60 pulses per second is used in order to create a ‘fright zone’ which herds the fish ahead of the electro-seine unit without causing electro-narcosis.

The area sampled was a 70 m wide and 3.5m deep channel connecting Lake Pamamaroo and Copi Hollow. During sampling, a medium flow was running from Copi Hollow into Lake Pamamaroo. Fish were herded along the length of the channel towards a mesh haul net. When the shot was completed, the punts were detached from the electro-seine and were used to retrieve the haul net and harvest the herded fish.

Electro-seining was tested on the 29 November, 1999. Three shots were conducted which took one day to complete. Operation of the electro-seine required a minimum of four staff to operate the electrofishing boat, the support boats and the setting and retrieval of the haul net.

3.2.2.2. Fyke nets

Fyke nets are cone shaped fish traps that has leaders or wings (guide walls) which guide fish towards the trap entrance. The design of the fyke nets used included three leader nets attached to the 2m x 2m net entrance, one perpendicular to the bank and 20m long, and two 5m wings set on either side at 45^0 to the net entrance (Figure 5). Two cone traps within the net prevented escape.

Figure 5. Fyke net set in Menindee Lake.

Both small mesh (35 mm) and large mesh (85 mm) fyke nets were set in similar habitats approximately 400 m apart in shallow water (0 m – 1.6 m) on the North-Eastern shore of Lake Menindee (Figure 5). The substratum was uniform sand. Each fyke net was hauled and reset every 2 days (with the exception of the large mesh net which was set for 3 days on the first set). Five consecutive replicate samples were collected for each net. After capture, all fish were counted, measured and released approximately 500 m away from the net site.

3.2.2.3. Pound nets

Pound nets are fish traps that have guide walls leading fish into aggregation chambers (Figure 6). The nets used in this study were constructed of 50 mm mesh walls supported by stakes secured into the substratum. Pound nets were set in relatively shallow water (0 m - 1.7 m) on the North-Eastern shore of Lake Menindee over a substrate of uniform sand. Pound nets were hauled and reset every two days. Four replicate samples were taken.

Figure 6. Pound net in Menindee Lake.

3.3. Results

3.3.1. Carp capture efficiency

The gear type that caught the most carp was the small-meshed fyke net, capturing 266 carp at an average of 53 ± 11carp per day. This was followed by the electro-seine capturing 10 carp per day, the pound net with a total of 35 carp captured at an average of 8.8 ± 1 carp per day and lastly, the large mesh fyke nets with a total of 16 carp at 3.2 ± 1 carp per day (Table 7 and 8). The small-mesh fyke nets and pound nets caught carp of a wider range of size classes than the large-mesh fyke nets which only caught fish larger than 200 mm (Figure 7).

Table 7. Number of fish caught per replicate using each sampling method.

Method	Date set	Fish Species					
		Goldfish	Carp	Spangled perch	Golden perch	Bony herring	Total
Electroseine	29/11/99						
	29/11/99						
	29/11/99		10			40	50
	Total	0	10	0	0	40	50
Fyke net (small mesh)	30/11/99	2	63	1	2	914	982
	2/12/99	1	46		12	418	477
	4/12/99	1	13		2	102	118
	6/12/99		68		3	161	232
	8/12/99	1	76		15	112	204
	Total	5	266	1	34	1707	2013
Fyke net (large mesh)	29/11/99		4			66	70
	2/12/99		3		1	59	63
	4/12/99		1		2	20	23
	6/12/99		5		1	27	33
	8/12/99		3		2	31	36
	Total	0	16	0	6	203	225
Pound net	1/12/99		8		1	44	53
	3/12/99		12			303	315
	5/12/99		6		1	29	36
	7/12/99		9			33	42
	Total	0	35	0	2	409	446
Grand total		5	327	1	42	2359	2734

Data on capture efficiency of the electro-seine was likely to be a poor representation of the efficiency of this gear type. Of the three shots undertaken, the first two were considered failures due to problems with retrieval of the haul net where all fish escaped. Given these difficulties electro-seine trails were abandoned and effort was subsequently concentrated on the netting methods. The electro-seine data is not representative of the potential efficiency of this gear type and therefore are not presented further.

