Local eradication of trout from streams using rotenone: the Australian experience

Mark Lintermans[1,3] and Tarmo Raadik[2,3]

[1]Environment ACT, P.O. Box 144 Lyneham, ACT 2602, Australia
[2]Arthur Rylah Institute for Environmental Research, Department of Natural Resources and Environment, 123 Brown St., Heidelberg 3084, Australia
[3]Cooperative Research Centre for Freshwater Ecology
mark.lintermans@act.gov.au; Tarmo.Raadik@nre.gov.au

ABSTRACT

Rotenone has been used for sampling stream fish assemblages in Australia for many years but there have been only two instances where it has been used to eradicate trout populations from streams or sections of streams. In 1992, rainbow trout *Oncorhynchus mykiss* was removed from c. 2.4 km of Lees Creek, a small montane stream in the Australian Capital Territory. A barrier at the downstream end of the treated section was augmented to prevent trout reinvasion, and the recolonisation of the native species mountain galaxias *Galaxias olidus* was monitored. The short-term effects of the rotenone treatment on the aquatic macroinvertebrate fauna was also investigated. In 1994 and 1995 a total of 20 km of stream length in seven small streams in the Goulburn River catchment in Victoria were treated with rotenone to remove *O. mykiss* and brown trout *Salmo trutta*. This catchment contains some of the only remaining populations of the nationally endangered species barred galaxias *Galaxias fuscus* which was threatened by predation from invading trout. Barriers to prevent trout reinvasion were first constructed, trout were removed by ichthyocide treatment and the downstream recolonisation by *G. fuscus* of rehabilitated sites was monitored. The methodology and results for the two projects are presented along with lessons learnt and future directions.

1. INTRODUCTION

Trout form the basis of a highly valued recreational fishery in southeastern Australia. However in some areas, the impact of trout on native fish species is severe and control of trout populations is required. Exotic salmonids have had deleterious effects on small native fish of the family Galaxiidae in Australia and New Zealand (Frankenberg 1966, 1974; McDowall 1968, 1990; Cadwallader 1978, 1996; Fletcher 1979, 1986; Jackson & Williams 1980; Jackson 1981; McIntosh et al. 1992, 1994). Both brown trout *Salmo trutta* L. and rainbow trout *Oncorhynchus mykiss* (Richardson) were introduced to Australian waters more than a century ago, before accurate distribution or abundance data had been collected for native fish species. Consequently, much of the evidence of the effects of salmonids is anecdotal or inferred from the distribution patterns of native and exotic species (see Jackson & Williams 1980; Lintermans & Rutzou 1990; Townsend & Crowl 1991).

Predation is considered one of the major mechanisms by which trout have affected galaxiids (Tilzey 1976; Wager & Jackson 1993; Raadik 1995; Cadwallader 1996), with trout predation pressure considered a major threat for several galaxiid species of national conservation concern (Sanger & Fulton 1991; Raadik 1995; Raadik et al. 1996; Crook & Sanger 1997). Management options to deal with trout predation include relocation of threatened species to trout-free waters (Crook & Sanger 1997) or eradication of trout from the critical habitats of threatened fish species (Raadik 1995).

There have been two Australian projects which have attempted to eradicate trout from streams and this paper outlines the issues, methodology and lessons learnt from both of these projects. The first project was conducted in Lees Creek in the Australian Capital Territory and was designed as a trial to investigate the feasibility of trout eradication using the ichthyocide rotenone, and to examine whether the native fish mountain galaxias *Galaxias olidus* (Günther) would naturally recolonise the stream. The second project was conducted in the Goulburn River catchment in Victoria and formed part of a recovery programme for the nationally threatened fish barred galaxias *Galaxias fuscus* (Mack).

Galaxias olidus is not a listed threatened species in any state or territory in Australia, but is widely reported as having either dramatically reduced abundance or severely fragmented distributions in the presence of trout (Cadwallader 1979a; Jackson & Williams 1980; Jackson & Davies 1983; Jones et al. 1990; Koehn & O'Connor 1990; Lintermans & Rutzou 1990; Lintermans 1991).

The barred galaxias *G. fuscus* is a small native freshwater fish endemic to southeastern Australia, and is considered to be one of Australia's most endangered fish species. It is restricted to a small area in the upper reaches of the Goulburn River basin in southeastern Australia, with 12 extant populations known from seven small streams. Exotic trout are actively colonising upstream through eight of these populations, and since the discovery and description of the galaxiid in the 1930s, four populations are known to have become extinct (Raadik 1995).

Direct predation by exotic trout species on juveniles, and to a lesser degree on adults, has been identified as the process most threatening the survival of *G. fuscus* (Raadik 1995).

The use of toxicants in waterways to remove unwanted fish is a management practice used in at least 30 countries (Lennon et al. 1970), with rotenone one of the most commonly used ichthyocides. In Australia it was commonly used in fish surveys to obtain accurate estimates of fish biomass where a small section of the stream is treated (Cadwallader 1979b; Baxter 1987; Lintermans & Rutzou 1990; Koehn et al. 1995). However, concerns about the effects of rotenone on aquatic non-target organisms such as aquatic macroinvertebrates has limited its use in recent years. No fish eradication using toxicants had previously been conducted in streams in Australasia. Consequently, the feasibility and methodology of complete fish removal from streams and the non-target effects on aquatic macroinvertebrates required assessment.

