Preliminary assessment of oral rotenone baits for carp control in New South Wales

Peter C. Gehrke

NSW Fisheries Office of Conservation, Port Stephens Fisheries Centre, Private Bag 1, Nelson Bay, NSW 2315, Australia[1]

ABSTRACT

Floating pellet baits containing a lethal dose of rotenone were tested to assess their potential for carp control in Australia. Application of rotenone pellets in three replicated billabongs killed only 12 carp. Approximately 3000 non-target Australian smelt died in one billabong after feeding on fine dust from the pellets. Failure to achieve significant carp control was ascribed to poor flotation of the pellets, resulting in at least half of the pellets being unavailable to carp at the surface, and low palatability of pellets containing rotenone. Seven other fish species in the billabongs appeared to be unaffected. In aquaria, crimson-spotted rainbowfish, western carp gudgeons and Australian smelt suffered high mortality (95–100%) if pellets were left in the water. However, no mortality of rainbowfish or gudgeons occurred if pellets were removed after 30 min. Three species of decapod crustaceans were relatively unaffected (0–5% mortality) by exposure to rotenone pellets. In a pond trial, 5 carp (5%) and 37 bony herring (39%) died after application of rotenone pellets. All carp, but only 10 bony herring contained traces of pellets in their guts, confirming they had fed on pellets. The cause of death of the other 27 bony herring is unknown. Extending the training period using non-toxic pellets, establishing flotation standards for pellets and improved palatability may improve the effectiveness of rotenone baits against carp. Screening pellets to prevent fines from entering the water and removing uneaten pellets after 30 min are also recommended to reduce the risk to non-target species. Pellet baits have potential for use in carp control, but the current product and application procedures require further development and testing to demonstrate effectiveness in reducing carp populations with acceptably low risk to non-target species in Australia.

Keywords: pest fish, carp, rotenone, poisoned baits

---

1 Present address: CSIRO (Land and Water), 120 Meiers Rd, Indooroopilly, Qld 4068, Australia.

1. INTRODUCTION

Carp (*Cyprinus carpio*) are a major pest species in Australian rivers (Koehn et al. 2000). 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 be used only 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. This is because the fish are initially trained to feed on non-toxic pellets until they readily accept the baits, and because the fish swallow pellets directly. Uneaten pellets can be removed from the water, resulting in very little escape of rotenone to the water. Rotenone products are widely registered for use worldwide because they are safe to many non-target organisms, and because they biodegrade rapidly.

Carp trainer pellets contain vegetable meal products flavoured with corn to attract carp. 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 in reducing carp populations under Australian conditions
- assess the effects of application on non-target species such as small fish and crustaceans
- identify the size of carp targeted, with respect to the size of the pellet
- determine whether the size of the pellet provides secondary protection for non-target species
- establish the duration of baiting required to get an effective kill of carp.

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 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 (Koehn et al. 2000). The second objective considers whether, irrespective of the success or failure of the pellets to reduce carp populations, undesirable effects on non-target species will limit the habitats in which the product may be used. Objectives 3–5 are intended to optimise application to obtain the greatest reduction in carp populations with the minimum application of product.

2. METHODS

2.1 Billabong experiment

The effectiveness of rotenone bait pellets against carp in natural fish communities was tested in three replicate billabongs near Narrandera in southwestern New South Wales: Kurrajong, Sheepwash and Bulgari Lagoons. Billabongs were selected if they contained established carp populations in water at least 1 m deep. The minimum size for suitable billabongs required that three feeding stations could be located in each billabong at a distance of 100 m apart. The maximum size requirement was that the billabongs be no larger than necessary to fit the three feeding stations. Potential sites were sampled with fyke nets, gill nets and electrofishing to confirm the abundance of carp.

Intensive mark-recapture assessments were done 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, carp caught were examined to identify whether they had been marked in the previous sample, and 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 marked fish in the population, *C* is the 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 obtain an estimate of the composition of the fish communities in each billabong (Gehrke & Harris 2000).

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. 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 benthic non-target organisms at each station. A distance of c. 100 m was maintained between stations.