Table 8. Mean (± SE) catch of fish per day with three net types.

Gear type	Average Catch/day Fish species					
	n	Goldfish	Carp	Spangled perch	Golden perch	Bony herring
Fyke net (small mesh)	5	1.0 ± 0.3	53.2 ± 11.2	0.2 ± 0.2	6.8 ± 2.8	341.4 ± 154.3
Fyke net (large mesh)	5	0	3.2 ± 0.7	0	1.2 ± 0.4	40.6 ± 9.2
Pound net	4	0	8.8 ± 1.3	0	0.5 ± 0.3	102.3 ± 67.0

3.3.2. Proportion of native fish caught by different gear types

Native fish (mostly bony herring) made up a majority of the catch across all four sampling methods (Figure 8, Table 7). All three netting techniques caught similar proportions of alien (goldfish and carp) and native fish, but small-mesh fyke nets caught 6% more goldfish and carp than the other netting methods. Further, the small-mesh fyke nets caught five species of fish, while the other gear types only caught three species (Table 7).

3.3.3. Risk to native fish

The large-mesh fyke nets accounted for the majority of fish (89.5%) that were gilled (opercula entangled in the mesh), with 148 bony herring, five carp and a single golden perch becoming entangled (Table 9). The remaining 10.5 % of gilled fish was comprised of 16 bony herring and two carp that were gilled in the small-mesh seine net. No fish were gilled in the pound net.

Table 9. Number of fish gilled by different gear types.

Gear type	Number of fish gilled					
	Fish species					Total
	Goldfish	Carp	Spangled perch	Golden perch	Bony herring	
Fyke net (small mesh)	0	2	0	0	16	18
Fyke net (large mesh)	0	5	0	1	148	154
Pound net	0	0	0	0	0	0
Total	0	7	0	1	164	172