2. STUDY AREAS

2.1 Australian Capital Territory

Lees Creek is located in the lower Cotter River catchment in the west of the Australian Capital Territory in southeastern Australia (Fig. 1). Lees Creek is a perennial fourth-order stream that rises in the eastern slopes of the Brindabella Ranges (Fig. 2). The altitude of the catchment varies from 600 m a.s.l. to 1320 m a.s.l. with mean annual precipitation of c. 990 mm (Talsma & Hallam 1982). The majority of the catchment is covered by a mix of dry and wet sclerophyll forest, with the lower catchment containing a commercial plantation of *Pinus radiata*. Stream width is generally 1–2 m with average depth of 100–300 mm (Thomas et al. 1989). The lower Cotter catchment contains several v-notch stream-gauging weirs built between 1964 and 1972, one of which was on Lees Creek (Fig. 2). Blundells Creek is a third-order perennial tributary of Lees Creek, with an average width of 1 m and depth of 100–300 mm. Coree and Bushrangers Creeks are both perennial fourth-order streams with average widths of 2.5–3 m and depths of 100–400 mm. Trout were first introduced into the Cotter River catchment in 1888 (Anon. 1980).

A stream survey of the lower Cotter River catchment in early 1990 recorded populations of *O. mykiss* in Lees, Bushrangers and Coree Creeks, with *S. trutta*

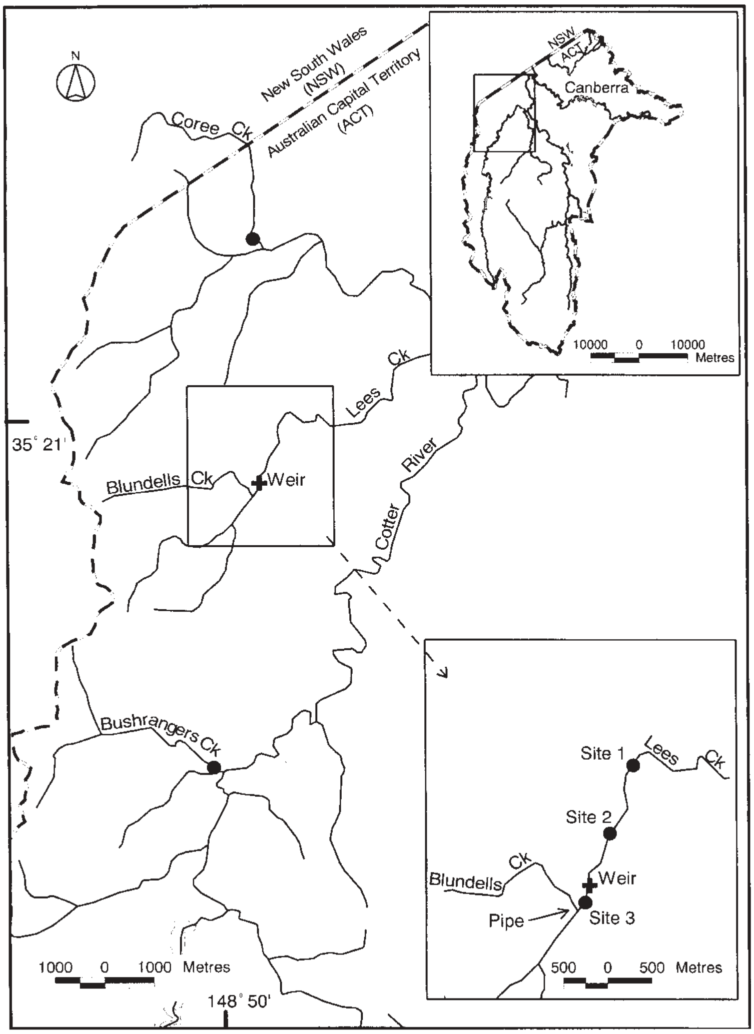


Figure 1. Location of the Lees Creek study area in the Australian Capital Territory showing the three fish monitoring sites and two fish reference sites.

Figure 2. Lees Creek, Australian Capital Territory, a perennial fourth-order stream.

also present in Coree Creek. Trout were present above and below the stream-gauging weir on Lees Creek. *Galaxias olidus* was not present in any of these streams. However, the 1990 survey recorded *G. olidus* at Blundells Creek but no trout (Lintermans, unpubl. data). Blundells Creek discharges into Lees Creek via a 15-m-long piped outlet (pipe diameter 300 mm) under a management road. The relatively fast, unbroken flow of water in this pipe prevents trout moving from Lees Creek upstream into Blundells Creek. However, it does not prevent downstream displacement of *G. olidus* from Blundells Creek, and it was hoped that this would allow *G. olidus* to recolonise Lees Creek following trout removal.

2.2 Victoria

Small headwater streams designated for ichthyocide treatment were located in two areas, Woods Point and Marysville, both in the upper reaches of the Goulburn River system in Victoria. Both areas have had extensive gold mining (mid 1800s) and timber harvesting (until early 1980s) within most of the catchments that are now heavily forested. Three stream systems were located in the Woods Point area (Morning Star Creek and its tributary Pheasant Creek; Perkins Creek; and Raspberry Creek with its tributary Godfrey Creek) and one system in the Marysville area (Taggerty River with its tributaries Keppel Hut Creek and Cameron Creek).

All sites were above 400 m a.s.l., well wooded with steep-sided valleys, very narrow to non-existent floodplain width, narrow channel width, shallow, relatively fast flowing, relatively steep gradient, and pool-riffle sequence as the most common habitat type. All streams were permanent, stream order was generally 3 for the majority of sites, though the Taggerty River itself was the largest stream, with stream orders between 2 and 5.

Populations of *G. fuscus* were present in the very upper reaches of the Taggerty River above two large natural waterfalls which had been breached by *O. mykiss*, and above a secure waterfall in the very upper reaches of Keppel Hut Creek. *Galaxias fuscus* were also present in the very upper reaches of Pheasant, Perkins, Godfrey and Morning Star Creeks, and all populations were being encroached upon and eliminated by upstream penetrating populations of *O. mykiss* and *S. trutta*.