Non-toxic trainer pellets were applied once daily within each feeding station. The starting application rate of 600 g of pellets per day was altered daily according to the amount of pellets consumed by carp within 20 min. Pellets were broadcast by hand into the floating feeding stations in two consecutive 10 min 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 min feeding period. Trainer pellets were applied for 9 days, and management pellets were substituted on the tenth day.

After the training period, when carp were considered to be feeding maximally on trainer pellets, pellets containing rotenone were substituted and 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.

2.3 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 gudgeons (*Hypseleotris klunzingeri*); and three species of decapod crustaceans: freshwater prawn (*Macrobrachium* sp.), freshwater shrimps (Atyidae) and yabbies (*Cherax destructor*) were collected from nearby creeks and ponds.

The experiment consisted of three treatments: (1) control; (2) pellets removed after 20 min; and (3) 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 atyid shrimps (mean carapace length = 9 mm). Five individuals were used for yabbies (20 mm), freshwater prawns (27 mm) and crimson-spotted rainbowfish (67 mm).

Animals in control aquaria were fed daily on natural plankton collected from nearby ponds and pieces of carrot. Animals in the second treatment were fed daily on five trainer pellets, which were removed after 20 min. In the third treatment, five pellets were added daily and not removed until feeding time 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*; silver perch *Bidyanus bidyanus*; golden perch *Macquaria ambigua*; Macquarie perch *M. 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. These species were not available in sufficient numbers for quantitative assessment, so this part of the assessment was confined to individuals held in captivity at the time of the experiment.

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 water bodies 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 detritivorous 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 min 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 observed daily for the next three days, and affected fish were collected and dissected for traces of glitter from management pellets in the digestive tract. On the final day the pond was drained to count all surviving fish and carcasses not collected previously.

3. RESULTS

3.1 Billabong experiment

Carp was the most abundant species in Kurrajong and Sheepwash Lagoons, whilst 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 ranged from 768 carp in Bulgari Lagoon to 1054 carp in Sheepwash Lagoon (Table 2).

Feeding intensity of carp in the three billabongs appeared to stabilise on day 8–9 of applying trainer pellets (Fig. 1). Water temperature declined gradually during the training period from 23ºC at the start of training to 20ºC on the final day. Management pellets containing rotenone were applied on day 10. The weight of rotenone pellets applied at each feeding station was proportional to the weight of trainer pellets consumed at the end of the training period (Table 3).

At Bulgari Lagoon, dead and dying Australian smelt were observed near the downwind shore of the billabong within 2 hours of applying management pellets. Over the next 2 hours, Australian smelt were collected over 150 m of

TABLE 1. SUMMARY OF FISH CATCHES BEFORE PELLET APPLICATION FROM THREE BILLABONGS. Numbers with [a] 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	[a]5	[a]5	[a]5
Hypseleotris klunzingeri	Western carp gudgeons	[a]5	[a]5	[a]5
Maccullochella peelii	Murray cod	1	0	0
Macquaria ambigua	Golden perch	0	1	0
Nematalosa erebi	Bony herring	0	8	[a]250
Perca fluviatilis	Redfin perch	4	20	0
Retropinna semoni	Australian smelt	0	0	[a]1000
Number of species		6	7	6

TABLE 2. CARP POPULATION ESTIMATES BEFORE AND AFTER TREATMENT. *M* = number of carp fin-clipped and returned to the water during the initial sample; *C* = number of fish caught in the second sample; *R* = number of fin-clipped fish in the second sample; *N* = population estimate.

SITE	*M*	*C*	*R*	*N*	± SD
Before treatment					
Bulgari	63	35	2	768	(400–1136)
Sheepwash	218	153	31	1054	(891–1217)
Kurrajong	199	97	22	852	(700–1004)
After treatment					
Kurrajong	153	146	16	1332	(1036–1627)

Figure 1. 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.

