Biology and potential impacts of rudd (*Scardinius erythrophthalmus* L.) in New Zealand

Brendan J. Hicks

Centre for Biodiversity and Ecology Research, Department of Biological Sciences, The University of Waikato, Private Bag 3105, Hamilton, New Zealand. b.hicks@waikato.ac.nz

ABSTRACT

Rudd (*Scardinius erythrophthalmus*) is a cyprinid fish native to Europe that was illegally introduced into New Zealand in 1967. Between the 1960s and 1980s rudd were illegally spread to a number of lakes, ponds, and rivers in New Zealand, principally from the Waikato north. They now also occur in the Wanganui, Manawatu, Nelson, and Canterbury regions. Rudd undergo ontogenetic changes in diet as they grow. Young-of-the-year rudd (58–65 mm mean fork length (FL)) ate a mixture of planktonic cladocerans and chironomid pupae, and potentially competed for these foods with common smelt (*Retropinna retropinna*). Larger rudd (100–149 mm FL) were primarily benthivorous, and potentially competed with perch (*Perca fluviatilis*) of the same size, brown bullhead catfish (*Ameiurus nebulosus*), and probably common bullies (*Gobiomorphus cotidianus*). Rudd of still larger sizes were increasingly herbivorous, until at >200 mm FL their diet was >80% plant material. As rudd prefer native species of aquatic macrophytes to the introduced species, they can probably modify native plant communities and aid the invasion of introduced aquatic weeds. They may also have contributed to the switch of Hamilton Lake from a macrophyte-dominated state to a phytoplankton-dominated state. It is time for the threats posed by rudd to be recognised, and for an education campaign to be mounted. As past rudd introductions have been done outside the law, increasing the severity of penalties for further illegal transfers is unlikely to be effective, and the coarse angling community should instead be included in management decisions concerning rudd.

Keywords: rudd, autecology, introduced fish, aquatic macrophytes

1. BIOLOGY, INTRODUCTION, AND LEGAL STATUS

1.1 Rudd in their native range

Rudd (*Scardinius erythrophthalmus* L.) are a cypriniform fish in the family Cyprinidae. Other cyprinids in New Zealand are goldfish (*Carassius auratus* L.), tench (*Tinca tinca* L.), koi carp (*Cyprinus carpio* L.), orfe (*Leuciscus idus* L.), grass carp (*Ctenopharyngodon idella* Valenciennes), and silver carp (*Hypophthalmichthys molitrix* Valenciennes). Rudd originated in the Old World (United Kingdom, southern Europe, and Russia), where their natural predator is the pike (*Esox lucius* L.), a fish that is absent from New Zealand. The latitudinal range of rudd in its native habitat extends from 38°N in southern Italy to about 70°N, which suggests that rudd could occupy suitable habitats throughout New Zealand's latitudinal range (34°S to 47°S).

In their natural range, rudd live in still or slow-flowing fresh waters, and principally occupy ponds and lakes. The description of rudd in a standard European text alludes to their ability to overpopulate habitats: 'The rudd is happiest in lowland lakes often heavily overgrown with vegetation, in which condition they may reach a weight of 4 pounds, although in small ponds they stunt badly and become overcrowded' (Midgalski & Fichter 1976).

Large rudd (>150 mm) are primarily herbivorous (Kane 1995) and have the capacity to affect macrophyte communities. In the small (1.5 ha), shallow (mean depth 1.5 m) Lake Zwemlust an increase in the rudd population caused a change in macrophyte species composition, followed eventually by a decline in macrophyte abundance and periodic phytoplankton blooms (Van Donk & Gulati 1995). In Europe, rudd are also found in the slow-flowing reaches of rivers (Muus & Dahlstrøm 1971).

1.2 Introduction of rudd to New Zealand

A consignment of rudd to New Zealand in 1864 failed to survive, but in February 1967 an illegal importation from England was successful (McDowall 1990). These rudd were a highly-coloured aquarium stock that was smuggled into the country with a load of vegetables from the cargo vessel Rangitoto (J. Stewart Smith, Massey, pers. comm.).

Rudd have been spread illegally in New Zealand since their original importation. Between the 1960s and 1980s rudd were spread illegally to a number of lakes, ponds, and rivers in New Zealand, principally from the Waikato north. Naturalised populations of rudd now exist from Northland to Canterbury, though their principal concentration is around Auckland and the Waikato (Fig. 1). Most recently, rudd have also been found near Wanganui and in the Manawatu (Miller 2001).