3. METHODS—AUSTRALIAN CAPITAL TERRITORY

3.1 Ichthyocide treatment

A total length of 2.4 km of Lees Creek upstream of the weir (Fig. 3) was treated with rotenone. Rotenone treatment commenced at the weir (Fig. 1) and proceeded upstream over a period of two days (23–24 March 1992), with mesh stop-nets erected after each section had been treated to prevent downstream trout reinvasion. Treated sections were c. 500 m long with the stop-nets left in place until the treatment of the next section had been completed. Treatment was carried out when stream flows were low (current velocity between 0.37 m/s and 0.53 m/s) and water temperatures were approximately 13°C.

Rotenone is more effective at higher temperatures, as well as breaking down more rapidly (Penick 1963; Dawson et al. 1991). Approximately 300–350 ml of a 5% rotenone emulsion, along with a fluorescent dye (sodium fluoroscein) to mark the progress of the rotenone slug, was added over a 15 min period to the stream section being treated. The quantity of rotenone added to the stream was calculated according to previous experience of the author with this chemical in the Canberra region, with the final concentration of rotenone estimated to be c. 0.05 part per million. When the rotenone reached the downstream limit of the treated section, c. 350–500 g of an oxidant (potassium permanganate) was added to the stream to neutralise the effects of the rotenone. Affected fish were collected, identified to species, weighed and measured (caudal fork length).

Lees Creek bifurcates into two main arms near its headwaters, and both arms were treated with rotenone. The upstream limit of treatment was established by the presence of a road culvert on one arm, and a section where the stream runs underground on the other arm. Electrofishing of both creek arms above these

Figure 3. Lees Creek weir before augmentation.

Figure 4. Lees Creek weir after augmentation with metal grill.

barriers failed to locate trout, although *G. olidus* was present. After treatment of Lees Creek, the stream-gauging weir was augmented with a heavy steel grill to present a vertical barrier of 1.75 m (Fig. 4).

3.2 Monitoring of fish populations 1993–1995

Fish populations were sampled annually in autumn from 1993 to 1996 at three sites in Lees Creek. Two sites were sampled in the untreated stream below the weir, sites 1 and 2 being 1750 m and 750 m downstream of the weir, respectively. Site 3 was in the treated section immediately above the weir (Fig. 1). Sampling was carried out using a backpack electrofisher (Smith-Root Model 12) with all fish collected identified to species and measured (caudal fork length). Lengths of stream sampled at each site were determined largely by the presence of natural pools and runs, with stream lengths of 40 m, 70 m and 170 m sampled at sites 1, 2 and 3, respectively. Greater sampling effort was directed at site 3 in order to be sure that *O. mykiss* had not reinvaded the treated section.

3.3 Monitoring of reference sites

In 1996 two additional sites on streams which had been sampled in the 1990 stream survey of the catchment were resampled. These two streams (Bushrangers and Coree Creeks) were used to provide comparisons with both the treated and untreated sections of Lees Creek, as well as with the 1990 survey results. The two sites were sampled using rotenone (as in the 1990 stream survey), with stream lengths of 75 m and 60 m sampled in Bushrangers and Coree Creeks, respectively.

3.4 Impacts on aquatic macroinvertebrates

Macroinvertebrate populations were sampled at four sites before and after rotenone treatment (Fig. 5). Sites 1 and 2 were reference sites on Blundells Creek that were not treated with rotenone. Site 3 was in the rotenone treatment section of Lees Creek and site 4 was c. 500 m downstream of the treatment section on Lees Creek. Benthic macroinvertebrates were sampled with a surber

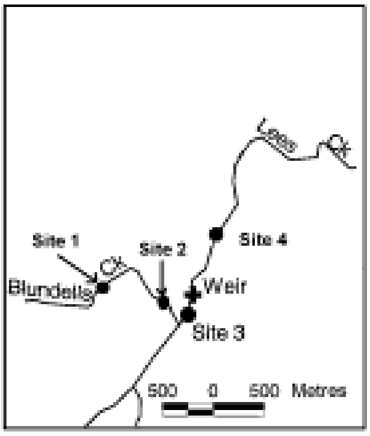


Figure 5. Location of macroinvertebrate sampling sites on Lees and Blundells Creeks.

sampler (30 × 30 cm frame with a 500 µm mesh) on three occasions (pre treatment, 4 days post treatment and 7 weeks post treatment). On each occasion five replicate samples were taken at each site. Invertebrate drift was sampled at the same four sites (30 × 15 cm frame with 500 µm mesh) on four occasions (pre treatment, during treatment, 4 days post treatment and 7 weeks post treatment). Drift was sampled for a 2 h period on each occasion.

All macroinvertebrates were preserved in the field, returned to the laboratory and identified to family level under a stereo dissecting microscope.

4. METHODS—VICTORIA

Unlike Lees Creek in the ACT, very few suitable barriers were present in the Victorian catchments. Therefore the first activities involved location of suitable barrier sites followed by barrier construction, and then the delineation of the stream reach upstream of the barriers to be treated with ichthyocide.

The ichthyocide treatment was conducted in two parts, over 2 years. The first treatment was a pilot study in which all aspects of the treatment method were assessed and further developed to be effective in the specific catchments, and the second was the actual treatment in all target catchments. The main aim of the ichthyocide treatment was to create predator-free zones in each stream into which barred galaxias could expand, with a one-off ichthyocide treatment. Therefore the treatment needed to produce a 100% kill of trout.

4.1 Barrier construction

Barriers were designed to mimic three key aspects of effective natural trout barriers in other systems: 1.5 m or greater vertical drop; in higher flows all flow is directed towards the middle of the channel with no slower overland flow passing down each bank; and no deep pool below the barrier from which trout could jump the barrier.