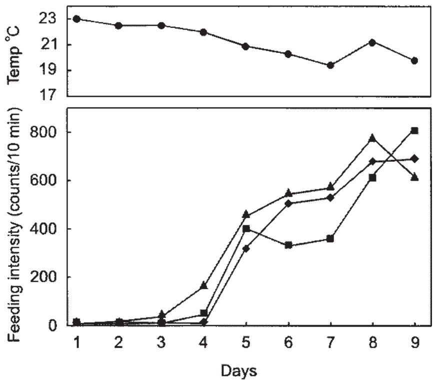

TABLE 3. DAILY RATE OF TRAINER AND MANAGEMENT PELLET APPLICATION AT FEEDING STATIONS IN EACH BILLABONG. Application rate was determined by the consumption rate by carp at each station on previous days, and modified daily in accordance with actual consumption. Low application rates for management pellets 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

shoreline at an estimated density of 20 fish m^{-1} giving a total estimate of 3000 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 3 days, only two carp were recovered from Kurrajong Lagoon, one from Sheepwash Lagoon, and nine from Bulgari Lagoon. Dead carp collected ranged from 473 mm to 651 mm in length, and weighed between 1.9 kg and 4.9 kg.

The final mark-recapture population estimate for Kurrajong Lagoon (1332) was larger than the pre-treatment estimate (852), 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.

3.2 Aquarium experiment

Mean 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 (REPLICATES = 2) OVER 24 h.

SPECIES	INDIVIDUALS PER REP	CONTROL	PELLETS REMOVED	PELLETS NOT REMOVED
Gudgeon	10	100	100	5
Rainbowfish	5	100	100	0
Smelt	10	85	5	0
Yabby	5	100	100	100
Atyid	10	100	100	100
Prawn	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.

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 (Fig. 2). 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 3 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. 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.

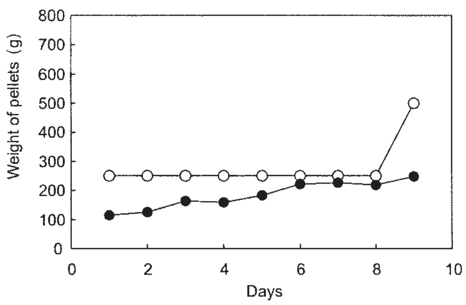

Figure 2. Number of pellets fed (hollow symbols) and eaten (solid symbols) per day during training (days 1–8) and application of management baits (day 9) in the pond experiment.

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	[a]37	36	21
Carp	100	1	5	91	3

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

4. DISCUSSION

4.1 Affects on fish

Only small numbers of carp were killed in billabong and pond experiments, with no detectable reduction of carp populations in billabongs. Non-target mortality of Australian smelt in billabongs was supported by high mortality in aquaria. 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 of this species 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. Only small numbers of large native species were available for pellet-feeding experiments, and more rigorous evaluation is necessary to explore 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 can be significantly reduced by removing uneaten pellets within 30 min of application. Crustaceans appear to have low susceptibility to rotenone in pellet form.

Results from the present study differ from experiences in North America. 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). It was also estimated that the grass carp removed accounted for 65% of all the affected individuals. 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 in water bodies containing common carp removed a total of 4288 carp, and 130 non-target fish from four species, for an average non-target mortality of 1.3% (Prentiss Inc. unpubl. 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, it was assumed that 60–70% of grass carp affected by rotenone were removed, but the number of grass carp surviving in the lake was not estimated.

The low mortality of carp in billabongs in this study is attributed to problems with the pellet formulation, because an estimated 50% of management pellets did not float, and were therefore not available to carp trained to feed from the surface. Furthermore, feeding intensity on management baits 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, respectively. It therefore appears that fewer carp than expected actually ingested floating baits. Rotenone and piperonyl butoxide are relatively bitter to taste, and may inhibit feeding.

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.