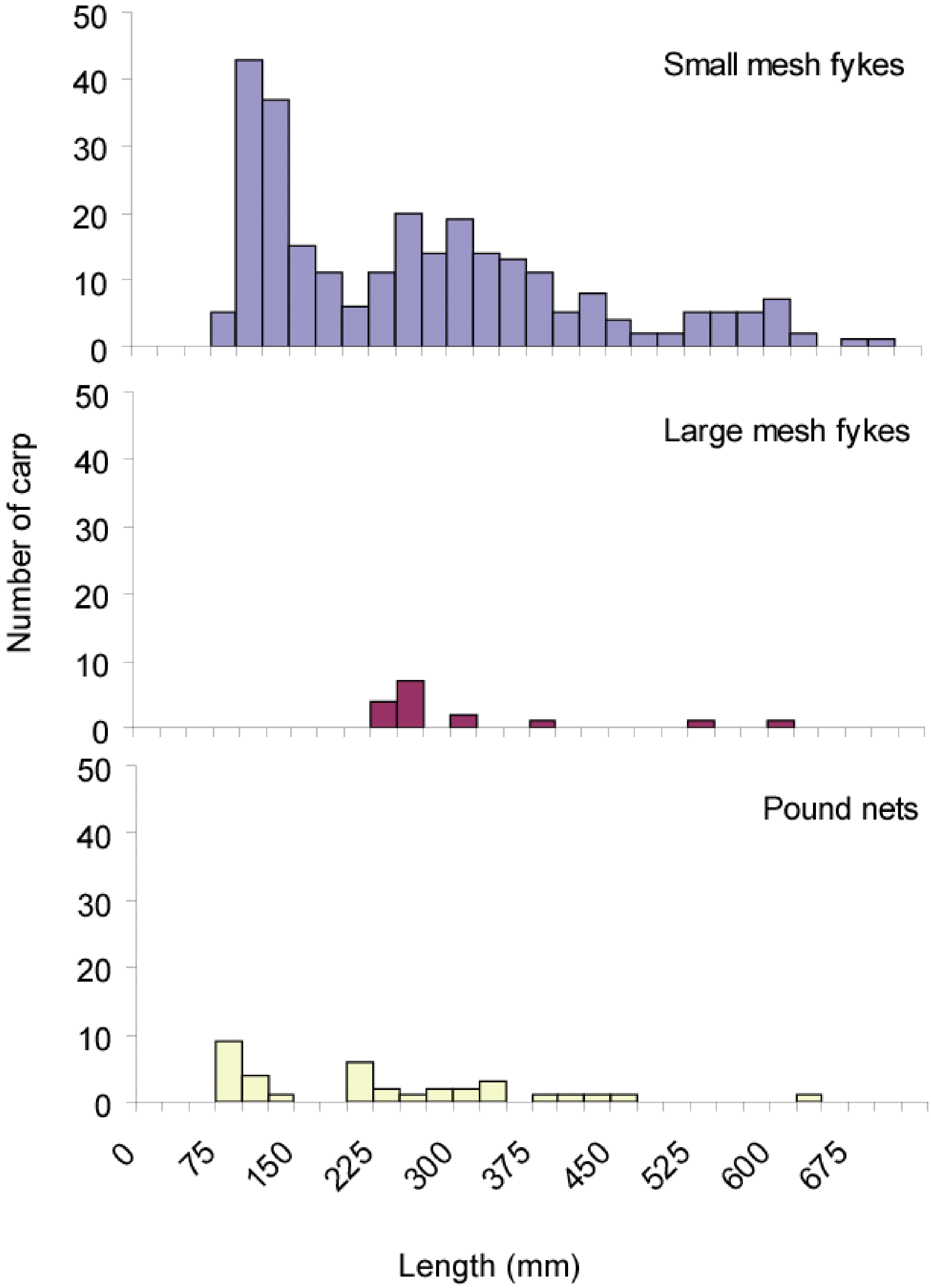

Figure 7. Size distribution of carp captured in three net types.

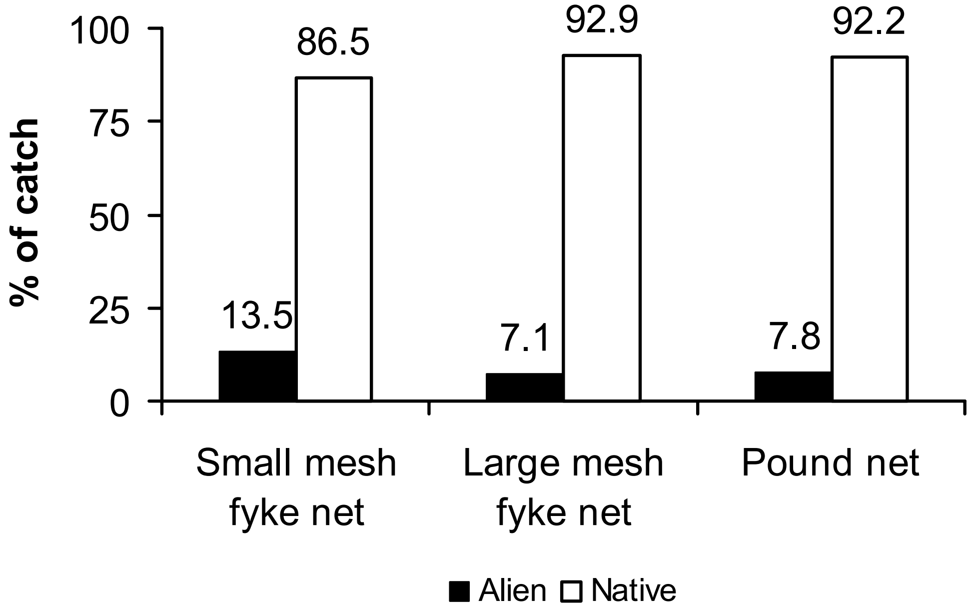

Figure 8. Percentage of alien (goldfish + carp) and native fish captured by each net type.

3.3.4. Cost

The initial cost of an electro-seine system includes the purchase of a 5 m Smith-Root electrofishing boat (approximately US$70, 000), two support boats (AUS$11,600) and the electro-seine hardware and modifications required to the standard electrofishing system (AUS$13,000). A haul net is also required to harvest the herded fish. In addition, electrofishing systems also require maintenance and running costs of approximately $400 per day.