Three artificial barriers were constructed, one each on the lower reaches of Morning Star and Perkins Creeks, and Godfrey Creeks at Woods Point. Godfrey Creek is a tributary of Raspberry Creek and a 2-m-high existing concrete weir was used as the downstream limit of the treatment section in this system. The Godfrey Creek barrier was constructed to further partition off the catchment. Barriers consisted of two large hardwood logs placed on top of each other and set across the stream, with each end keyed 1.5 m into each bank, creating a vertical drop of between 1.5 m and 1.8 m (Fig. 6). The upstream side was backfilled with crushed rock to reduce hydraulic pressure on the structure and to prevent any weir pool from forming. Large flat rocks were placed below the barriers to prevent scour pools forming.

Figure 6. Constructed barrier on Godfrey Creek.

Initially, water flowed through the crushed rock and seeped from between the logs, but as finer sediments were progressively washed downstream, the crushed rock became consolidated and the streams began to flow over the tops of the structures. Careful attention was directed at ensuring that in higher flows water was still directed towards the middle of the stream and over the mid-portion of the barrier by placing crushed rock on the edges of the stream, and cutting a notch into the upper log. This also ensured that no side erosion could occur that would have produced a low-gradient passage for trout up past the vertical structure.

Barrier construction was undertaken by local contractors using heavy machinery. The weight of the largest eucalypt log used was 7 t.

4.2 Delineation of treatment sections

The exact stream length to be treated was determined in each system by sampling the fish fauna. The dynamics of the trout/*G. fuscus* interaction created an area from which *G. fuscus* had been totally eliminated, an overlap zone in which the trout were actively moving up through the *G. fuscus* population (a relatively short and defined zone) and, above this, a galaxias-only zone into which the trout had as yet not colonised. Ichthyocide treatment was to be conducted only on the trout-only zone so as not to sacrifice any *G. fuscus*.

Before ichthyocide treatment, each overlap zone was intensively electrofished to remove all trout using a portable Smith-Root Model 12 backpack electrofisher. All overlap zones were in relatively clear stretches of river, lacking significant amounts of woody debris which would have made this operation unviable. This task was made easier by the fact that at that time of year, deeper water preferred by this species was limited, causing fish to congregate in available deep water.

4.3 Other pre-treatment activities

Other important pre-ichthyocide treatment activities were as follows:

- Organisation of relevant permits (Victorian EPA permit to allow use of ichthyocide and potassium permanganate (to detoxify)).
- Purchase of sufficient quantities of derris cube (for the ichthyocide) and industrial grade crystallised potassium permanganate (50 kg drums).
- Formulation of derris cube powder into a 5% active ingredient liquid emulsion.
- Notification of dates of ichthyocide treatment to downstream users (e.g. stock and domestic water extractors, fish farms, local water authorities) so that they could organise alternative water supplies for those dates.
- Notification of treatment activities to state fisheries agency, local police and other services.
- Organisation of an alternative water supply for one domestic dwelling at Woods Point.
- Organisation of sufficient field staff for ichthyocide application teams (two people per team, one team per stream tributary), detoxification team (two staff), and staff for transport duty (transport of ichthyocide teams), and a spare staff member to monitor all activities and provide help where needed.

4.4 Pilot study

The pilot study was conducted in January and February 1994 in two streams, the Pheasant/Morning Star Creek, and Perkins Creek. The method of rotenone treatment employed was as follows.

For both stream systems, fluorescein was added at the top end of the treatment section and its rate of movement (in hours) through the section was determined. This provided an indication of the time the treatment activity would take the following day, and helped determine the starting time so that the whole treatment (including detoxification) could be accomplished during the day.

4.5 Pheasant/Morning Star Creek—treatment length 6 km

1. Fine mesh stop-nets were set up in the middle of the zone for treatment, and also c. 300 m downstream from the bottom of the site. The detoxification site was also established at the barrier at the downstream end of the site.
2. To enable detection of the ichthyocide front as it moved down the catchment, 1 L of fluorescein dye was added at the top of the treatment section. A total of 20 L of liquid rotenone formulation (8% active ingredient) was then added over a 15 min period. The rotenone solution was added to a riffle area to aid mixing.
3. A flurometer was established at the detoxification site and this detected fluorescein at the bottom end of the treatment section 7 h after application at the top. Detoxification began by sprinkling crystallised potassium permanganate into the water as it flowed over the barrier. Detoxification continued for 6 h.
4. Three polypropylene bags with a coarse mesh, filled with potassium permanganate, were left in the stream overnight. The potassium permanga-

nate seeped from the bags and continued the detoxification process till the morning, when it was continued by hand.

5. The fine mesh stop-net below the treatment site was monitored for dead fish for two consecutive days.

The day following treatment, trout were observed alive in the lower reaches of the catchment and it was determined that the highly concentrated front of ichthyocide applied had become reduced in concentration by being retarded in pools as it dispersed down the catchment, and had become sufficiently diluted as to be non-toxic.

The methodology was altered to maximise the persistence of a highly concentrated, toxic, ichthyocide front and the upper reaches of the system were re-treated. In this application, 1 L of ichthyocide solution was added to the ichthyocide front every 200 m of stream length as it travelled down the catchment. The front was detected by adding fluorescein, and this was topped up when necessary.

Monitoring of seepage of residual ichthyocide from the catchment was also noted on the days following the end of detoxification, by the use of sentinel trout held in cages just upstream of the barrier at the downstream end of the treated section. The detoxification method was altered to eliminate this seepage. Potassium permanganate was carried into the catchment, and 5 kg amounts were added to the stream and thoroughly mixed at 500 m intervals from the top of the treatment section to the downstream end.

Overall, c. 700 kg of potassium permanganate were used.