Lethal concentrations of rotenone vary among species, but are in the vicinity of 50 µg L^{-1} (Rach & Gingerich 1986). The toxicity of rotenone to Australian smelt is not known. If the total rotenone content of the pellets leached into the water to a depth of 1 m below the feeding station, the resulting concentration at Bulgari Lagoon would have been 1.9 mg L^{-1}. However, given the slow rate of leaching and the degree of wind-mixing in the water column on the day of application, it is unlikely that toxic concentrations would have occurred in the water column. This study has shown that Australian smelt are highly susceptible to rotenone leached from management pellets compared with crimson-spotted rainbowfish and western carp gudgeons. Consequently, 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 to ensure the full weighed dose was applied, allowing fine pellet dust to enter the water. This action would have allowed Australian smelt to ingest suspended particles containing rotenone. Pellet containers at other billabongs were not inverted, preventing pellet dust from entering the water. Australian smelt are omnivorous planktivores that feed in the water column (McDowall 1996). This feeding behaviour combined with the availability of rotenone in the water column is likely to have exposed large numbers of smelt.

Whilst the conservation status of Australian smelt is secure at this time (Gehrke et al. 1995; Harris & Gehrke 1997), the results of this study provide cause for concern over other small species with similar feeding habits, such as galaxiids, hardyheads and rainbowfishes, some of which are threatened (Crook 2000), and which could also be at high risk where they coexist with carp.

4.2 Assessment of rotenone pellets

This trial has shown that corn-flavoured trainer pellets are effective in attracting carp to feeding stations, and that carp can be trained to take pellets. However, the effectiveness of the pellet method of delivery to reduce carp populations under Australian conditions requires further investigation.

Risks to non-target species are ecologically significant, and can be reduced by only using intact pellets, removing uneaten pellets after 30 min and disposing of fine pellet particles away from the water. Flotation certification by the manufacturer, and a minimum water depth for application would help reduce the concentration of rotenone leached into the water column.

Adult and juvenile carp as small as 112 mm were killed in this study, indicating that the size of the pellets provides little size-selectivity. Accordingly, application before spawning has potential to target individuals that contribute most of the reproductive potential of carp populations, as well as recruits from the previous year. However, the results of this study are inconclusive because of the small number of fish affected.

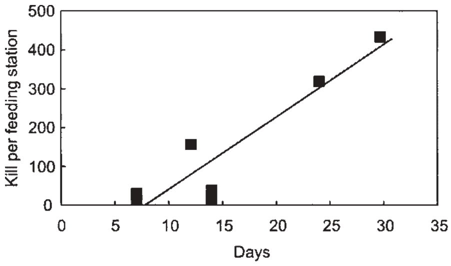

Figure 3. Influence of the number of days over which carp are trained to feed on trainer baits, on effectiveness of management baits against carp in the US (Prentiss Inc. unpubl. data). y = –147.7 + 18.6x (R^2 = 0.83). Data are from seven trials involving from one to six feeding stations.

The presence of glitter in the guts of 10 dead bony herring in the pond experiment suggests that the pellet size and corn flavour intended to attract only carp do not provide adequate protection for some non-target species.

One week of training was sufficient to attract a stable number of carp to the feeding stations in this study. However, data from Prentiss Inc. suggest that the effectiveness against carp in North America increases almost linearly with the duration of training up to at least 30 days (Fig. 3), with only low kill rates from training periods of one week. Consequently, further investigation is needed to test whether effectiveness in Australia can be increased by extending the training period.

The pellet method also has potential to be modified to deliver other control agents, including other ichthyocides such as antimycin (Rach et al. 1994), reproductive inhibitors (Hinds & Pech 1997) or molecular controls (Grewe 1997) to carp populations in the wild. These possibilities remain to be investigated under Australian conditions.

5. CONCLUSIONS

The trainer pellets were effective in attracting carp, but substitution of rotenone pellets did not result in a significant reduction of carp numbers.

Australian smelt have been identified as being at high risk to rotenone leached from pellets and from pellet dust. These risks can be reduced by removing uneaten pellets and screening pellets to remove fines before application.

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.

The duration of baiting with trainer pellets in this study was possibly too short to achieve an effective kill of carp.

The poisoned pellet method has potential for carp control, as demonstrated by studies conducted in the United States. However, further development is needed to refine the formulation of pellets and application procedures for effective reduction of carp populations, with acceptable levels of risk to non-target species in Australia.