The objectives of this report are to examine the potential for rudd to affect freshwater ecosystems in New Zealand, to document the New Zealand research into rudd autecology, and to review of the status of rudd in New Zealand in the light of this research, and the potential of rudd to be spread by human intervention.

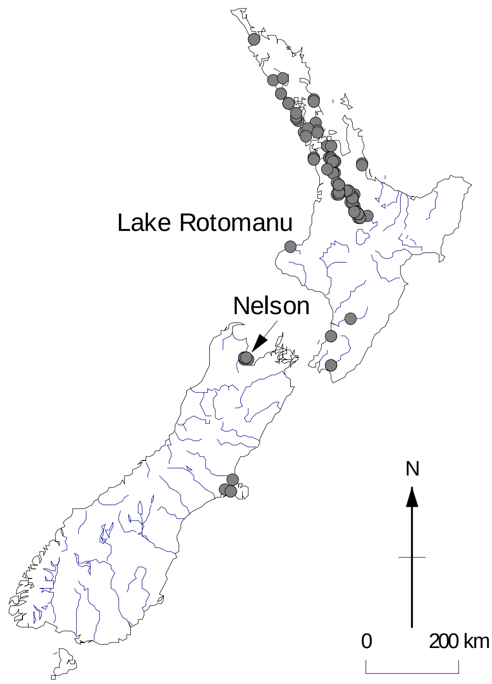

Figure 1. The distribution of rudd (*Scardinius erythrophthalmus*) in New Zealand (source: New Zealand Freshwater Fish Database, NIWA, Hamilton, 3 November 2001).

1.3 Biology of rudd

Rudd can be distinguished from other cyprinids in New Zealand by their bright red fins, and downward-curved lateral line which follows the curve of the abdomen (McDowall 1990). Rudd can tolerate a wide range of temperatures, but sexual maturation appears to be controlled by temperature. At 14–15°C rudd grew continuously to about half the size of wild fish, but did not mature. However at 20–21°C rudd grew faster than wild fish, and also became sexually mature (Audige 1921, cited in Cadwallader et al. 1977).

Male rudd generally mature at age 1 year, when they are >60 mm fork length (FL). Females generally mature at age 2, and have c. 1000–100 000 1-mm-diameter eggs, depending on female size (McDowall 1990). In Auckland ponds, rudd ranging in weight from about 5 g to 90 g had means of between 1000 and 40 000 eggs per female. Females as small as 69 mm total length and 3.4 g contained mature eggs (Lane 1983). Rudd spawn in spring and summer, when the water temperature exceeds 18°C (McDowall 1990). In Hamilton Lake (Lake Rotoroa), the gonosomatic index was maximal in October (Wise 1990). Spawning adults move inshore, and deposit their eggs amongst vegetation (McDowall 1990). Larvae 10–12 mm long were found in mid-November 1992 in Hamilton Lake under waterlily leaves (*Nymphaea* spp.; Hicks unpubl. data).

Rudd in New Zealand have demonstrated their ability to colonise lakes, ponds, streams, and rivers that also hold aquatic macrophytes (e.g. *Egeria*). Rudd are extremely abundant in the Waikato River, occupying such diverse habitats as the tail race below the Karapiro Dam and the trout spawning tributaries of Lake Karapiro (Ben Wilson, Auckland/Waikato Fish & Game, pers. comm.).

Rudd are omnivores, and eat a wide variety of vegetation and invertebrates (Lane 1983; Wise 1990; Kane 1995; Lake 1998). Cadwallader et al. (1977) speculated, on the basis of overseas studies, that rudd in New Zealand might compete with trout for food. Because the habitat of rudd can include the lower reaches of trout spawning and rearing tributaries, and littoral habitats in lakes where trout may rear, these fears seem to be justified. Lake (1998) found overlapping diets of rudd and rainbow trout in the littoral zone of Lake Karapiro. Cadwallader (1977) also speculated that rudd might eat trout fry, but this seems unlikely as rudd do not normally inhabit trout spawning areas (Lane 1983).