4.6 Perkins Creek—treatment length 3 km

The modified methodology was successfully applied to a 3 km length of Perkins Creek. Ichthyocide volume was 1 L to 200 m of stream length and 200 kg of potassium permanganate was used to detoxify.

4.7 Main eradication attempt

The main eradication attempt conducted during March 1995 re-treated the two stream systems from the pilot study (Pheasant/Morning Star Creek, and Perkins Creek) as well as the Rasberry/Godfrey Creek system at Woods Point, and the Cameron and Keppel Hut Creeks and Taggerty River at Marysville. The lower reaches of Perkins Creek was re-treated because the artificial barrier failed during high flows allowing trout to recolonise 400 m upstream into the treated area.

The only additional modifications to the methodology were in respect to the timing of treatment of tributaries and main stem of the Taggerty River system (including Cameron and Keppel Hut Creeks), and the Raspberry/Godfrey Creek. For both systems the requirement was for the ichthyocide front to move down the tributaries and join the main stem of the system just after the concentrated ichthyocide front had passed. This was to avoid target fauna from moving out of the main stem and into tributaries after the front had passed and therefore avoiding elimination. This required knowledge of the rate of water flow down each tributary and main stem, and then back calculation to determine ichthyocide treatment commencement times for each stream in order to facilitate this.

Consequently, additional fluorescein transport time trials were conducted in both catchments of Raspberry Creek to determine rate of flow and passage of fluorescein.

5. RESULTS AND DISCUSSION—AUSTRALIAN CAPITAL TERRITORY

5.1 General

The fish results of the Lees Creek eradication exercise have been fully documented in Lintermans (2000, 2001) but are summarised below. A total of 30 *O. mykiss* and five *G. olidus* were collected during rotenone treatment of Lees Creek. Additional fish were probably killed by the treatment as dead fish that drifted into instream aquatic vegetation or debris accumulations may have been missed. Four of the five *G. olidus* were collected from the most upstream collection site on the western arm of Lees Creek, and this probably indicates that this very small and shallow section of stream was becoming marginal for trout. Trout collected were 76–222 mm long with most less than 170 mm.

Rotenone treatment eradicated *O. mykiss* from Lees Creek upstream of the weir although they were present in every sample at both monitoring sites below the weir (Table 1). Augmentation of the weir to block upstream trout migration was successful, as no trout reinvaded the treated section of stream during the study (Table 1). The numbers of *G. olidus* in the treated stream section increased with time but galaxiids were never encountered at the two downstream monitoring sites (Table 1). By 1996 a thriving population of *G. olidus* with multiple age classes had established in the treated section above the barrier.

TABLE 1. NUMBER OF *ONCHORHYNCHUS MYKISS* AND *GALAXIAS OLIDUS* CAPTURED IN LEES CREEK AT THREE MONITORING SITES. – = NOT SAMPLED.

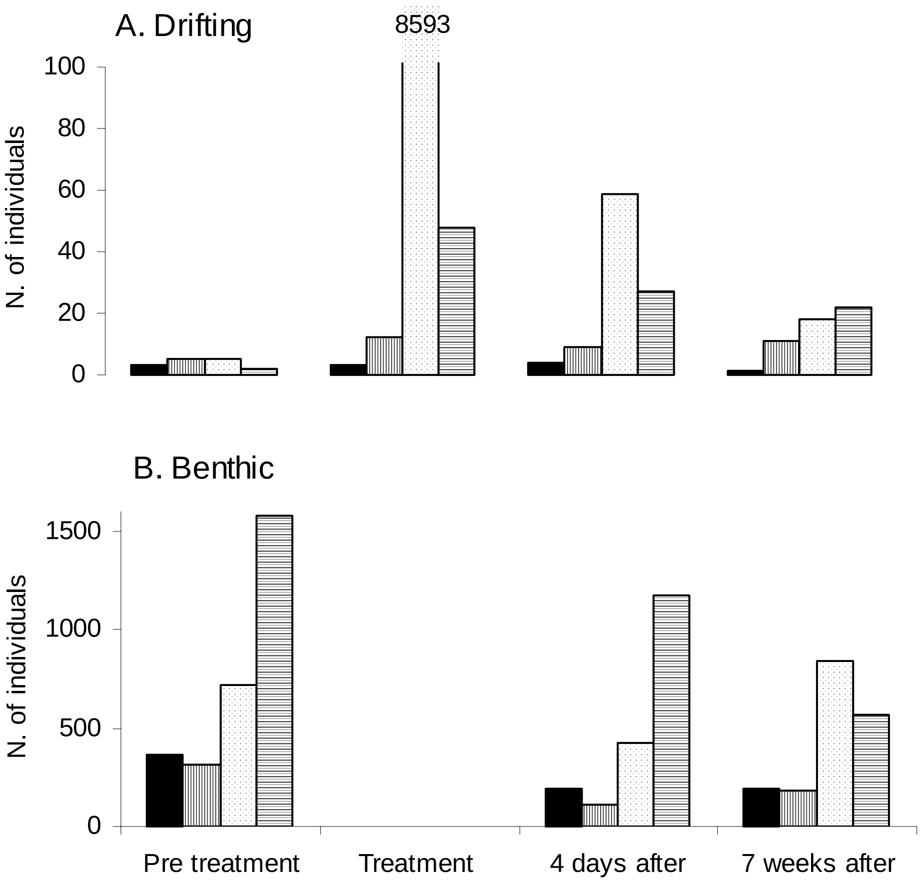
SAMPLING	D/STREAM REF SITE 1		D/STREAM REF SITE 2		SITE 3 (TREATMENT)	
DATE	*O. MYKISS*	*G. OLIDUS*	*O. MYKISS*	*G. OLIDUS*	*O. MYKISS*	*G. OLIDUS*
24 Jan 1990[a]	–	–	–	–	35	0
23 Apr 1993	2	0	5	0	0	10
31 Mar1994	11	0	18	0	0	8
6 Jun 1995	7	0	9	0	0	19
3 Apr 1996	7	0	28	0	0	75

[a] Results from the 1990 stream survey, 2 years before rotenone treatment.