Since this paper was presented, further experiments with the same formulation of rotenone pellets and with a modified formulation, indicated low palatability of rotenone pellets, resulting in mortality as low as 0% among treated carp. Carp that ingested rotenone pellets egested a large but unmeasured quantity of rotenone pellet fragments, creating a risk of ingestion by bottom-feeding non-target species (P. Gehrke, unpubl. data). More development is clearly required before the product can be used effectively to reduce carp numbers, with an acceptable level of risk to non-target species. Until such time, approval by regulatory agencies for field application of rotenone pellets to control pest fish is not recommended.

6. ACKNOWLEDGEMENTS

I thank the New Zealand Department of Conservation for inviting me to this workshop, and for supporting my attendance. Prentiss Inc. generously provided the product tested. Dr Jim Fajt and Gray Jamieson contributed to the experimental designs, whilst Rolly Henderson and Grant Renall assisted with experiments. From NSW Fisheries, Dr Craig Schiller, Ian Wooden, David McGill, Matt Macintosh, Nick Whiterod, Keith Breheny and Lee Baumgartner also assisted with field experiments. This work was conducted under Permit Number 3484 from the National Registrations Authority, and Animal Research Authorities 00/03 and 00/11 from the NSW Fisheries Animal Care Ethics Committee.

7. REFERENCES

Crook, D. 2000: Conservation status of Australian fishes—2000. *Australian Society for Fish Biology Newsletter 30(2)*: 44–50.

Fajt, J.R. 1996: Toxicity of rotenone to common carp and grass carp: respiratory effects, oral toxicity, and evaluation of a poison bait. Unpublished PhD thesis, Auburn University.

Fajt, J.R.; Grizzle, J.M. 1993: Oral toxicity of rotenone to common carp. *Transactions of the American Fisheries Society 122*: 302–304.

Gehrke, P.C.; Harris, J.H. 1994: The role of fish in cyanobacterial blooms in Australia. *Australian Journal of Marine and Freshwater Research 45*: 905–915.

Gehrke, P.C.; Harris, J.H. 2000: Large-scale patterns in species richness and composition of temperate riverine fish communities. *Marine and Freshwater Research 51*: 165–182.

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

Grewe, P. 1997: Potential of molecular approaches for the environmentally benign management of carp. Pp. 119–127 in Roberts, J.; Tilzey, R. (eds) Controlling carp: exploring the options for Australia. Proceedings of a workshop 22–24 October 1996, Albury. CSIRO and Murray-Darling Basin Commission.

Harris, J.H.; 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. 298 p.

Hinds, L.A.; Pech, R.P. 1997: Immuno-contraceptive control for carp. Pp. 108–117 in Roberts, J.; Tilzey, R. (eds) Controlling carp: exploring the options for Australia. Proceedings of a workshop 22–24 October 1996, Albury. CSIRO and Murray-Darling Basin Commission.

Koehn, J.; Brumley, A.; Gehrke, P.C. 2000: Managing the impacts of carp. Bureau of Resource Sciences, Canberra. 247 p.

McDowall, R.M. (ed) 1996: The freshwater fishes of south-eastern Australia (2nd edn.). Reed, Sydney. 247 p.

Rach, J.J.; Gingerich, W.H. 1986: Distribution and accumulation of rotenone in the tissues of warmwater fishes. *Transactions of the American Fisheries Society 115*: 214–219.

Rach, J.J.; Luoma, J.A.; Marking, L.L. 1994: Development of an antimycin-impregnated bait for controlling common carp. *North American Journal of Fisheries Management 14*: 442–446.

Rowe, D. 1999: Prentox®: a method for removing grass carp from lakes. *Water & Atmosphere 7(2)*: 15–17.

Seber, G.A.F. 1982: The estimation of animal abundance and related parameters. 2nd edn. Macmillan, New York.

Wiley, R.W.; Wydoski, R.S 1993: Management of undesirable fish species. Pp. 335–354 in Kohler, C.C.; Hubert, W.A. (eds) Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.