1.4 Legal status of rudd in New Zealand

Rudd were declared to be noxious in all parts of New Zealand under the Freshwater Fisheries Regulations 1983, meaning that it is illegal 'to have under control, or rear, raise, hatch or consign' this species. However, in 1986 the status of rudd as a noxious fish was rescinded in the Auckland/Waikato Fish & Game Region under Amendment 4 of the Freshwater Fisheries Regulations 1983 because of their popularity with coarse-fish anglers. The Freshwater Fisheries

Regulations 1983 were consolidated under the Conservation Law Reform Act 1990, and acclimatised fish became known as sports fish, which are controlled by the fish and game councils of New Zealand. Rudd are now a sports fish, like trout and perch, in the Auckland and Waikato regions and thus remain under the control of the Auckland/Waikato Fish & Game Council. Like any sports fish, rudd cannot be transferred between water bodies or kept in captivity without permission, and cannot be caught without a licence. In the rest of New Zealand, rudd continue to be classified as a noxious fish. Thus whether rudd are a sports fish or a noxious fish, their transfer and breeding are illegal, but neither status has done anything to curb their spread.

Rudd were illegally spread widely in the northern third of the North Island between 1967 and 1984, and pressure from the coarse-fish angling fraternity for further releases led the Auckland/Waikato Fish & Game Council to fund a study on the feeding ecology of rudd in the Waikato region (Lake 1998).

2. THE POTENTIAL IMPACTS OF RUDD

2.1 Rudd in Hamilton Lake (Lake Rotoroa)

Hamilton Lake is a shallow 54-ha urban lake with a maximum depth of 6 m. Before human intervention, Hamilton Lake probably contained shortfinned eels (*Anguilla australis* Richardson), common bullies (*Gobiomorphus cotidianus* McDowall), and longfinned eels (*Anguilla dieffenbachii* Gray). Common smelt (*Retropinna retropinna* Richardson) were also in the lake in the 1920s and 1930s, and these may have been diadromous in origin, as in the nearby Lake Ngaroto (Hicks et al. 2001). Since that time there have been substantial changes to the fish fauna. Common smelt are no longer found in Hamilton Lake, but their disappearance may have resulted from impediments to migration resulting from urbanisation rather than from the fish introductions. Other changes have resulted from legal and illegal introductions (Table 1). Perch have been in the lake for almost 100 years, but the lake was closed to perch fishing for many years prior to 1977. Mosquitofish (*Gambusia affinis* Baird & Girard) were present in 1976, and the first catfish were caught during July 1977.

The date that rudd first arrived in Hamilton Lake is not certain, but is likely to have been between 1978 and 1980. Rudd were not found in eight comprehensive netting surveys between July 1976 and April 1978 (Eric

TABLE 1. INTRODUCTIONS OF FISH TO HAMILTON LAKE (LAKE ROTOROA). AAS, Auckland Acclimatisation Society, which is now known as the Auckland/Waikato Fish & Game Council (AWFGC).

DATE	FISH SPECIES	SOURCE
1905	Perch legally introduced by the AAS	AAS records
1976	Goldfish present	Graynoth unpubl. data
1976	Mosquitofish present	Graynoth unpubl. data
1977	Brown bullhead catfish first found	Graynoth unpubl. data
1983	Rudd numerous (introduced 1978–1980?)	AAS records
1989–1990	Tench introduced legally by AWFGC	Ben Wilson, pers. comm.

TABLE 2. THE RELATIVE ABUNDANCE OF RUDD AND PERCH CAUGHT BY GILL NETTING IN HAMILTON LAKE OVER A 25-YEAR PERIOD.
[a], rudd not yet introduced; AWFGC, Auckland/Waikato Fish & Game Council.

YEAR	CATCH RATE (FISH h^{-1} 100 m^{-1} NET)		RUDD/ PERCH (%)	SOURCE
	RUDD	PERCH		
1976	0.00[a]	0.11–0.17	0	E. Graynoth, unpubl. data
1983	7.00	1.30	538	AWFGC, unpubl. data
1989–1990	1.50	0.45	336	Wise (1990)
1993–1994	1.21	2.02	60	Kane (1995)
2001	1.12	3.11	36	P. Roberts, unpubl. data

Graynoth, unpubl. data). However, by 1983 rudd were very numerous (Table 2), and already quite large, suggesting that they were introduced several years previously. The largest rudd caught on 7 June 1983 was 325 mm (776 g; Auckland/Waikato Fish & Game Council, unpubl. data).

The current fish fauna of Hamilton Lake has nine fish species. These are: shortfinned eels, common bullies, perch, rudd, goldfish, brown bullhead catfish (*Ameiurus nebulosus* Le Sueur), tench, mosquitofish, and longfinned eels. In 1993 and 1994 there was no evidence that tench were breeding in the lake (Kane 1995), but in 2001 four size classes of tench were found (P. Roberts, unpubl. data), showing that breeding had taken place. No tench have been released since 1990 (Ben Wilson, Auckland/Waikato Fish & Game Council, pers. comm.).