5.2. Impacts on aquatic macroinvertebrates

The application of rotenone to the stream induced catastrophic drift of aquatic macroinvertebrates in the treatment section, with slightly elevated levels of drift at the downstream monitoring site (Fig. 7A). Dudgeon (1990) and Cook & Moore (1969) have also recorded catastrophic drift after rotenone application.

Figure 7. Numbers of drifting (A) and benthic (B) macroinvertebrates for four different sites before, during and after treatment.



Elevated drift levels were still occurring in Lees Creek four days after treatment indicating that there may have been some residual rotenone still leaching out of the treatment site.

The total abundance of benthic macroinvertebrates decreased at all sites after treatment (Fig. 7B). The reduction at sites 1 and 2 was unexpected as there was no rotenone treatment at these sites. This result is probably because of the small size of the stream and the short time interval between sampling events not allowing full recovery of the macroinvertebrate fauna. Doeg & Lake (1989) found that species density had recovered after 8–21 days but this was in a much larger stream than Blundells Creek where recovery was possibly slower. The decreased abundance at site 4 was not unexpected as the neutralising agent (potassium permanganate) which was added to the stream above this site had probably impacted the benthic fauna. Seven weeks after treatment the benthic abundance had increased above pre-treatment levels at the treatment site although the numbers at site 4 were still low. Unfortunately, logging activity commenced adjacent to site 4 soon after treatment, with significant sediment loads entering the stream and this is thought to explain the continued drop in benthic abundance.

The impact of rotenone on aquatic macroinvertebrates varied substantially between taxa with some families within an order dramatically affected whilst others appeared to show little response (Table 2). The simuliid dipterans were severely affected with high numbers present in the drift and none remaining on the benthos. However, they recovered quickly and within 7 weeks were above pre-treatment levels. In contrast chironomids appeared relatively unaffected.

TABLE 2. NUMBERS OF MACROINVERTEBRATES RECORDED IN BENTHIC AND DRIFT SAMPLING PRE AND POST TREATMENT. DAY 0 WAS WHEN THE ROTENONE APPLICATION OCCURRED.

TAXA	DRIFT				SURBER		
	PRE TREAT	DAY 0	4 DAYS POST	7 WEEKS POST	PRE TREAT	4 DAYS POST	7 WEEKS POST
Diptera							
Chironomidae	0	60	2	0	19	29	20
Simuliidae	20	4505	0	2	64	0	142
Plecoptera							
Gripopterygidae	0	76	18	4	83	70	150
Ephemeroptera							
Baetidae	0	485	1	0	11	2	43
Leptophlebiidae	0	1222	4	5	59	64	92
Trichoptera							
Hydrobiosidae	0	561	0	0	15	0	3
Ecnomidae	0	227	0	0	0	0	0
Helicopsychidae	0	1	0	0	18	8	7
Glossosomatidae	0	0	0	0	28	13	121
Conoesucidae	0	970	7	0	81	121	120
Coleoptera							
Elmidae	1	14	10	5	107	32	100
Psephenidae	1	1	3	0	26	11	12

This difference in response is probably related to life-history strategies with simuliids, being filter feeders, occupying exposed positions on the surface of stones whilst chironomids are detritovores, occurring in the sediments where rotenone penetration would be minimal if administered in a short pulse as in this study. It has also been suggested that the rapid recovery of simuliids to above pre-treatment levels may be a response to the release from predation pressure with both fish and invertebrate predators removed by rotenone (Cook & Moore 1969).

It is important to note that although there was catastrophic drift at the treatment site, benthic macroinvertebrates remained in significant numbers. One of the criticisms of the use of rotenone in streams is that it totally denudes the stream of aquatic life, hence leaving no food resources for the recolonising or reintroduced fish (Morrison 1977). The results of this short-term study clearly demonstrate that this is not the case.

6. RESULTS AND DISCUSSION—VICTORIA

6.1 General

In total, c. 20 linear km of stream length were rehabilitated for *G. fuscus* by successfully removing all trout predators. A total of c. 60 L of ichthyocide, neutralised by 1100 kg of potassium permanganate, were used in the eradication effort during 1995. Rotenone volumes varied for each stream, ranging between 0.3 L and 0.5 L per 100 m of stream length.

6.2 Pilot study

The pilot study was successful in eradicating trout from the shorter Perkins Creek section but was unsuccessful in fully eradicating trout from the lower section of the much longer Pheasant/Morning Star Creek system. The failure to eradicate trout from the lower section of Pheasant/Morning Star Creek was a result of the significant dilution of the ichthyocide to lower than toxic levels and poor mixing in the larger pools present in the lower sections of Morning Star Creek. In addition, because of entrainment of ichthyocide in pools in the catchment, low levels of ichthyocide were found to seep out of the catchment over a long period of time following completion of detoxification, which was only conducted at the downstream end of the treatment section.

6.3 Main eradication attempt

A total of c. 25 kg of trout was removed from the treated streams (Sanger & Koehn 1997) with the majority of fish being <150 mm total length. No *G. fuscus* were poisoned. The change in ichthyocide application methodology between the pilot and main treatment was effective in that complete eradication was achieved in all streams although trout have subsequently re-established in Raspberry Creek and the lower reaches of Morning Star Creek at Woods Point. In both instances this is thought to be from a deliberate re-introduction by anglers. The change in neutralisation procedure was also effective with no mortality of sentinel fish in the main eradication attempt.