The large mesh fyke nets cost $512 and the small mesh fyke nets cost $793. The fyke nets used for these trails took approximately 20 minutes to assemble and a further 20 minutes to set. Retrieval times were dependent on the amount of fish captured and number of personnel.

The pound net cost approximately $7,700. Set time took approximately 1 hour by three people. As with fyke nets, retrieval times were dependent on the number of fish captured and the number of personnel available to assist.

3.4. Discussion

Of the four potential large-scale carp control options investigated, small mesh fyke nets were identified as the most cost-effective, safe and easy to use gear type. The preliminary trials suggest that this gear type is the most suitable carp harvest technique for use by community groups and other organisations under relevant NSW Fisheries permits. Small mesh fyke nets caught the most carp, were the 2nd cheapest gear type to purchase (large mesh fyke nets were cheaper), were the easiest to set and retrieve and only resulted in a low level of potential injury to native fish.

3.4.1. Electro-seine

The electro-seine was the most expensive gear type evaluated. The initial cost of an electro-seine system is ~ AUS$120,000 with an ongoing operation cost of $400 per day. Further, electro-seines are very labour intensive and require at least four highly trained technicians to operate effectively. As a result, they are inappropriate for use by community groups and other organisations.

More effective assessment and testing is required to determine the true efficiency of this gear type for the harvest of carp in Australia. Fish herding devices similar to electro-seines are used for commercial applications in China, reportedly achieving capture efficiencies of 92% for goldfish and up to 54% for carp (Lui 1990). It is likely that our system of haul-netting fish was not appropriate, requiring refinement in order to represent an effective demonstration of the potential of this harvest technique.

Even with operational refinement, the electro-seine still remains limited in its adaptability to a variety of habitats due to its requirement for a haul net to be set, and a relatively shallow and uniform depth to operate in. Such restrictions suggest that electro-seines may not be suitable for use in rivers or deep lake environments such as impoundments, but may be suitable for harvest from floodplain wetlands.

Alternative electro-seine designs are also available for assessment. A mesh-net electric seine has been developed that has a ground rope acting as an anode and a remote cathode system (Miselovich and Aslanov 1990; Lui 1990; Lui *et al.* 1990). Trials with this gear type within reservoirs showed that capture efficiency ranged from 62% to 92% for silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) (Lui 1990). It was also found to be four times more effective than seine nets in ponds between 20 and 400 ha in area containing common carp and goldfish (Lui *et al.* 1990).

Given its operational limitations, its hi-tech nature, and proneness to mechanical and electrical problems, electro-seining is likely to only be feasible for large-scale commercial or scientific operations. As a result, it is unlikely to be suitable for widespread use throughout the Murray-Darling Basin.

3.4.2. Pound nets

The pound net was not cost-effective for large-scale carp harvest. The pound net used in this trial caught relatively few carp or native fish. Similar observations are reported by commercial carp fisherman who very rarely use pound nets, and if so, only in conjunction with fyke nets and standard electrofishing (K. Bell pers. com. 2003; R. Kopanica pers. comm. 2003).

The poor performance of pound nets in this trial is likely to result from the ease with which fish could escape. Success of the pound nets used in this trial relied on fish swimming consistently in one direction. If the fish turned around and followed the wall of the pound net in the opposite direction, they would be guided straight out of the net entrance. To overcome this, a funnel trap should be placed at the entrance of pound nets. Secondly, the top of the mesh wall floated on the water surface (Figure 6). Carp would have been more than capable of jumping free of the enclosure once they had entered the net (Stuart *et al.* 2003). To overcome this problem, the wall of the pound net should extend above the waters surface by at least 0.5 m to prevent escape.

The pound nets were not only ineffective in catching carp, they were also the second most expensive gear type, costing AUS$7,700. They were also relatively difficult to set. As a result, pound nets are not recommended as a suitable large-scale carp harvesting tool.

3.4.3. Fyke nets

Of the gear types assessed, fyke nets were the cheapest to purchase (<AUS$800) and were the easiest to set and retrieve. Fyke nets are a commonly used gear type for fisheries departments in Australia and around the world (Murphy and Willis 1996). They are an effective and non-destructive gear type that is often used in conjunction with other gear types in ecological studies (e.g. Harris and Gehrke 1997). Fyke nets are most effective under conditions of low flow (but with water movement) and at catching active benthic fish species.