At the time that rudd were introduced, the lake was dominated by the native plants *Potamogeton cheesemanii* A. Benn. and charophytes (*Nitella* spp.), and the introduced oxygen weeds *Lagarosiphon major* (Ridley) Moss ex Wager, and *Elodea canadensis* Michx. At this time, the water was very clear, and the lake bed was visible from the surface at its deepest point (5 m deep; Eric Graynoth, pers. comm.). Also in 1977, *Egeria densa* Planch. was first recorded in the lake, and this plant subsequently displaced the other oxygen weeds (Tanner et al. 1990). Concurrent with the expansion of the *Egeria* between 1977 and 1989, the rudd population increased dramatically.

In 1990, Hamilton Lake underwent a switch from a stable, macrophyte-dominated state to a stable, phytoplankton-dominated state. *Egeria* suffered a catastrophic collapse, and has not been found in the lake since. The water clarity has also declined since 1990, and the Secchi depth since 1990 has been 1–2 m (Burns 1994; de Winton et al. 2000).

The cause of this switch in state was probably complex, but rudd might have been a contributory factor. Rudd were implicated in a switch from a clear-water, macrophyte-dominated state in Lake Zwemlust, The Netherlands, to a stable, turbid state characterised by high algal biomass (Van Donk & Gulati 1995). Rudd are relatively efficient grazers, but inefficient assimilators, and they can recycle much of the nutrients in the plants through their faeces (Prejs 1984), making nutrients available to phytoplankton. However, Hamilton Lake was also subject to periodic macrophyte control by chemicals, so rudd were not the sole agent acting on the macrophytes. Also, rudd have not eliminated macrophytes in large, deep lakes such as Lake Karapiro (5.4 km^2 in area, 30 m maximum depth; Lowe & Green 1987), where the plant community is dominated by introduced macrophytes such as hornwort (*Ceratophyllum demersum*). It seems clear that in some habitats at least, rudd can establish a balance with the macrophyte community. Lake Karapiro is a hydroelectric impoundment with rapid flushing (Hoare & Spigel 1987), so the short residence time (<0.3 yr) and lack of stratification may also moderate the influence of rudd.

2.2 Ontogenetic dietary changes

Rudd undergo an ontogenetic dietary change as they grow. As fry, rudd in Ireland ate attached unicellular algae and phytoplankton. From 10 mm FL through to age 1, rudd ate zooplankton and chironomids (Kennedy & Fitzmaurice 1974). Young-of-the-year (YOY) rudd of 56–58 mm mean FL in Lake Karapiro ate a mixture of planktonic cladocerans and chironomid pupae, suggesting the potential for competition for these foods with common smelt in the littoral zone. Some dietary overlap was also evident between rudd and common bullies, and between rudd and small rainbow trout (*Oncorhynchus mykiss* Walbaum; 87 mm mean FL; Lake 1998). In Lake Ngaroto, YOY rudd of 65 mm FL ate planktonic cladocerans, chironomid larvae and pupae, and filamentous algae, overlapping with the diets of the common bullies, which ate chironomids almost exclusively.

Analysis of the gut contents of wild rudd of 100–149 mm FL in Hamilton Lake showed that they ate predominantly chironomid pupae, with plants being only 27% of their diet by volume (Kane 1995). The predominance of chironomid pupae in the diet of small rudd (100–149 mm FL) indicates that they are primarily benthivorous, and that their diet overlaps considerably with the small perch and brown bullhead catfish in the lake, and probably also with the common bullies (Kane 1995).

Plants make up an increasing proportion of the diet of rudd as they grow. For rudd of 150–199 mm FL, material in the gut was 54% plants, and for rudd >200 mm FL, 84% was plant material (Kane 1995), precisely the same percentage that Wise (1990) estimated.

Rudd have persisted in Hamilton Lake despite the collapse of the submerged macrophytes, and have shown flexibility in their consumption of plants. Wise (1990) determined that in 1989 the predominant plant taxa eaten by rudd were the submergents *Nitella* spp. and *Egeria densa*, whereas following the collapse of these species in 1990, the large rudd fed predominantly on the emergent plants *Iris pseudacorus* and *Baumea articulata*, and cultivars of *Nymphaea* (Totome 1993; Kane 1995).