By 2000 (five years after treatment), *G. fuscus* has recolonised c. 4 km of the 20 km of stream treated (Raadik 2000). Recolonisation by *G. fuscus* is significantly slower than *G. olidus* which recolonised the entire treated section of Raspberry Creek (c. 2.9 km) within 1 year.

7. LESSONS LEARNT

Considerable planning is required for the use of ichthyocides. All Australian states and territories have legislation restricting the use of chemicals and rotenone is not registered for fish control in Australia. Consequently in most jurisdictions an ‘off label use’ permit is required and is issued under strict conditions. A considerable lead time is necessary to arrange permits, source and purchase the ichthyocide and neutralising agent, construct and/or augment barriers, notify local water and/or land management authorities, councils, police etc and inform and/or liaise with local landholders/affected parties.

Prior to carrying out the treatment you must have detailed knowledge of:

- animal ethics certification (if required)
- approval to use chemicals instream (e.g. EPA permit)
- distribution of target fish species in the catchment
- distribution of the fish species to be conserved
- presence and distribution of other significant aquatic species (frogs, insects, molluscs, crayfish, platypus) in the catchment

- presence and location of other water uses/users in the catchment (domestic and irrigation water supply dams, pumps, pipelines, fish farms, fishing tour operators).

The human resource requirements for an eradication programme are significant. Disposal of significant volumes of dead fish can be a major issue in some situations. Eradication programmes are often conducted in headwater streams in remote and hazardous environments where Occupational Health & Safety issues are especially important. Such issues include the requirement for good communication equipment (radios etc), long work hours or adverse climatic conditions and associated fatigue, correct safety equipment and procedures for handling chemicals etc.

A public information programme is an essential part of any eradication attempt and the American Fisheries Society provides extensive guidance on the requirements for such a programme (Finlayson et al. 2000). There is considerable resistance from the public and in particular from angling groups (and some scientists) to the concept of using 'poisons' in streams (McClay 2000). Often people see 'hidden agendas' (e.g. the total eradication of trout from a jurisdiction) where there are none, and the eradication proponent needs to be 'upfront' and devote considerable effort to ensuring that interested parties are well informed. Much of the good planning work can come unstuck if adverse media comments are attracted, so a media strategy is also an essential component. Without strong public and political support, chemical eradication programmes are unlikely to be effective.

A contingency plan for accidents (e.g. significant overkill, accidents with chemicals, accidents in remote locations) is also essential, including enough staff to manage the accident as well as continuing with the eradication programme if possible. You do not want to be put in a situation where a minor accident necessitates the cancelling of the whole programme.

Targeted eradication of fish from streams is a valuable part of fisheries management and by using an adaptive management approach, it can also contribute significantly to scientific knowledge.

7. REFERENCES

Anon. 1980: Murrumbidgee River Valley Study. National Trust of Australia, ACT Branch, Canberra.

Baxter, A.F. 1987: A study to determine how quickly trout recolonise streams treated with the piscicide rotenone. *Arthur Rylah Institute for Environmental Research Technical Report Series No. 54*. Department of Conservation, Forests and Lands. Victoria.

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

Cadwallader, P.L. 1979a: Distribution of native and introduced fish in the Seven Creeks river system. *Australian Journal of Ecology 4*: 361–385.

Cadwallader, P.L. 1979b: Fish collecting techniques used by fisheries biologists in the Murray-Darling River system. Pp 144–158 in Proceedings of a Symposium on Biology and Microbiology of Water, Canberra, 25–26 August 1977. AGPS, Canberra.

Cadwallader, P.L. 1996: Overview of the impacts of introduced salmonids on Australian native fauna. Australian Nature Conservation Agency, Canberra.

Cook, S.F.; Moore, R.L. 1969: The effects of a rotenone treatment on the insect fauna of a California stream. *Transactions of the American Fisheries Society 72*: 539–544.

Crook, D.; Sanger, A.C. 1997: Recovery plan for the Pedder, Swan, Clarence, swamp and saddled *galaxias*. Inland Fisheries Commission, Hobart.

Dawson, V.K.; Gingerlich, W.H.; Davis, R.A.; Gilderhus, P.A. 1991: Rotenone persistence in freshwater ponds: effects of temperature and sediment adsorption. *North American Journal of Fisheries Management 11*: 226–231.

Doeg, T.J.; Lake, P.S. 1989: Colonization of experimentally disturbed patches by stream macroinvertebrates in the Acheron River, Victoria. *Australian Journal of Ecology 14*: 207–220.

Dudgeon, D. 1990: Benthic community structure and the effects of rotenone piscicide on invertebrate drift and standing stocks in two Papua New Guinea streams. *Archiv für Hydrobiologie 119(1)*: 35–53.

Finlayson, B.J.; Schnick, R.A.; Cailteux, R.L.; DeMong, L.; Horton, W.D.; McClay, W.; Thompson, C.W.; Tichacek, G.J. 2000: Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethseda, Maryland.

Fletcher, A.R. 1979: Effects of *Salmo trutta* on *Galaxias olidus* and macroinvertebrates in stream communities. Unpublished MSc thesis, Monash University, Clayton.

Fletcher, A.R. 1986: Effects of introduced fish in Australia. Pp. 231–238 in de Decker, P.; Williams, W.D. (eds) Limnology in Australia. CSIRO, Melbourne and Junk, Dordrecht.

Frankenberg, R. 1966: Fishes of the family Galaxiidae. *Australian Natural History 15*: 161–164.

Frankenberg, R.S. 1974: Native freshwater fish. In: Williams, W.D. (ed) Biogeography and Ecology in Tasmania. W. Junk, The Hague.