The CARPSIM simulation results reported by Brown *et al.* (2003) suggest that harvesting techniques are most effective at controlling carp biomass when they sample as broad a range of size classes as possible. Therefore, mesh size plays an important role in determining the effectiveness of carp control. For fyke nets, differences in mesh size significantly altered the capture efficiency and injury to native fish by-catch. The small mesh fyke net (35 mm) caught a broader range of size classes than the large mesh net (85 mm). Further, the large mesh net caught very few fish in comparison to the net constructed from smaller mesh. This difference was partly due to the smaller mesh retaining more small fish (<200 mm), but the smaller mesh net also caught more individuals in larger sizes classes.

When caught in the larger mesh size net, a greater proportion of fish were caught via their opercula. These ‘gilled’ fish often died. The small mesh fyke nets caused much less mortality than the large meshed nets, as fewer fish were capable of pushing their heads through the mesh. On the negative side, the small-mesh fyke nets did catch more native fish than the other gear types. To reduce the impact on native fish, the fyke net used in this trial could be re-designed to incorporate a ‘fish drafting device’ such as that under development for fishway traps (Stuart *et al.* 2003).

3.5. Conclusions

These preliminary trials of four alternative gear types suggest that small mesh fyke nets caught the most carp, were the easiest to use, caused minimal injury to native fish and were a cost effective gear type. For these reasons the small mesh fyke nets are proposed as the most suitable method for community groups and other organisations to use for harvest of carp from local waterbodies.

4. THE ECOLOGICAL IMPACT OF ADULT AND JUVENILE CARP AT HIGH AND LOW DENSITIES

Craig Schiller

4.1. Introduction

No data exists on the relative impacts of different life stages of carp on ecosystem components. Population structure could have significant effects on the ecological impacts at a given biomass of carp in any one habitat. For example, it could be hypothesised that juvenile carp less than 150 mm are likely to have substantially different impacts to large adult carp > 500 mm. The carp stock-recruitment curve presented in Koehn *et al.* (2000: page 44) suggests that carp recruitment is density-dependent, with recruitment success increasing with increasing numbers of mature fish up to densities of a little over 100 fish ha^{-1}. At densities greater than this, the stock recruitment curve presented suggests that recruitment success declines. As a result, it would be expected that sites have either very high densities of juveniles, or high densities of adults, but infrequently have high densities of both juvenile and adult size classes.

If this model of density-dependent recruitment of carp is valid, the selective removal of adult carp from waterways could potentially improve the recruitment success of juvenile carp. If high densities of juvenile carp have a greater ecological impact than medium densities of adult carp, then the harvest of adult carp could lead to greater ecosystem degradation. In this case, reducing the reproductive output of adult carp through 'recruitment sabotage' (harvest or habitat manipulation practices designed to inhibit or limit recruitment) would be a more ecologically sound management strategy than targeting of adult fish.

Therefore, information on both the relationship between carp density and level of ecological impact, and the relative impacts of adult and juvenile size classes is required in order to undertake an effective integrated pest management strategy which would manage the impacts of carp as well as control their population size.

The purpose of this study was to investigate differences in ecological impact of adult versus juvenile carp at high and low densities.

4.2. Methods

4.2.1. Site selection

In the initial project proposal, it was hoped that by carefully evaluating all the enclosed water bodies in both the Murray or Murrumbidgee catchments, 15 replicate sites could be found suitable for conducting the proposed experiments. The criteria for selection of billabongs were: 1) not unduly affected by livestock grazing, 2) size between about 1 and 10 hectares, 3) low probability of drying or flooding over the study period, 4) reasonable depth, 5) accessible, 6) wet during the previous 6 months, 7) no or limited inflow of irrigation tailings or poor quality water, and 8) suitable carp density. Of the 165 wetland sites assessed for these criteria, only five were identified as suitable. This was considered too small a number of replicates to provide sufficient power to assess the typically variable responses expected.