2.3 Plant preferences of rudd

In tank experiments, rudd 100–300 mm FL were offered aquatic plants and algae tied in bunches with lead tape to simulate natural plants. Pre-weighed bunches were removed and reweighed at daily intervals for 14 days. These experiments showed that rudd consumed plants equivalent to about 20% of their body weight per day in spring and summer (Lake et al. 2002). They nibbled the growing tips of the oxygen weeds, and showed clear and consistent preferences for certain plant species (Fig. 2). The plant preference, determined from percentage biomass loss over time ranked from highest to lowest, was:

Nitella spp. > *Potamogeton ochreatus* > *Elodea canadensis* > *Chara globularis* = *Chara fibrosa* > *Egeria densa* = *Lagarosiphon major* > *Myriophyllum propinquum* > *Ceratophyllum demersum*.

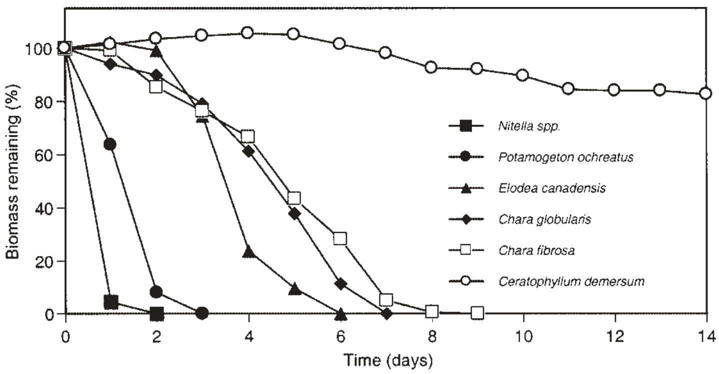

Figure 2. Time taken by rudd of 100–300 mm fork length (FL) to consume aquatic macrophytes in tanks in January 1999 at 1–20°C (from Lake et al. 2002).

Field trials in Lake Karapiro showed similar results (de Winton & Dugdale present volume; Lake et al. 2002). From these results we can be confident that the native plants *Nitella* spp. and *Potamogeton ochreatus* are likely to be eaten selectively in the wild, suggesting that rudd will have a profound impact on native plant communities, particularly where these communities are also under threat from invasion by introduced plant species.

2.4 Changes in the abundance of rudd in Hamilton Lake

Fish have been captured in Hamilton Lake over a 25-year period by a combination of gill and fyke netting (Graynoth, unpubl. data; Wise 1990; Kane 1995; P. Roberts, unpubl. data). Comparison of perch and rudd catch rates is useful because they are both pelagic fish that are susceptible to capture in gill nets. Rudd catch rates were greater in gill nets than in fyke nets, and the abundance of rudd relative to perch in gill net catches has changed considerably (Table 2). Following their introduction, rudd increased dramatically in abundance. In June 1983, rudd were five times more abundant than perch. An overnight set of 30 m of 85-mm mesh gill net at the northern end of the lake caught 38 rudd and 7 perch (Auckland/Waikato Fish & Game Council, unpubl. data). To calculate catch rates, the gill net was assumed to have been set for 18 h. With the collapse of the *Egeria* beds in 1990, it appears from the catch rates that rudd also declined in abundance, as rudd were three times more abundant than perch that year. By 1993 to 1994, rudd catch rates were only 60% those of perch, and by 2001 rudd abundance appears to have decreased still further, while the perch abundance has continued to increase (Table 2).

3. CONCLUSIONS

Large rudd (>200 mm FL) in New Zealand are obligate herbivores that can eat a wide range of aquatic plants and algae. As smaller fish, they are first planktivores, and then benthic carnivores, suggesting that they might compete with common smelt, trout, and common bullies. From their plant preferences, I conclude that rudd will selectively remove some important components of native plant communities, which may enhance the invasive ability of the oxygen weeds (*Elodea canadensis*, *Lagarosiphon major*, and *Egeria densa*) and hornwort (*Ceratophyllum demersum*). From the evidence of their currently naturalised populations in New Zealand, it appears that rudd have thrived in every location into which they have been introduced. Further, from comparing their native range to New Zealand's latitudinal position, it can be safely assumed that rudd will thrive in lakes, ponds, and slow-flowing rivers with macrophytes throughout lowland New Zealand. For the good of plant communities and native fish and trout in these environments, the further spread of rudd should be viewed with extreme concern. While it seems that rudd can contribute to the demise of aquatic macrophytes in small ponds and lakes, they appear to coexist with some species of macrophytes in large lakes (e.g. hornwort in Lake Kakapiro).