Jackson, P.D. 1981: Trout introduced into south-eastern Australia: their interaction with native fishes. *Victorian Naturalist 98*: 18–24.

Jackson, P.D.; Davies, J.N. 1983: Survey of the fish fauna in the Grampians region, south-western Victoria. *Proceedings of the Royal Society of Victoria 95(1)*: 39–51.

Jackson, P.D.; Williams, W.D. 1980: Effects of brown trout, *Salmo trutta* L., on the distribution of some native fishes in three areas of southern Victoria. *Australian Journal of Marine and Freshwater Research 31*: 61–67.

Jones, H.A.; Rutzou, T.; Kukolic, K. 1990: Distribution and relative abundance of fish in the Naas-Gudgenby catchment. *Research Report 3*. ACT Parks and Conservation Service, Canberra.

Koehn, J.D.; O'Connor, W.G. 1990: Distribution of freshwater fish in the Otway region, south-western Victoria. *Proceedings of the Royal Society of Victoria 102(1)*: 29–39.

Koehn, J.D.; Doeg, T.J.; Harrington, D.J.; Milledge, G.A. 1995: The effects of Dartmouth Dam on the aquatic fauna of the Mitta Mitta River. Report to the Murray-Darling Basin Commission, Canberra.

Lennon, R.E.; Hunn, J.B.; Schnick, R.A.; Burress, R.M. 1970: Reclamation of Ponds, Lakes and Streams with Fish Toxicants: a Review. *FAO Fisheries Technical Paper No. 100*. FAO, Rome.

Lintermans, M. 1991: The decline of native fish in the Canberra region: the impacts of introduced species. *Bogong 12(4)*: 18–22.

Lintermans, M. 2000: Recolonisation by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of rainbow trout *Oncorhynchus mykiss. Australian Journal of Marine and Freshwater Research 51*: 799–804.

Lintermans, M. 2001: Corrigendum to Recolonisation by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of rainbow trout *Oncorhynchus mykiss. Australian Journal of Marine and Freshwater Research 52*: 257.

Lintermans, M.; Rutzou, T. 1990: The fish fauna of the upper Cotter River catchment. *Research Report 4*. ACT Parks and Conservation Service, Canberra.

McClay, W. 2000: Rotenone use in North America (1988–1997). *Fisheries 25(5)*:15–21.

McDowall, R.M. 1968: Interactions of the native and alien faunas of New Zealand and the problem of fish introductions. *Transactions of the American Fisheries Society 97*: 1–11.

McDowall, R.M. 1990: Filling in the gaps—the introduction of exotic fishes into New Zealand. Pp. 68–82 in D. Pollard (ed) Introduced and translocated fishes and their ecological effects. Proceedings of the Australian Society for Fish Biology Workshop, Magnetic Island, Townsville, Queensland, 24–25 August 1989. *Bureau of Rural Resources Proceedings No 8.* AGPS, Canberra.

McIntosh, A.R.; Townsend, C.R.; Crowl, T.A. 1992: Competition for space between introduced brown trout (*Salmo trutta* L.) and a native galaxiid (*Galaxias vulgaris* Stokell) in a New Zealand stream. *Journal of Fish Biology 41*: 63–81.

McIntosh, A.R.; Crowl, T.A.; Townsend, C.R. 1994: Size-related impacts of introduced brown trout on the distribution of native common river galaxias. *New Zealand Journal of Marine and Freshwater Research 28*: 135–144.

Morrison, R.S. 1977: The effects of rotenone on the invertebrate fauna of three hill streams in Scotland. *Fisheries Management 8(4)*: 128–139.

Penick, S.B. & Company 1963: Noxfish and pro-noxfish for fisheries management.

Raadik, T.A. 1995: A research recovery plan for the barred Galaxias in south-eastern Australia. *Flora and Fauna Technical Report No. 141*. Department of Conservation and Natural Resources, Victoria.

Raadik, T.A. 2000: Barred Galaxias Recovery Project—final report. *Endangered Species Program Project No. 6092.* Report to Environment Australia, Canberra. Freshwater Ecology, Arthur Rylah Institute, Victoria. 34 p.

Raadik, T.A.; Saddlier, S.R.; Koehn, J.D. 1996: Threatened fishes of the world: *Galaxias fuscus* Mack, 1936 (Galaxiidae). *Environmental Biology of Fishes 47*: 108.

Sanger, A.C.; Fulton, W. 1991: Conservation of endangered species of Tasmanian freshwater fish. *Inland Fisheries Commission Occasional Report 91–01*. Inland Fisheries Commission, Hobart.

Sanger, A.C.; Koehn, J.D. 1997: Use of chemicals for carp control. Pp. 37–57 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. 129 p.

Talsma, T.; Hallam, P. 1982: Stream water quality of forest catchments in the Cotter valley, ACT. Pp. 50–59 in First National Symposium on Forest Hydrology, 1982. *National Conference Publication No. 82/6.* Institution of Engineers, Melbourne.

Thomas, K.; Chilvers, G.A.; Norris, R.H. 1989: Seasonal occurrence of conidia of aquatic hyphomycetes (Fungi) in Lees Creek, Australian Capital Territory. *Australian Journal of Marine and Freshwater Research 40*: 11–23.

Tilzey, R.D.J. 1976: Observations on interactions between indigenous Galaxiidae and introduced Salmonidae in the Lake Eucumbene catchment, New South Wales. *Australian Journal of Marine and Freshwater Research 27*: 551–564.

Townsend, C.R.; Crowl, T.A. 1991: Fragmented population structure in a native New Zealand fish: an effect of introduced brown trout? *Oikos 61*: 347–354.

Wager, R.; Jackson, P.D. 1993: The action plan for Australian freshwater fishes. Australian Nature Conservation Agency, Canberra.