As an alternative, the feasibility of using billabongs partitioned into a number of smaller waterbodies using impermeable barriers such as those used by Robertson *et al.* (1997) was assessed. This was rejected due to the prohibitive cost and difficulties associated with the installation and maintenance of impermeable barriers in large billabongs. Therefore, it was decided that mesh barriers (i.e. permeable ones) would be used to partition the waterbodies into replicate enclosures.

4.2.2. Sites

Four billabongs; Frying-pan Billabong, Cooks Lagoon, Flowerdale Lagoon (Figure 9) and the Narrandera Fisheries Centre settlement pond were used as field sites. Each billabong was divided into 4 replicate enclosures by the construction of 10 mm plastic mesh fences constructed by professional fencing contractors. The base of each fence was reinforced with sandbags to inhibit escape and the top of each fence extended 500 mm above the water surface to avoid possible problems with carp jumping between enclosures.

Figure 9. Carp enclosures at Flowerdale Lagoon.

4.2.3. Study design

Carp were removed from each enclosure using repeated five minute electrofishing shots covering the entire area of enclosure. Fishing ceased upon four consecutive shots with zero carp captures. Individual carp were tagged with individually numbered dart tags for identification. This was to enable the identification of individual fish for subsequent assessment of growth and survival. Three treatment populations and a control were added to each of the replicate enclosures within each billabong:

The treatments in each enclosed waterbody included;

1. Low density (400 individuals) of small carp (< 200 mm) + low density (50 – 75 kg ha^{-1}) of large carp (>350 mm).
2. Low density (400 individuals) of small carp (< 200 mm) + high density (500 – 700 kg ha^{-1}) of large carp (>350 mm).
3. High density (1000 individuals) of small carp (< 200 mm) + low density (50 – 75 kg ha^{-1}) of large carp (>350 mm).
4. Control (no carp).

Changes in habitat and aquatic biota were assessed over time, including turbidity, suspended solids, macrophyte abundance, and abundance and species composition of phytoplankton and zooplankton. Although the mesh barriers limited the independence of the treatments for these parameters, the expected carp effect sizes were anticipated to be much greater than any effects associated with permeability-linked non-independence.

4.3. Results and Discussion

4.3.1. Problems with enclosures

After the experiment was finished, the carp in the enclosures were removed so that individual tagged carp could be aged and the survival and growth of adult and juvenile size classes could be determined. However, it was discovered that the fences were inefficient at preventing the escape of carp from replicate enclosures as individuals had dispersed throughout all replicate treatments. Therefore, the ecological data collected could not be interpreted regarding either carp density or size class composition. No data analysis was undertaken.

4.3.2. Future experiments using separating barriers

In future experiments, non-permeable barriers such as those used by Robertson *et al.* (1997) could be used. In addition, the fence should extend more than 500 mm above the water surface to further inhibit carp jumping between enclosures.

5. GENERAL DISCUSSION

Neither oral rotenone baits or any of the gear types tested were particularly effective at controlling large numbers of carp over a broad area. Although the size of pellet and flavour were acceptable to carp, low palatability of poisoned baits resulted in limited effectiveness. Further, the risks posed to native fishes were unacceptably high based on these experimental trials. Although the rotenone pellet method has potential for carp control on small local scales, further development is needed to refine the formulation of pellets, with acceptable levels of risk to non-target species. The pellet method could also be investigated for delivery of other control agents, including alternative ichthyocides such as antimycin (Rach *et al.* 1994), reproductive inhibitors (Hinds and Pech 1997), or molecular controls (Grewe 1997). Similarly, none of the four large-scale gear types trialled were particularly effective at capturing carp, with none being as effective as standard commercial techniques such as electrofishing or gill netting. However, for small waterbodies with low flows, small meshed fyke nets showed some promise as a carp harvesting technique that could be utilised by community groups under appropriate NSW Department of Primary Industries permits.

Given the limited ability of either the chemical or physical control options tested to control carp over broader areas, the feasibility of other techniques, such as biological controls like the daughterless carp program (Thresher and Bax 2003), fishway trapping using the ‘William’s carp separation cages’ (Stuart *et al.* 2003), excluding adult carp from spawning areas using ‘fish screens’ (Nichols and Gilligan 2004) or the use of pheromone attractants (Sorensen 2003) should be assessed as potential alternative carp control strategies.

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