4. RECOMMENDATIONS

Much of the concern about rudd comes from the stealth and rapidity of their illegal spread following their illegal importation in 1967, and their ability to thrive in New Zealand. The people propagating and spreading rudd have unfortunately done a good job. The very widespread nature of the present distribution of rudd, and the expense and impracticality of eradication in many locations, means that it is probably time to review the status of rudd and to focus on education rather than penalties. The noxious status of rudd has failed to prevent their spread, even when individuals have been successfully prosecuted under the current legislation. Further harsh penalties are only likely to precipitate further illegal releases.

Three courses of action seem appropriate.

1. DOC, fish and game councils, and coarse-fish anglers need to work together to reconcile the legal status of rudd, to give all three groups ownership of any decisions reached. Acceptance of their status as sports fish in habitats where they already are seems an obvious solution. The current regulations surrounding sports fish are stringent enough, and fish and game councils are the legal administrators of these regulations.
2. To protect the biodiversity of indigenous ecosystems, rudd need to be prevented from spreading into habitats where they are not currently present, and eradicated where possible in regions where only a few isolated populations exist.
3. Education of the threats posed by rudd to aquatic ecosystems needs to be promoted nationally to raise awareness of the risks of their further spread. Notices at boat ramps and leaflets distributed with fishing licences are some simple tools.

Finally, despite the status of research into rudd in New Zealand (Lane 1983; Wise 1990; Kane 1995; Lake 1998; Lake et al. 2002), more information is needed on the current distribution of rudd, and on their specific ecological effects, such as the influence of rudd on trout and native fish species and the role of rudd in controlling macrophyte communities in water bodies of different sizes. A comprehensive survey of the size, residence time, nutrient status, and macrophyte communities of lakes with rudd would lead to a substantial advance in our knowledge of the ecological consequences of this prolific fish.

5. ACKNOWLEDGEMENTS

The fish capture in Hamilton Lake by Daryl Kane and Peter Roberts was funded by the Hamilton City Council, and the feeding experiments carried out by Michael Lake were funded by the Auckland/Waikato Fish & Game Council. Peter Roberts is currently undertaking his MSc research at the University of Waikato. I thank the MSc students Geoff Wise, Mike Lake, Daryl Kane, and Peter Roberts for their hard work, and John Clayton, Tony Dugdale, and Rohan Wells of the National Institute of Water and Atmospheric Research Limited (NIWA), Hamilton, for their assistance with the student research. Jody Richardson from NIWA, Hamilton, provided the data for Fig. 1, which was drawn with Ian Jowett's mapping programme, *Fish DB*. I thank Eric Graynoth for making his unpublished data for Hamilton Lake available, and Ben Wilson of the Auckland/Waikato Fish and Game Council for providing unpublished data, making records available, advising on the legal status of rudd, and constructively criticising the manuscript. Technicians at the University of Waikato (Dudley Bell, Lee Laboyrie, and Shona Duncan) assisted with field work and laboratory analysis associated with fish sampling.

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Managing invasive freshwater fish in New Zealand

PROCEEDINGS OF A WORKSHOP HOSTED BY DEPARTMENT OF CONSERVATION, 10–12 MAY 2001, HAMILTON

Published by
Department of Conservation
P.O. Box 10-420
Wellington, New Zealand

This work may be cited as:
Department of Conservation 2003: Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10-12 May 2001, Hamilton. xiv + 174 p.

This report was prepared for publication by DOC Science Publishing, Science & Research Unit; editing and layout by Ruth Munro. Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.
All DOC Science publications are listed in the catalogue which can be found on the departmental web site http://www.doc.govt.nz

ISBN 0-478-22423-0

National Library of New Zealand Cataloguing-in-Publication Data

Managing invasive freshwater fish in New Zealand : proceedings of a workshop hosted by Department of Conservation, 10-12 May, 2001, Hamilton.
Includes bibliographical references.
ISBN 0-478-22423-0
1. Freshwater fishes—New Zealand—Congresses. 2. Introduced fishes—Control—New Zealand—Congresses. 3. Nonindigenous aquatic pests—Control—New Zealand—Congresses. I. New Zealand.—Dept. of Conservation.—Science and Research Unit.
363.780993—dc 21

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